



Contextualising the Industrial Engineering Body of Knowledge within red-meat cattle production systems in KwaZulu-Natal

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ABSTRACT

South Africa has many cattle farmers providing food security and job creation. Farmers aim to manage their farms to maximise profit while maintaining a sustainable farm to pass on to the next generation. Industrial engineering is a scientific discipline and has tools and technologies that can potentially help farmers. The problem is that Industrial Engineering research has not been aligned with the beef cattle industry, thereby limiting the development of pragmatic solutions to food security challenges. This research aims to contextualise the Industrial Engineering Body of Knowledge (IISE-BOK) within red-meat cattle production systems in KwaZulu-Natal, thus initiating transdisciplinary collaboration between industrial engineering and red-meat cattle production to address food security challenges.

This study used a case study approach, limited to the Midlands and Highveld regions of KwaZulu-Natal. To achieve this aim, a scoping review was conducted to identify overlaps in the literature between industrial engineering and beef cattle production. Of the 308 records retrieved across three databases, 95 studies were analysed after screening. The review found that the existing literature focuses on isolated technical problems, with limited evidence of integrated farm-level application.

Semi-structured interviews were then conducted with 14 cattle farmers, including smallholder and commercial producers. The interview transcripts were analysed inductively using thematic analysis to identify key challenges and their interconnections from a systems perspective. The findings showed that these challenges do not occur in isolation, but are interconnected, often resulting in cascading effects that influence overall farm performance.

Afterwards, the interview data were analysed again deductively, using the IISE-BOK as a coding framework to develop an IISE-BOK Cattle Production Contextualisation Matrix (CPCM). This matrix maps the challenges reported by farmers to the relevant industrial engineering knowledge areas, connecting how existing farming practices align with established engineering concepts, even where these are not explicitly recognised. The matrix was evaluated through expert review, where consensus confirmed its validity and relevance.

The study showed that many challenges in cattle production correspond to established principles of industrial engineering, but these relationships have not been previously explored. By contextualising IISE-BOK within cattle production systems, this research provides a foundation for future application of Industrial Engineering methods to improve productivity, sustainability, and resilience in the red-meat sector.

Keywords

Industrial engineering, Beef cattle production, Scoping review, Semi-structured interviews, Cattle production challenges

PREFACE

This dissertation was compiled and presented in article format in accordance with the academic rules of the North-West University (Approved on 13 March 2024).

Rule A.4.4.2 states:

“Faculty rules may provide that full or partial compliance with the research component of a master’s degree may take the form of one or more publishable or published research articles in a specified field, taking into account the requirements of Rule 4.13 and Rule 4.14 and specifying the minimum number of research articles required instead of a dissertation, a mini dissertation, or the research component of a professional master’s degree.”

Rule A.4.13.1 states:

“Where faculty rules require that a research article must be submitted to an accredited scholarly journal as part of the requirements for the degree, the candidate must provide evidence of such submission.”

Rule A.4.13.2 states:

“Where a candidate is allowed to submit the research product in the form of a research article or articles, such research product must be presented for examination purposes as an integrated unit, supplemented with a problem statement, an introduction and a synoptic conclusion, and the manuscript submission guidelines, or the URL link to the manuscript guidelines, of the journal or journals concerned.”

Rule A 4.13.3 states:

“Where any research article to which the candidate for a master’s degree and other authors have contributed is submitted as the research product of a master’s degree programme, the candidate must obtain a written statement from each co-author in which it is stated that such co-author grants permission for the research product to be used for the stated purpose, and in which it is further indicated what each co-author’s academic contribution to the research product concerned had been.”

The following research papers have been submitted to accredited academic journals, as illustrated in Table 1.

Table 1: List of research papers

Research paper	Article name	Journal to which the article has been submitted
1	The Intersection of Industrial Engineering and Beef Cattle Production Systems: A Scoping Review	Int. J. of Industrial and Systems Engineering
2	Challenges in KwaZulu-Natal Beef Production: A Systems Approach	International Journal of Industrial Engineering, Theory, Applications and Practice

LAYOUT OF DOCUMENT

The dissertation is presented in an article format. This causes the layout, numbering, and references to be inconsistent. Articles may also make the overall dissertation appear shorter in page count, due to the shorter nature of article writing.

The dissertation consists of two research papers. The research is done in phases; each phase aligns with a research objective, and some phases contain the articles written. The research phases are outlined in Table 2. The table illustrates each research phase (column 1), research objective (column 2), research method (column 3), dissertation chapter (column 4), and article affiliation (column 5). Figure 1 illustrates the entire research method used throughout the study. The figure will also be at the start of the applicable chapters to guide the researcher like a map.

Table 2: Research stages

Chapter	Method	Research Objective	Phase	Article
1	Introduction to the research	N/A	1	N/A
2	Literature study	N/A	1, 2	N/A
3	Research design	N/A	3	N/A
4	Scoping literature review	1. To investigate available literature on the application of IE knowledge in the beef cattle production systems via a scoping review.	2 & 3	1
5	Farmer interviews and analysis	2. To explore the challenges and their root causes experienced in cattle production lines via interviews.	2, 3, 4, 5, & 6	2
6	Contextualisation Matrix	3. To contextualise the Industrial Engineering body of Knowledge (IISE-BOK) within red-meat cattle production systems in KwaZulu-Natal by creating a contextualisation matrix.	6	N/A
7	Expert survey	4. To verify that the contextualisation matrix complies with the design requirements through expert review. 5. To prove that a valid problem, method, and artefact were developed in this study through expert review.	3, 4, 5, & 6	N/A
8	Verification and Validation	4. To verify that the contextualisation matrix complies with the design requirements through expert review. 5. To prove that a valid problem, method, and artefact were developed in this study through expert review.	6	N/A
9	Conclusions	N/A	N/A	N/A

Numbering – The page numbers of articles will align with the specific publication's page numbers and will interrupt the numbering of the rest of the dissertation. The numbering of tables, figures, and equations will restart in each research paper.

References –The list of references for chapters 4 and 5 can be found at the end of their respective chapters (research papers), while the referencing for the other chapters can be found at the end of the dissertation.

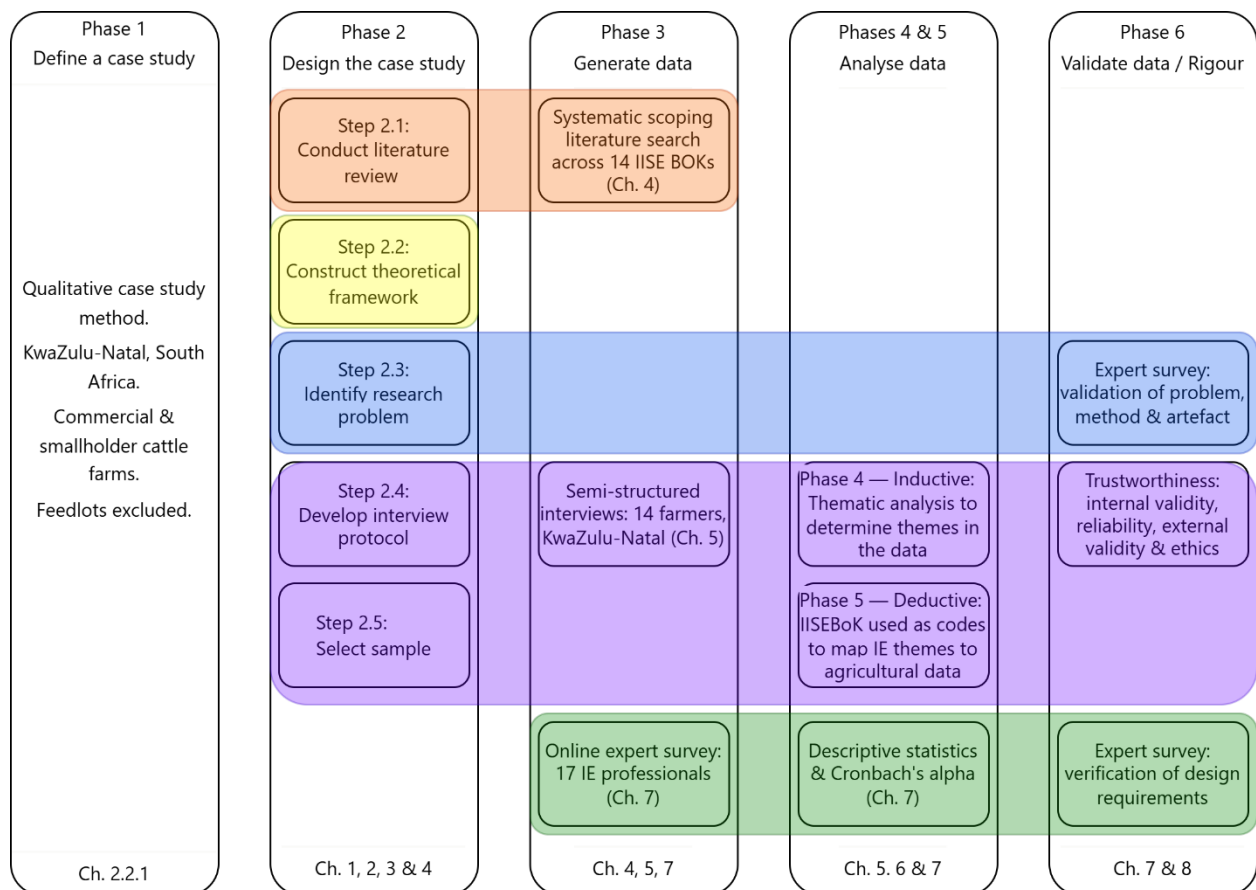


Figure 1: Research method

The colours in Figure 1 group related activities that form a single strand of work across the research phases. The orange grouping represents the scoping review strand, from its design in Phase 2 through to execution in Phase 3. The yellow grouping represents the construction of the theoretical framework using the IISE BOK. The purple grouping represents the farmer interview strand, starting from the design of the interview protocol, data collection, inductive and deductive analysis, and the subsequent validation of the research problem, method, and artefact. The green grouping represents the expert survey strand, from data collection and statistical analysis through to verification of the CPCM's design requirements. Reading across a row, therefore, shows how each strand of work progressed through the research phases.

STATEMENT OF CO-AUTHORS

To whom it may concern,

The listed co-authors hereby give consent that Herme Nel may submit the manuscript(s) as part of her dissertation titled, "Contextualising the Industrial Engineering body of knowledge within red-meat cattle production systems in KwaZulu-Natal" for the degree Master of Engineering in Industrial Engineering, at the North-West University (NWU).

This letter of consent complies with rule A4.13.3 of the academic rules, as stipulated by the North-West University.

Prof Rojanette Ceetzee

12 June 2026

Date

Dr Mia Mangaroo-Pillay

12 June 2026

Date

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I would also like to thank the rest of my family for their ongoing support and encouragement. A special thanks goes to my grandparents, who often let me sit and work at their house when my focus was running low—and who always made sure I had snacks nearby while I worked.

Finally, I am grateful to everyone who supported and encouraged me along the way. Your kindness and encouragement meant more than you know and helped make this journey possible.

I would also like to thank all participants who helped make this study possible, and for their fascinating insights and stories.

LIST OF ABBREVIATIONS

AAM	Livestock Agents & Auctioneers
BOK	Body of Knowledge
CA	Brucellosis
CPCM	Cattle Production Contextualisation Matrix
FMD	Foot-and-Mouth Disease
ha	Hectar
IISE	The Institute of Industrial and Systems Engineers
IISEBoK	Industrial and Systems Engineering Body of Knowledge
IE	Industrial Engineering
kg	Kilogram
KPI	Key Performance Indicators
KZN	KwaZulu-Natal
LP	Linear Programming
NWU	North West University
OR	Operations Research
ROI	Return on Investment
TB	Tuberculosis

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CHAPTER 1 INTRODUCTION TO THE RESEARCH

1.1 Introduction

This chapter discusses the background, problem statement, aim, objectives, and scope. Figure 1-1 illustrates a map of the research method, showing the current position within it with a red dashed square.

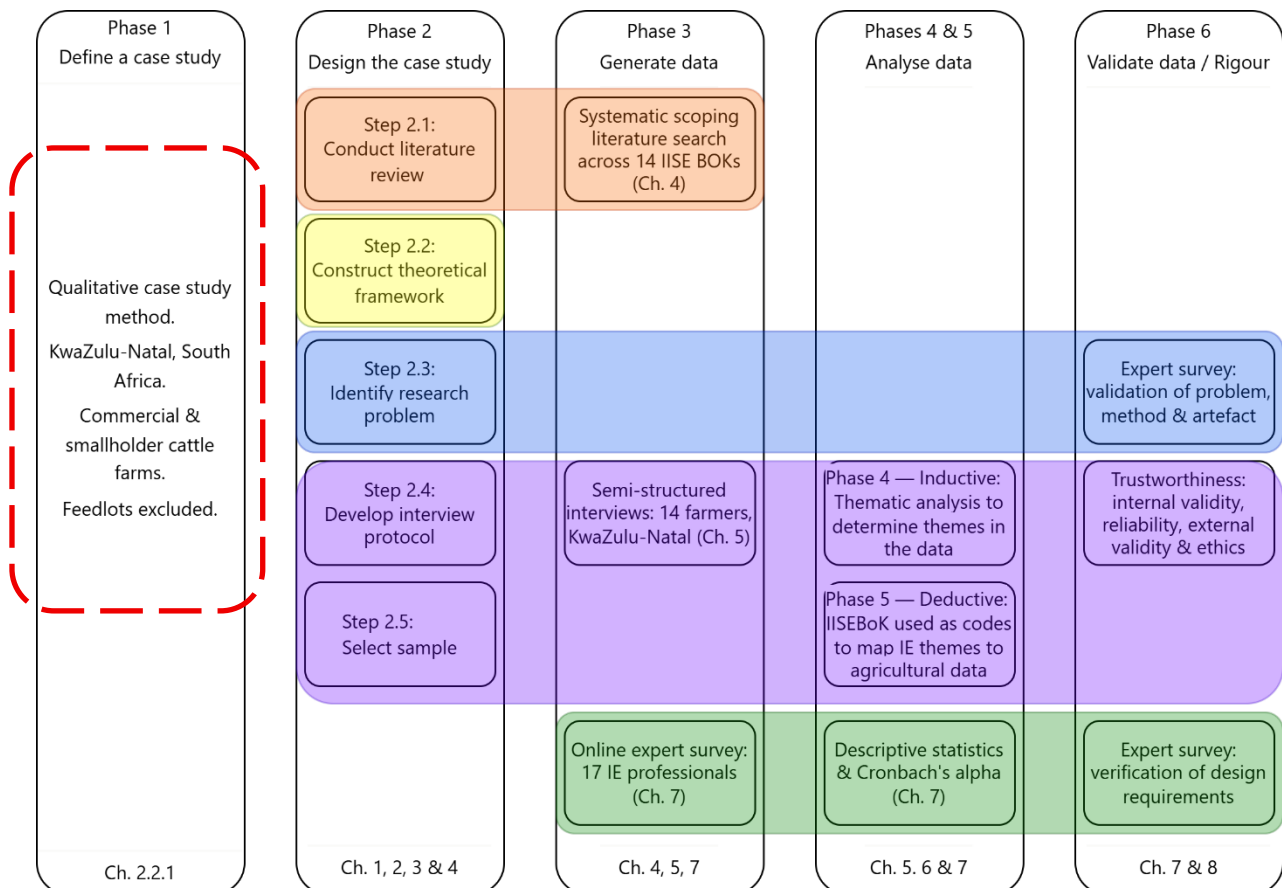


Figure 1-1: Research method

1.2 Background

Agriculture is a cornerstone of South Africa's economy, playing a vital role in job creation, foreign exchange, and food security (Jonck & Mabaso, 2025). The agricultural sector contributes significantly to the country's gross domestic product (GDP) and supports the livelihoods of millions of people. Within this sector, livestock farming is particularly important. Specifically, in 2022, red meat production in South Africa totalled almost 3.26 million beef cattle used for consumption (Cowling, 2024).

Despite global efforts to address hunger, food insecurity remains a major challenge. According to the State of Food Security and Nutrition in the World report, an estimated 673 million people experienced hunger worldwide in 2024 (FAO, IFAD, UNICEF, WFP, & WHO, 2024). The 1996 World Summit defined food security and has since been adopted by many organisations as “when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO, 2008; CFS, 2012). From this definition, four pillars of food security have been identified (FAO, 2008; CFS, 2012):

1. Availability – The supply and production (including stock levels and net trades) of food.
2. Access – The economic and physical ability to obtain food.
3. Utilisation – The nutritional quality, safety of foods, and the dietary needs of people.
4. Stability – The resilience of the food supply over time.

Livestock systems contribute to food security in several ways. Livestock convert low-value biomass and materials that are often inedible to humans into animal-source foods such as meat, milk, and eggs, which are rich in high-quality protein and essential micronutrients necessary for human health and development (Davis & White, 2020). Beyond direct food production, livestock also support rural livelihoods through income generation, asset growth, and the supply of inputs like manure and draft power in mixed farming systems, therefore indirectly strengthening household food access and agricultural productivity (van Wijk, et al., 2018; Banda & Tanganyika, 2021)

As stated earlier, the red-meat sector is an important component of the South African food system and therefore contributes to national food security. Domestic beef production declined from approximately 751,000 tonnes in 2015 to about 701,000 tonnes in 2022 (BFAP, 2025), before increasing again to an estimated 778,000 tonnes in 2024, largely driven by higher slaughter volumes and heavier average carcass weights (Red Meat Industry Services, 2024). Total slaughter volumes in South Africa rose to just under 2.6 million heads in 2023 and were projected to reach 2.8 million heads in 2024 (Red Meat Industry Services, 2024).

The red meat (beef) value chain touches all four pillars of food security. The red-meat (beef) value chain comprises four core functions (production, aggregation, processing and distribution) and in practice involves a network of actors including upstream input suppliers (e.g. feed, genetics and animal-health services), producers (cow–calf, backgrounding and finishing operations), processors/abattoirs, distributors (wholesalers, retailers and informal markets), and final

consumers, with additional by-product streams such as hides and offal (FAO, 2018; African Union, 2024).

The global importance of food security is also reflected in the United Nations Sustainable Development Goals (SDGs). In particular, Sustainable Development Goal 2 aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture (United Nations, 2015). The targets associated with SDG 2 focus on increasing the productivity and incomes of small-scale food producers, improving the sustainability and resilience of agricultural systems, and reducing food losses along value chains (United Nations, 2015). These priorities align closely with the role of industrial and systems engineering, which can improve efficiency, productivity, and coordination across agricultural value chains.

Figure 1-2 illustrates how the key stages of the red-meat value chain influence the four pillars of food security within the context of Sustainable Development Goal 2 (Zero Hunger). The upper layer of the figure presents the main value-chain functions (production, aggregation, processing, and distribution) while the middle layer represents the four food-security pillars (availability, access, utilisation, and stability). The lines indicate how performance at each stage of the value chain affects different outcomes in food security. Improvements or disruptions at any node of the value chain can therefore ripple through the system and influence the availability, accessibility, nutritional quality, and stability of food supplies (Food and Agriculture Organisation of the United Nations, 2014; HLPE, 2020)

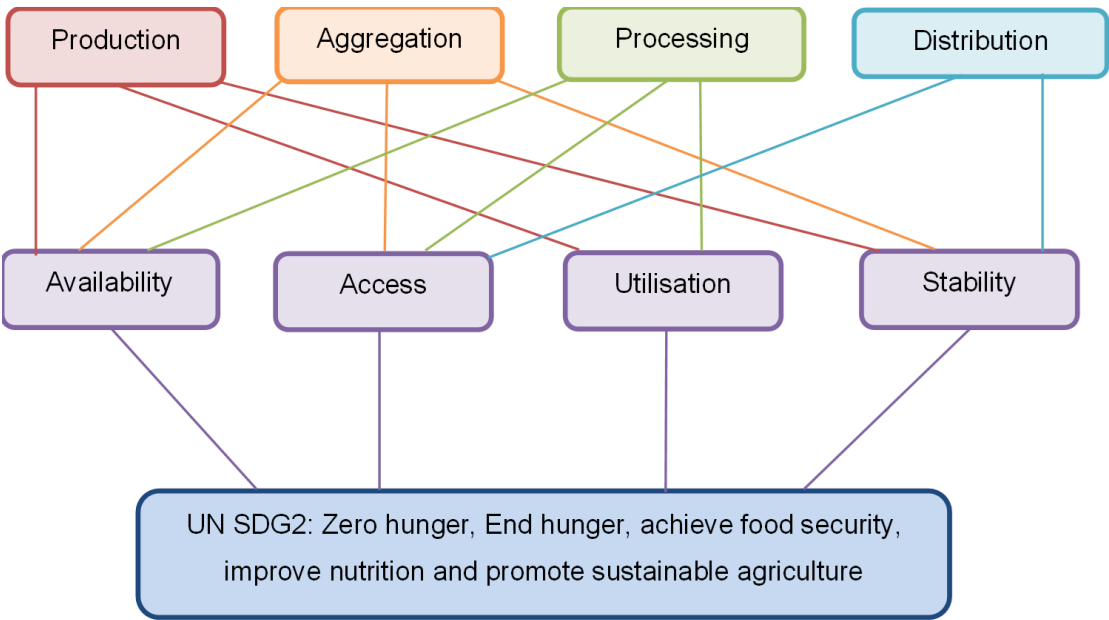


Figure 1-2: The influence of the red-meat value chain on the four pillars of food security (Author's own creation)

In general, the influence of each value-chain stage on food security can be summarised as follows:

1. Production: Production activities, including herd management, feed availability, genetics, and animal health, determine the amount of meat produced and, therefore, influence national food availability. These factors also impact meat quality and safety. Resilient production systems also reduce the risk of supply disruptions caused by drought, disease, or other shocks (van Wijk, et al., 2018).
2. Aggregation: Aggregation involves collecting and organising livestock from multiple producers. Effective aggregation systems increase marketable volumes, lower transaction costs, and enhance producer market access. These improvements support food availability and economic access while reducing seasonal supply volatility (Food and Agriculture Organisation of the United Nations, 2014; van Wijk, et al., 2018).
3. Processing: Processing determines the efficiency with which live animals are converted into edible products. Processing capacity and hygiene significantly influence the quantity of available meat, food safety, and shelf life, while processing efficiency can also impact consumer prices and, therefore, food access (FAO, 2007; FAO, 2011; FAO, 2018).
4. Distribution: Distribution systems (including transport networks, wholesale markets, and local markets) determine whether consumers can physically and economically get meat products. Efficient logistics and refrigerated storage and transport systems help preserve meat quality, extend shelf life, and maintain supply during disruptions (UNEP and FAO, 2022; Han, et al., 2021)

Together, these relationships illustrate how improvements in the performance and coordination of the red-meat value chain could strengthen food security and advance Sustainable Development Goal 2. Therefore, improvements or failures anywhere in the beef value chain (from on-farm productivity and input supply, through aggregation and processing, to distribution and retail) can influence national meat availability, producer income and consumer prices (access), food safety and nutritional quality (utilisation), and the sector's resilience to shocks (stability).

Despite its significance, farming in South Africa faces various challenges. These include production issues such as managing feed costs, ensuring animal health, and optimising breeding practices. In 2022, there were 600,000 smallholder cattle farmers, 2.3 million subsistence cattle farmers, and 40,000 commercial cattle farmers (Farmer's Weekly, 2022). Smallholder family farmers in South Africa often rely on traditional technologies, management techniques, practices,

and approaches that have been handed down over many generations (Van Niekerk et al., 2015). Farmers aim to manage their farms to maximise profit while maintaining a sustainable farm that can be passed on to the next generation.

KwaZulu-Natal is one of the main livestock farming provinces in South Africa (National Department of Agriculture, 2025). As KwaZulu-Natal has the highest rainfall in South Africa, it boasts higher-quality agricultural land than any other province (McBride, et al., 2022). The province leads the country in a variety of agricultural products. KwaZulu-Natal is home to a considerable proportion of South Africa's small-scale farming population, although it accounts for only a relatively small portion of the nation's total geographical area (National Department of Agriculture, 2025; Agribook Digital, 2024). The area's agriculture is varied and is influenced by the region's topography (Agribook Digital, 2024). This excellent agricultural region is centred in the Midlands, between Pietermaritzburg and the Drakensberg, with the Midlands and Highveld being the primary regions of beef cattle production in KwaZulu-Natal (Hitayezu, et al., 2014).

A few knowledge areas that already exist to assist the agricultural community include agricultural engineering, agricultural science, and animal science (Palmer, et al., 2023). In South Africa, agricultural engineering is represented by the South African Institute of Agricultural Engineers (SAIAE), which defines agricultural engineering (also called bioresource engineering) as the application of engineering principles to agriculture and other bio-based industries. This discipline connects plant/animal systems, soil and water resources, and production technologies with engineering systems, machinery and mechanisation (SAIAE, 2024).

Agricultural science is the study of food processing and production, including technologies for crop production and harvesting, soil cultivation, animal production, etc (Palmer, et al., 2023). Animal science includes the management, breeding, genetics, nutrition, ecology, ethology and applied animal physiology of livestock (Palmer, et al., 2023).

However, these traditional agricultural knowledge areas often do not address broader systemic challenges. Farmers also face issues such as access to land and markets, essential training, relevant technologies, and business development skills (Rangarajan & Chitja, 2020). They also struggle with low product prices, inadequate workforces, and competition (Van, et al., 2024). Some farmers also struggle with a lack of entrepreneurial skills, financial literacy, risk management, and fact-based decision-making (Clune & Downey, 2022). Other challenges include high transportation costs (Reis, 2017), water scarcity (Suleiman, et al., 2015), and livestock marketing (Alemneh & Getabalew, 2019). These broader issues necessitate a different approach. These challenges and lack of skills are not necessarily addressed in the agriculture

knowledge areas, but could possibly be addressed in the industrial engineering (IE) knowledge area.

The Institute of Industrial and Systems Engineers (IISE) defined industrial engineering as follows: “Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of people, material, information, equipment and energy” (IISE, 2021). IE applies principles and methods from mathematical, physical, and social sciences to improve productivity, reduce costs, enhance quality control, and ensure worker safety (Savory, 2005).

Industrial engineering is situated in the scientific domain and has a toolbox of knowledge, tools, and techniques centred around producing the optimal outcome in a production scenario. According to the Institute of Industrial and Systems Engineering (IISE), there are 14 knowledge areas of Industrial and Systems Engineering (IISE, 2021). The knowledge areas are shown in Figure 1-3.

By viewing farming operations as a production system, Industrial Engineering could bring a unique perspective. Farmers can benefit from IE techniques such as process optimisation, supply chain management, and quality control. By applying these methods, farmers can better manage their resources, predict market trends, and improve overall productivity. From an industrial engineering perspective, a beef cattle farm can be compared to a factory, manufacturer, or organisation. The cattle are the raw material, and the beef at the end of the production line is the finished goods. If the production process is not functioning optimally, the quality and quantity of the finished product (meat) will be below the standard.

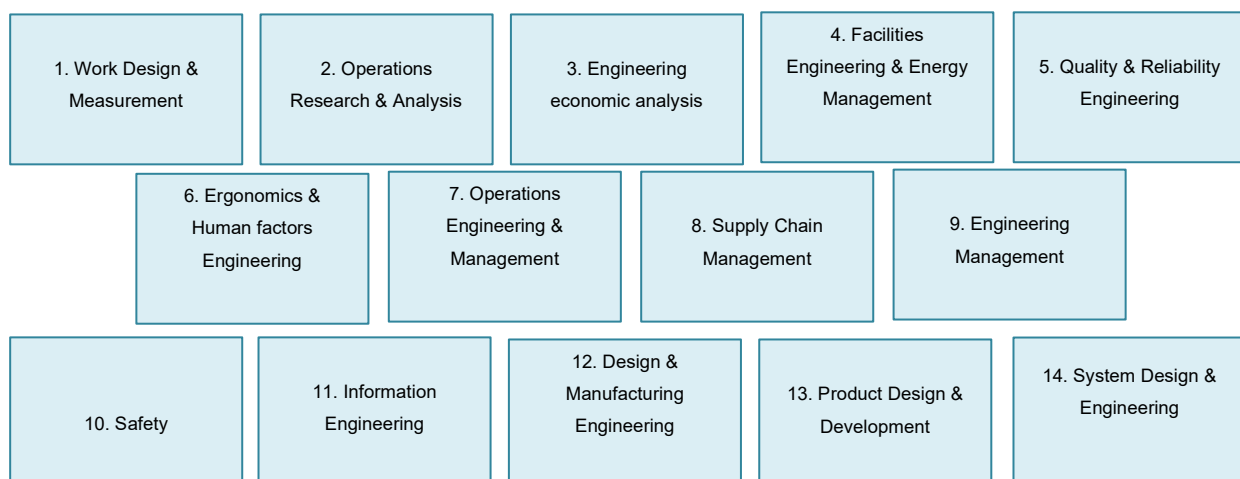


Figure 1-3: Knowledge areas of Industrial and Systems Engineering (Adapted from IISE (2021))

For example, outsourcing cattle feed can be a strategic choice to manage feed costs. Herd sizes can be optimised, and market prices predicted to ensure better production output, efficient

storage, and an adequate workforce. Problem-solving techniques and safety measures are crucial for protecting both the herd and the workers involved. Implementing record-keeping approaches helps in logging the herd's historical data and performance. Additionally, assessing whether the cattle meet quality standards or require a finishing period before sale or slaughter is essential to maintaining product quality.

There are many examples of how farmers operate and manage their cattle production lines. All these functions could be compared with industrial engineering methods. This analogy highlights how different aspects of agriculture can align with industrial engineering concepts. Therefore, applying industrial engineering knowledge could enhance cattle production approaches.

A search for “industrial engineering” and “agriculture” across various academic databases yields research that focuses specifically on industrial engineering in crop farming (Nichols & MacKenzie, 2023), food processing facilities, dairy production, and livestock feed manufacturers (Marcinowski, 2019). However, few studies report on how Industrial Engineering methods could be used to support farmers, specifically in red-meat cattle production.

A search for “industrial engineering” and “cattle production” in various academic databases results in research focused on dairy production and feedlots (intensive livestock facilities where cattle are confined and fed a high-energy diet to achieve rapid weight gain before slaughter (FAO, 2013)), but with limited studies specifically focused on beef cattle farms. A search for “industrial engineering” and “cattle farming” in various databases resulted in 14 studies that mostly focused on the effect that cattle farming had on wetlands (Miguel, et al., 2023), environmental impact (Clemencio, et al., 2014; Costantini, et al., 2021; Khatun, et al., 2022), and gases (Garcia-Perez, et al., 2018; Calise, et al., 2015). Four articles used industrial engineering techniques, such as Monte Carlo simulations (Ronyastra et al., 2024), modelling, and real-time data, to track or improve specific events, but only three of those articles focused on cattle farming. Of the three articles, one article focused on motion analysis cameras to detect a mating event (Tsai & Huang, 2014). The other article modelled certain situations to improve cattle health (van Heerden, et al., 2024). The last article used low-cost ear tags to identify cattle drinking at water troughs (Pretto, et al., 2024).

There seems to be a lack of alignment between industrial engineering and the red meat cattle production sector on farms, limiting the development of pragmatic solutions to food security challenges. An investigation into how industrial engineering knowledge areas can be applied to enhance cattle production approaches for farmers could provide a foundation for research aimed at developing strategies to implement these knowledge areas to increase farm production, sustainability, and flexibility.

Industrial and Systems Engineering (IISE) methods could help improve food security by making red-meat production systems more efficient, coordinated, and resilient. For example, process optimisation, data-driven decisions, and supply chain management can improve production efficiency and reduce losses, therefore improving food availability. Better logistics, aggregation, and market coordination can reduce transaction costs and make it easier for producers and consumers to access markets, supporting food access. Strict quality control can make food safer and improve product quality, thereby supporting its use. Risk management and system modelling can help production systems withstand disruptions such as drought, disease, or market changes, making food supplies more stable. Despite this potential, the application of IE methods in beef cattle production systems remains limited, showing an opportunity for further investigation.

Therefore, this study will initiate transdisciplinary collaboration between industrial engineering and red meat cattle production in the agriculture sector, allowing future researchers to transfer industrial engineering knowledge, methods, and tools to support farmers.

1.3 Problem statement

The problem is that Industrial Engineering research has not been aligned with the beef cattle industry, thereby limiting the development of pragmatic solutions to food security challenges.

1.4 Research Aim

This research aims to contextualise the Industrial Engineering body of knowledge (IISE-BOK) within red-meat cattle production systems in KwaZulu-Natal, thereby initiating transdisciplinary collaboration between industrial engineering and red-meat cattle production to address food security challenges.

1.5 Research objectives

To achieve the aim, the following objectives are set:

1. To investigate available literature on the application of IE knowledge in the beef cattle production systems via a scoping review.
2. To explore the challenges and their root causes experienced in cattle production lines via interviews.
3. To contextualise the Industrial Engineering body of knowledge (IISE-BOK) within red-meat cattle production systems in KwaZulu-Natal by creating a contextualisation framework.

4. To verify that the contextualisation framework complies with the design requirements through expert review.
5. To prove that a valid problem, method, and artefact were developed in this study through expert review.

1.6 Research Scope

The research will specifically focus on red meat cattle production in KwaZulu-Natal's Midlands and Highveld areas (hereinafter, cattle production). The research will specifically focus on cattle production on smallholder and commercial farms, not on feedlots.

For this study, smallholder cattle farms are described as lower-input farming systems that generally keep smaller herds, rely mainly on family labour, and participate irregularly in formal markets. In many cases, cattle on these farms serve multiple purposes, including household consumption, supplementary income, savings, and socio-cultural functions. Commercial cattle farms, by comparison, are more market-oriented and operate primarily for profit, usually with larger herd sizes, more structured production systems, and regular participation in formal beef value chains.

In operational terms, farms with fewer than 100 cattle were classified as smallholder farms, while those with more than 200 cattle were classified as commercial farms. Farms with herd sizes between 100 and 200 cattle were classified based on additional production characteristics, particularly the degree of market participation, production intensity, and level of commercial orientation. This approach reflects the fact that herd size alone is not always a sufficient indicator of production system type, particularly in mixed or transitional farming systems.

These classifications were used solely to provide context for interpreting production practices and the impact of disease within the study area.

1.7 Field of research

This study will lie within the field of Industrial Engineering applied to agriculture. As the aim of this study is to contextualise the Industrial Engineering Bodies of Knowledge within red-meat cattle production systems, it will focus on all Industrial Engineering knowledge areas (Figure 1-2).

1.8 Assumptions

The following assumptions guided this study:

- (1) The 14 IISE Bodies of Knowledge collectively represent the scope of industrial engineering knowledge applicable to this study;
- (2) Beef cattle production systems share characteristics with other production systems where IE methods have been applied;
- (3) The challenges described by farmers reflect actual operational conditions; and
- (4) The 14 interviews conducted were sufficient to capture the main challenges experienced within the study region.

1.9 Chapter divisions

Table 1-1 illustrates the chapter divisions for the dissertation.

Table 1-1: Chapter divisions for dissertation

#	Contents	Description	Research objective
1	Introduction to the research	Introduces the study by providing background on beef cattle production in South Africa and the role of industrial engineering. The chapter presents the problem statement, aim, and objectives, and defines the field and scope of the research.	N/A
2	Literature Study	Reviews the theoretical foundations of the study, including case study methodology, qualitative research design, and the IISE Body of Knowledge framework.	N/A
3	Research Design	Describes the research design, data collection procedures, sampling strategy, and analytical approach used in this study.	N/A
4	Scoping Literature Review	Presents the scoping review investigating the existing literature at the intersection of industrial engineering and beef cattle production systems, organised according to the 14 IISE BOKs.	1
5	Farmer Interview Findings	Reports the inductive findings from the 14 farmer interviews, identifying key challenges and their interconnections from a systems perspective.	2
6	Contextualisation Matrix	Presents the deductive mapping of farmer challenges to the IISE BOKs, producing the Cattle Production Contextualisation Matrix (CPCM).	3
7	Expert Survey	Describes the expert survey used to verify the matrix and support the validity of the research problem, method, and outputs.	4

8	Verification and Validation	Addresses the rigour of the study and evaluates the extent to which the research problem, methodology, and artefact meet the validation criteria.	5
9	Conclusions	Presents the conclusions, research contributions, limitations, and recommendations for future research.	N/A

1.10 Chapter Summary

This chapter established the background of this study, along with the problem, aim, and objectives.

CHAPTER 2 LITERATURE STUDY

2.1 Introduction

This chapter examines the relevant literature on the applicable research methods used in this study, specifically case study methodology, qualitative research design, thematic analysis, and rigour criteria. The substantive literature review on the intersection between industrial engineering and beef cattle production systems is presented in Chapter 4 as a scoping review. This chapter is therefore limited to the methodological approach adopted in the study, while the core subject-matter literature is addressed in Chapter 4 as a separate scoping review forming a major part of the empirical investigation of the dissertation. Figure 2-1 shows the current position in the research method.

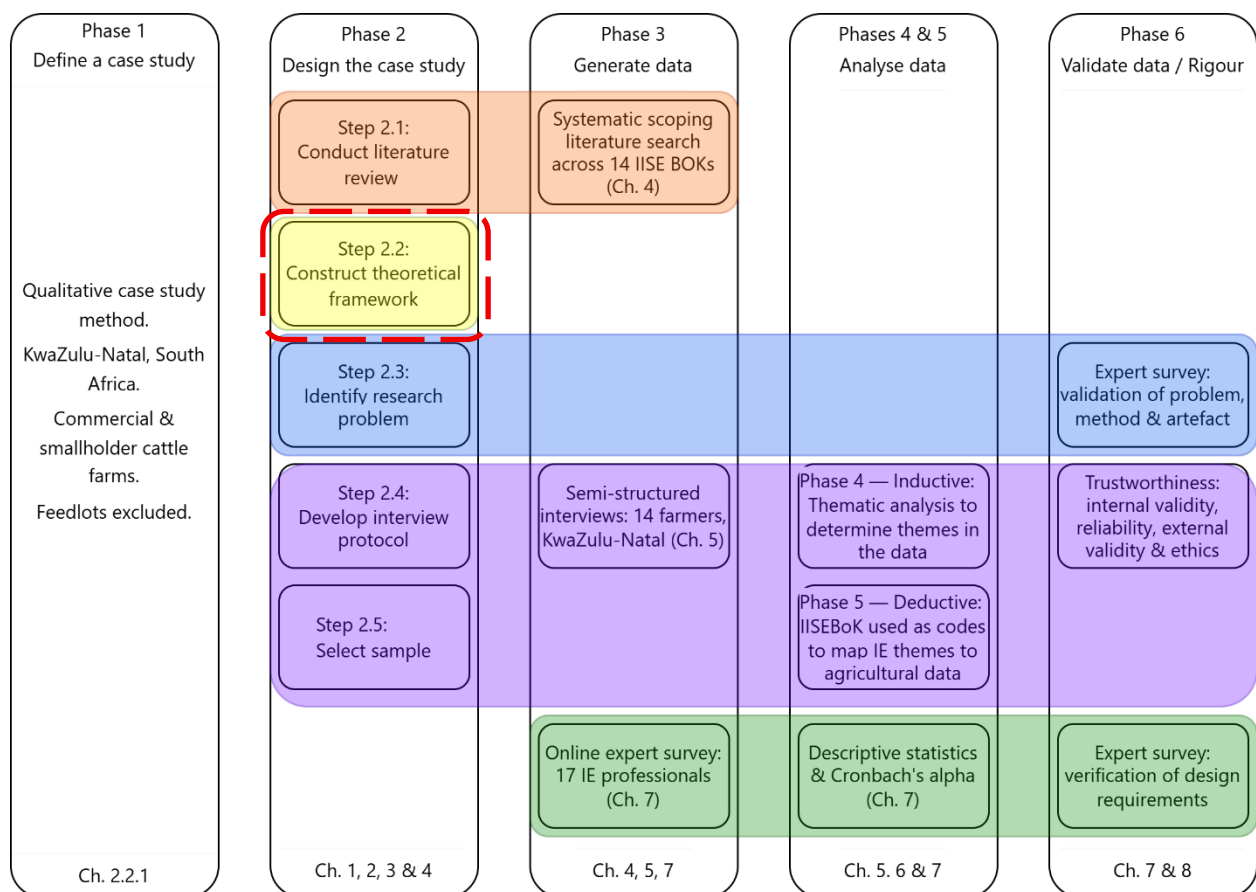


Figure 2-1: Research method

2.2 Case study design

The case study approach can be utilised as a methodology or a comprehensive research strategy (Denzin & Lincoln, 2005; Merriam, 2009; Yin, 2008; Creswell, 2007). It develops a

comprehensive, contextual overview of a situation using a variety of data sources (Yin, 2008). Therefore, case study research examines a topic through one or more instances within a bounded system (i.e., a setting or a context) (Yin, 2008). An exploratory case study design can be used when a phenomenon is not researched enough or poorly understood. It allows the researcher to study emerging concepts, explain research questions, and develop new theoretical insights within a real-world context (Merriam, 2009). A case study methodology can be used when (a) the study's goal is to provide answers to "how" and "why" questions; (b) the researcher is unable to control the behaviour of study participants; (c) the researcher wants to cover contextual conditions because he/she thinks they are important to understand the phenomenon being studied; or (d) it is unclear where the phenomenon and context boundaries are (Yin, 2008).

Among the most popular case study methodologists are Robert Stake (Stake, 1995), Robert Yin (Yin, 2018) and Sharan Merriam (Merriam, 2009). Merriam's approach is a well-defined, well-structured research methodology that novice qualitative researchers can use as a research strategy, combining Yin's and Stake's approaches (Yazan, 2015). The structure of Merriam's case study methodology is illustrated in Figure 2-1 and explained in the sections to follow.



Figure 2-2: Qualitative case study methodology.

2.2.1 Define a case study

A case is “a thing, a single entity, a unit around which there are boundaries”. It can be a person, a group, an organisation, etc. (Merriam, 2009). A qualitative case study is “an intensive, holistic description and analysis of a bounded phenomenon such as a program, an institution, a person, a process, or a social unit” (Merriam, 2009).

2.2.2 Designing the case study

Figure 2-2 illustrates the five steps of qualitative case study design. Although the five steps of designing a case study are clear, in practice, it is not a linear process (Merriam, 2009). Therefore, the process does not necessarily progress from reading literature to identifying a theoretical framework and then writing a problem statement (Merriam, 2009).

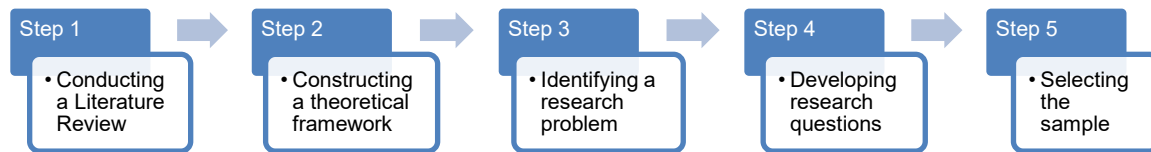


Figure 2-3: Case study design steps.

Step 1 & 2:

The literature review helps identify a theoretical framework (Merriam, 2009). The theoretical framework serves as the foundation of the study. The study's framework will draw on definitions, concepts, terms, and theories from the body of knowledge and disciplinary orientation (Merriam, 2009). This framework will influence the study's "problem", research questions, data gathering and analysis, and interpretations of the findings (Merriam, 2009).

Step 3:

The research problem can be likened to a funnel in shape – broad at the top and narrow at the bottom (Merriam, 2009). Therefore, the study's general interest is identified at the outset by introducing key concepts and outlining its significance (Merriam, 2009). The researcher then narrows the topic of interest while explaining the information gap in the knowledge base (Merriam, 2009). The knowledge gap is then restated as the study's problem statement (Merriam, 2009).

Step 4:

The research questions guide the study by outlining what it will address (Merriam, 2009). The research questions determine the areas of interest to explore through interviews (Merriam, 2009). Interview and research questions are not to be confused, as research questions are much broader (Merriam, 2009).

Step 5:

Once a general problem is selected, the researcher must choose a unit of analysis or sample (Merriam, 2009). Every research project involves several locations to be visited, occasions or activities to be examined, people to be interviewed, and documents to be examined (Merriam, 2009). Therefore, the researcher must decide what, when or whom to observe or interview (Merriam, 2009). Nonprobability sampling is the most commonly used sampling type in qualitative research (Merriam, 2009).

2.2.3 Data generation or data gathering

Case studies typically use qualitative data sources exclusively (Merriam, 2009). Researchers must gather data from multiple sources to fully capture the phenomenon (Merriam, 2009). The three data collection techniques for case studies are interviews, observations, and documents (Merriam, 2009).

- Interviews – The purpose of interviews is to obtain specific information (Merriam, 2009). The two forms of interviews are one-to-one and focus group interviews (Merriam, 2009). Interviews are categorised into three structures: Highly structured/Standardised, Semi-structured, and Unstructured/formal (Merriam, 2009).
- Observations – Observations are made at the location where the phenomenon occurs (Merriam, 2009). Observations are data collected with firsthand experience (Merriam, 2009). Informal interviews and conversations are often intertwined with observations (Merriam, 2009).
- Documents – Documents are “written, visual, digital, and physical material relevant to the study at hand” (Merriam, 2009). Documents include videos, photos, songs, newspapers, reports, poems, letters, etc. (Merriam, 2009).

To support effective interviewing, some practical recommendations for structuring and managing the conversation include (De Vos, et al., 2011a):

- Allowing participants to speak for most of the interview
- Keeping questions clear, concise, and asked one at a time
- Using open-ended questions unless a different format is justified
- Avoiding overly sensitive topics unless directly relevant
- Avoiding leading or suggestive phrasing
- Encouraging participants to speak freely while still maintaining direction and focus
- Allowing pauses where needed and returning to incomplete points
- Ending with a broad concluding question
- Refraining from interrupting unless necessary
- Following up on cues and statements provided by participants
- Monitoring participants' well-being and providing appropriate closure if needed

- Keeping the recording device running throughout
- Tracking interview length
- Redirecting the conversation promptly when it drifts off topic

Creswell and Creswell (2017) further recommend using an interview protocol to manage the practical demands of the interview process. Such a protocol acts as a structured guide for the researcher. Table 2-1 presents an example of an interview protocol.

Table 2-1: Interview Protocol adapted from Creswell and Creswell (2017)

Interview protocol for xxx		
Basic information – Record-keeping information such as date, participant number, etc.		
Introduction – The researcher introduces and explains the study and themselves. Discuss the logistics of the interview.		
Guiding research question – This is the main goal of the interview.		
Research question 1	Research question 2	Research question xx
Interview question Rephrase the question based on target audience - Add probing question 1 - Add probing question 2 - Add probing question 3	Rephrase the question based on target audience - Add probing question 1 - Add probing question 2 - Add probing question 3	Rephrase the question based on target audience - Add probing question 1 - Add probing question 2 - Add probing question 3
Closing instruction: Thank the participant, assure confidentiality, and request follow-up.		

2.2.4 Data analysis

Qualitative research is not a linear process; data collection and analysis should happen simultaneously (Merriam, 2009). Data analysis is “the process of making sense of the data” (Merriam, 2009). After the researcher has conducted the first interview, they should review the study's purpose and then analyse the first interview transcript (Merriam, 2009). The researcher should read and reread the interview data, make notes in the margins, and comment on the themes, hunches, etc., on the first dataset (Merriam, 2009). The researcher then notes things they want to ask the next interviewee in the second round of data collection (Merriam, 2009). After analysing the second set of data, the researcher compares it with the first, which then informs the next round of data collection (Merriam, 2009). All qualitative data analysis is inductive and comparative (Merriam, 2009).

Data analysis is the process used to answer the study's research questions (Merriam, 2009). The answers to the research questions constitute the study's findings and are also referred to as

categories or themes (Merriam, 2009). Data analysis begins by identifying parts of the data set that relate to the research questions (Merriam, 2009). This part is a unit of data that is a potential or a part of the answer to the research questions (Merriam, 2009). Therefore, a unit of data is any potentially meaningful part of data (Merriam, 2009). A unit can be as small as a single word or as long as several pages (Merriam, 2009). A unit must adhere to two criteria (Lincoln & Guba, 1985). Firstly, it must divulge information applicable to the study (Lincoln & Guba, 1985). Secondly, a unit should be the tiniest piece of information about the subject that can be understood without any further context (Lincoln & Guba, 1985).

Afterwards, the units of information are arranged to identify patterns. The units of information that relate to each other or recur can then be grouped into categories (Merriam, 2009). These categories also have to meet certain criteria and should be (Merriam, 2009):

- responsive to the purpose of the study.
- comprehensive (all data that was deemed significant should be placed into a category or subcategory).
- mutually exclusive (a unit of data cannot be found in more than 1 category or subcategory).
- sensitising (The naming of the category should be as sensitive as possible to the data).
- conceptually congruent (each category should possess the same level of abstraction).

There are two additional analysis methods: content analysis and analytical induction (Merriam, 2009). Content analysis focuses on communication and is quantitative in nature (Merriam, 2009). The content of the interviews, documents, and field notes is analysed to determine how many times a given phrase is used (Merriam, 2009). Therefore, the analysis focuses on the frequency of topics, situations, and settings (Merriam, 2009). Analytical induction involves inferring a hypothesis of the phenomenon of interest (Merriam, 2009). The hypothesis is modified if a case does not support it; otherwise, it remains valid if a case of the phenomenon does fit (Merriam, 2009).

2.2.5 Data validation

Conventional or quantitative research uses validation and verification, or reliability, methods to ensure that the study is credible and conducted rigorously (Merriam, 2009). Verification ensures that the system or design specifications and requirements are met (Merriam, 2009). Validation ensures that the system performs as intended (Merriam, 2009). Qualitative research uses the terms rigour and trustworthiness (Merriam, 2009). Merriam discusses the qualitative terms rigour and trustworthiness while referencing the quantitative terms validity and reliability (Merriam,

2009). Any research can address validity and reliability issues by carefully considering the study design, data collection, processing, and interpretation, as well as the presentation of the findings (Merriam, 2009). Qualitative studies can employ various techniques to enhance validity and reliability (Merriam, 2009). These techniques and strategies include (Merriam, 2009):

Internal validity – how well research findings match reality:

- Triangulation.
- Member checks/respondent validation.
- Long-term observation.
- Researcher's position/ reflexivity/ researcher bias.
- Peer examination/peer evaluation.

Reliability or consistency – how well research can be replicated:

- Triangulation.
- Peer examination.
- Audit trail.
- Investigator's position.

External validity – how well the findings can be applied to other situations:

- Use of rich and thick descriptions.
- Maximum variation.

Beyond validity and reliability, qualitative research is also guided by ethical considerations, as described in Patton's (2002) ethics checklist (Patton, 2002):

- Explaining the purpose of the inquiry and the methods to be used.
- Promises and reciprocity.
- Risk assessment.
- Confidentiality.
- Informed consent.
- Data access and ownership.
- Interviewer's mental health.
- Advice (who will be the researcher's counsellor on ethical matters).
- Data collection boundaries.
- Ethical versus legal conduct

2.3 Surveys

Surveys are widely used to investigate attitudes, perceptions, and behaviours of a population by analysing responses from a sample (Creswell, 2017). According to Sinkowitz-Cochran (2013), surveys offer an efficient way to collect structured information, allowing researchers to gather data on multiple topics simultaneously. The survey elements follow a standardised format; therefore, the resulting dataset is consistent and comparable across all participants.

Like all research instruments, surveys have both advantages and limitations. Kelley et al. (2003) note that surveys are particularly valuable for generating broad insights into a population because they can reach a wide audience at relatively low cost and often within a short time frame. The survey findings can also provide practical insight into real-world trends and behaviours. In contrast, researchers may conduct superficial analyses if they rely too heavily on descriptive results, or they may misinterpret findings when large response groups overshadow minority perspectives. Response rates can also be unpredictable, thereby affecting the representativeness of the sample.

There are two survey formats: interviewer-administered, in which the researcher poses questions directly, and self-administered, in which participants complete the instrument in their own time (OECD, 2012). Self-administered surveys can be administered through group settings, postal systems, drop-off methods, or online platforms. Among these, online surveys tend to offer the greatest practical benefits due to their ease of distribution, low cost, and convenience for participants (OECD, 2012). This study used an online survey in Chapter 7.

A consistent theme across the literature is that survey quality depends heavily on the clarity of the design and adherence to ethical and methodological standards (Creswell, 2017; De Vos et al., 2011b; Fanning, 2005; Kelley et al., 2003; Sinkowitz-Cochran, 2013). Key recommendations include:

- Ensuring an uncluttered, visually clear survey layout
- Providing instructions and a concluding thank-you message
- Using an established response scale
- Avoiding vague, ambiguous, or leading statements
- Eliminating jargon, unexplained acronyms, and double-barreled items
- Keeping items concise and grouped into logical sections
- Maintaining anonymity and confidentiality
- Using simple, accessible language that suits the intended participants

- Ensuring that each statement contributes meaningfully to the survey's validation purpose

2.4 Survey Statistics

Purposive sampling involves the deliberate selection of individuals with the specific expertise required for the research (De Vos, et al., 2011a). In this case, the participants were chosen because they are industrial engineers and have a sufficient familiarity with cattle production systems to evaluate the proposed framework meaningfully.

Because purposive sampling is a non-probability sampling method, it offers limited opportunities for statistical generalisation (De Vos, et al., 2011a). Nevertheless, several descriptive statistical techniques can still be used to summarise and analyse the survey results. The most fundamental calculation for Likert-type survey items is the mean (average) score, which indicates the group's overall level of agreement with each statement (Devore et al., 2013). The mean is calculated as follows:

$$\bar{x} = \frac{\sum_i^n x_i}{n}$$

Equation 2-1: Mean Figure

Where $\sum_i^n x_i$ is the sum of all responses, and n is the number of participants. A second useful statistic is the standard deviation, which reflects the spread of responses around the mean and indicates the degree of agreement or disagreement within the group. It is calculated as (Devore, et al., 2014):

$$s = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

Equation 2-2: Standard Deviation

Where s is the standard deviation of all the scores, x is the mean of the scores, and n is the number of responses. The variance is then obtained by squaring the standard deviation:

$$s^2 = \frac{\sum (x_i - \bar{x})^2}{n - 1}$$

Equation 2-3: Variance

The Variance represents the average degree to which the responses differ from the mean. To assess the internal consistency and reliability of a multi-item Likert scale, the Cronbach's alpha statistic can be calculated (Ercan et al., 2007; Taber, 2018). Cronbach's alpha is the most widely used reliability indicator in survey research. It is calculated as follows:

$$\alpha = \left(\frac{k}{k-1} \right) \left(\frac{s_y^2 - \sum s_i^2}{s_y^2} \right)$$

Equation 2-4: Cronbach's Alpha

where k is the number of survey items, s_y^2 is the variance of the total score for each participant, and $\sum s_i^2$ is the sum of the variances for each item. The resulting value of α reflects the degree of consistency across the survey items, with interpretation commonly based on established thresholds (illustrated in Table 2-2).

Table 2-2: Internal consistency interpretations of Cronbach's alpha (Vale, et al., 1997)

Cronbach Alpha	Internal Consistency
$\alpha \geq 0.9$	Excellent
$0.8 \leq \alpha < 0.9$	Good
$0.7 \leq \alpha < 0.8$	Acceptable
$0.6 \leq \alpha < 0.7$	Questionable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

2.5 Industrial engineering theoretical framework

As explained in section 2.2.2, step 2 of a case study design uses a theoretical framework. Industrial engineering concepts will inform this research, and therefore, the theoretical framework for this study is the Industrial and Systems Engineering Body of Knowledge (IISEBoK). The IISEBoK defines a classification of all the essential and relevant industrial engineering concepts (IISE, 2021). The IISEBoK provides the knowledge areas required for designing, improving, and implementing integrated systems of people, materials, information, equipment, and energy in any industry or service sector (IISE, 2021). As stated earlier, there are 14 knowledge areas in the IISEBoK (Figure 1-3), which include:

1. Work Design and Measurement

Work system design includes the breakdown, specification, integration and verification of human-machine systems, along with the tools, technology, workspaces, and work techniques required to complete productive tasks within an organisation (Freivalds & Niebel, 2014). It is crucial to ensure

that machine and human resource functions are combined into a fair day of work (Freivalds & Niebel, 2014).

The term "work system measurement" refers to the instruments and methods used to assess a system's output rates and other productivity metrics (Groover, 2006). Output rates reflect the time it takes workers to complete specific tasks in specific work environments at accepted performance levels (Groover, 2006). Tools for data gathering and analysis may range from simple instruments such as spreadsheets and stopwatches to advanced Big Data systems (Groover, 2006).

2. Operations Research and Analysis:

Operations Research (OR) and Management Sciences offer a range of problem-solving methods to enhance system efficiency and support decision-making (Hillier & Lieberman, 2021). When mathematical models are formulated and applied, operations research enables the optimisation of real-world systems and the achievement of real-time efficiency gains (Hillier & Lieberman, 2021). This discipline relies on mathematical and computational tools, including probability, statistics, calculus, algebra, and computing (Hillier & Lieberman, 2021).

3. Engineering Economics and Analysis:

Engineering projects are evaluated within the field of engineering economics (White, et al., 2020). Industrial engineers must understand the economic feasibility of a potential project and potential solutions to its problems (White, et al., 2020).

4. Facilities Engineering and Energy Management:

Facilities engineering involves the placement of physical resources such as machines, storage facilities, and operators to enable the optimal production and distribution of goods and services (Tompkins, et al., 2010). Energy management involves planning and operating energy systems in facilities to support production and distribution (Roosa, et al., 2020). These two topics tend to overlap and are therefore added to one section (IISE, 2021).

5. Quality and Reliability Engineering:

Quality engineering encompasses the methodologies used to prevent errors and defects in products and services (Montgomery, 2019). Reliability engineering involves evaluating a system's or component's ability to function under specified conditions for a given period (Elsayed, 2021).

6. Ergonomics and Human Factors:

Ergonomics and human factors encompass the design and analysis of equipment customised for people (Lehto & Landry, 2013). This discipline addresses physical, cognitive, and organisational aspects to create ergonomic solutions that improve system performance and user well-being (Lehto & Landry, 2013).

7. Operations Engineering and Management:

Operations engineering and management refers to the design and analysis of production and service processes, with a focus on efficiency and resource optimisation (Russell & Taylor, 2011). By applying a range of tools and techniques, this discipline ensures that business operations align with customer requirements while minimising resource use (Russell & Taylor, 2011).

8. Supply Chain Management:

Supply chain management (SCM) involves the oversight of raw materials, work-in-progress, and finished goods as they move from origin to final consumption (Huang, 2013). This involves coordination among suppliers, manufacturers, and service providers to meet customer demands effectively (Huang, 2013).

9. Engineering Management:

Organisational management can be enhanced by the application of engineering principles (Morse & Bobcock, 2013). While operations engineering and management focus on process design and analysis, engineering management emphasises the technical aspects of business operations (Morse & Bobcock, 2013).

10. Safety:

Occupational safety addresses workplace accident prevention, regulatory compliance, and hazard mitigation strategies (Goetsch, 2015). It focuses on measures for identifying and controlling physical hazards, as well as protocols for accident response and recovery (Goetsch, 2015).

11. Information Engineering:

Information engineering involves the planning, generation, analysis, and use of data collection systems to support decision-making and business communication (Mallach, 2016).

12. Design and Manufacturing Engineering:

Design and manufacturing engineering covers the entire product lifecycle, from conceptualisation to production (Groover, 2019). This area prioritises the development, optimisation, and standardisation of methods to efficiently transform raw materials into functioning products (Groover, 2019).

13. Product Design and Development:

Product design and development refers to the initiation and refinement of ideas that lead to the creation of new products (Ulrich & Eppinger, 2020). Throughout this process, industrial engineering principles are applied to support efficient and effective decision-making (Ulrich & Eppinger, 2020).

14. Systems Design and Engineering:

Systems Design and Engineering combines different engineering disciplines, including the consideration and integration of all project aspects (Eisner, 2008).

2.6 Thematic Analysis

A thematic analysis is a flexible procedure for identifying themes or patterns in qualitative data (Braun & Clarke, 2021). The flexibility allows researchers to use either an inductive or deductive approach or a combination of the two approaches (Braun & Clarke, 2021). An inductive approach is one in which data coding is derived from the content of the data (Braun & Clarke, 2021). A deductive approach involves the researcher presenting a series of ideas, concepts, or topics to the data, which are then used to code the data (Braun & Clarke, 2021). A thematic analysis is done in 6 phases (Braun & Clarke, 2021):

- 1) Familiarisation with the data: This phase involves reading and re-reading the data (interview transcripts, etc.) and noting initial ideas and analytical observations.
- 2) Generating initial codes: This phase is where the researcher produces initial codes from all the data by organising the data in a meaningful and systematic way.
- 3) Searching for themes: This phase includes analysing the codes to determine whether they fit into initial groups or named themes. A theme is a meaningful and coherent pattern in the data.

- 4) Reviewing themes: The candidate themes from the previous phase need to be refined in this phase. The themes are checked against the full data set and the coded extracts to see if they work. It might be necessary to split a theme into two or three, or to collapse two or three into one. It might also happen that all themes must be discarded, and the process needs to start over from phase 3.
- 5) Defining and naming themes: The “essence” of each theme should be captured in a precise, informative name.
- 6) Producing the report: The final analysis and write-up must be concise, logical, and coherent.

2.7 Chapter summary

This chapter explained the numerous methods and their processes utilised throughout this research.

CHAPTER 3 RESEARCH DESIGN

This chapter discusses the research design followed throughout this study. Figure 3-1 shows the current position in the research method. This chapter explains the entire study's design. Figure 3-1 has phases that correspond to the phases listed in Table 3-1: Study Design.

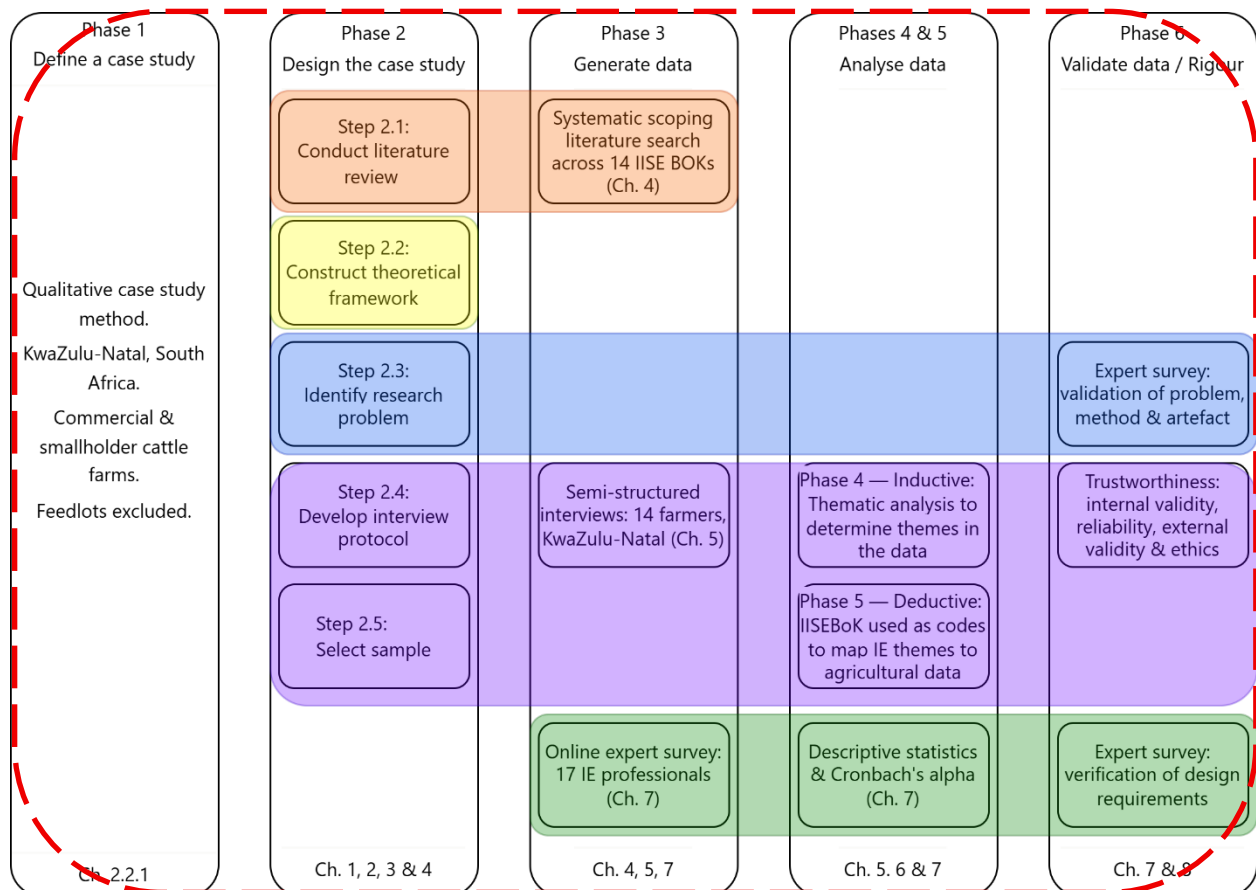


Figure 3-1: Research method

3.1 Introduction

The research conducted throughout this dissertation addresses the need to initiate transdisciplinary collaboration between industrial engineering and red-meat cattle production. Therefore, this study aimed to contextualise the Industrial Engineering body of knowledge (IISE-BOK) within red-meat cattle production systems in KwaZulu-Natal.

The study used an exploratory case study design. The study used Sharan Merriam's case study methodology, as it provides more concrete and thorough guidelines for designing qualitative research (Yazan, 2015). Merriam's case study methodology also gives step-by-step instructions for novice qualitative researchers to follow (Yazan, 2015). The overarching design of the study is

presented in Table 3-1. This study involves six phases: defining the case, designing the case, generating and gathering data, analysing the data inductively, analysing the data deductively, and ensuring rigour throughout the process. The table also shows exactly where each research objective is addressed throughout the research, along with the section where it can be found.

There are various methodological approaches in the engineering field, and no single approach is presented as the standard (Escudero-Mancebo et al., 2023). A recent study analysing papers from four leading engineering design journals found a preference for qualitative research methods for engineering design (Escudero-Mancebo, et al., 2023). This preference stems from qualitative research's ability to use an inductive approach to collect data, thereby constructing concepts, hypotheses, or theories, especially in the absence of pre-existing theories. Qualitative research focuses on process, meaning, and understanding, and the researcher is the primary instrument of data collection and analysis (Merriam, 2009).

Therefore, a qualitative design was the most appropriate for this study to gain knowledge and an in-depth understanding of the challenges faced by cattle farmers. An in-depth study of a bounded system was conducted; therefore, this study used a case study design as the overarching methodology. The case study approach can be used as a methodology or a comprehensive research strategy (Denzin & Lincoln, 2005; Merriam, 2009; Yin, 2008; Creswell, 2007). It enabled a thorough understanding of the production challenges that affect the profitability of farms in a specific region of KwaZulu-Natal. The farms' geographical location (the Midlands and Highveld areas of KwaZulu-Natal) and the type of farming (beef cattle production) bound the cases into a bounded system.

Table 3-1: Study Design

Phase	Case study Methodology phase/step			Method or detail	Research Objectives	Chapter Section(s)
1	Define a case study			What is a case and a case study?		2.2.1
2	Design the case study	2.1	Conduct a Literature review	Scoping review	1	Chapter 4
		2.2	Construct a theoretical framework	Industrial and Systems Engineering Body of Knowledge (IISEBoK)		2.5
		2.3	Identify a research problem	The problem is that Industrial Engineering research has not been aligned with the beef cattle industry, thereby limiting the development of pragmatic solutions to food security challenges.		1.3
		2.4	Develop research questions	Interview structure and protocol.		2.3 & Chapter 5
		2.5	Select the sample	Purposive sampling followed by snowball sampling.		3.2.5 & Chapter 5
3	Generate data (Gather data)			Semi-structured interviews.	1	Chapter 5
4	Analyse data inductively.			Thematic analysis to determine themes existing in the data.	1	Chapter 5
5	Analyse data deductively.			Analyse data using the IISEBoK as a codebook to transfer IE themes into the agricultural data.	2	Chapter 6
6	Validate data / Rigour			Internal validity, Reliability or consistency, External validity, Ethics.	3 & 4	Chapter 7 & Chapter 8

3.2 Design the case study.

3.2.1 Conduct a literature review.

As stated in the introduction, there is limited literature on how Industrial Engineering can enhance cattle production processes and systems. Therefore, a scoping review was conducted to investigate what is available to help farmers improve their processes and systems. The scoping review is presented in Chapter 4 of this dissertation.

Scoping studies can be carried out as independent projects on their own and, in general, “aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available.” (Mays, et al., 2001). Therefore, strict limitations are not necessarily placed on search terms, identification of relevant studies, or study selection (Arksey & O'Malley, 2005). A scoping review is an iterative process in which the researcher can repeat steps to ensure that the literature is accounted for comprehensively (Arksey & O'Malley, 2005).

A checklist, Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-SCR) checklist, provided in Annexure A, was also used to guide the scoping review for reliability and validity.

3.2.2 Construct a theoretical framework.

As industrial engineering concepts will inform the research, the theoretical framework for this study is the Industrial and Systems Engineering Body of Knowledge (IISEBoK), as explained in section 2.5.

3.2.3 Identify a research problem.

The problem is that Industrial Engineering research has not been aligned with the beef cattle industry, thereby limiting the development of pragmatic solutions to food security challenges.

3.2.4 Develop research questions

The structure of the interview protocol and interview questions is illustrated in Annexure C, with the 4 main research questions (RQ) as follows:

1. RQ 1 – What challenges do farmers currently experience with the farm's processes and systems?
2. RQ 2 - How do these challenges impact the farm's processes and systems?
3. RQ 3 – What causes these challenges?

4. RQ 4 - How were the farmers taught to deal with the challenges?

3.2.5 Select the sample

This study used nonprobability sampling techniques to explore common and unique instances (Sandelowski, 2000). The sampling techniques that were used were purposive and snowball sampling. Snowball sampling required the researcher to rely on participants to identify additional potential participants (Naderifar et al., 2017). The sample was further expanded upon in Chapter 5 (Research article 2). The inclusion and exclusion criteria for participant selection are expanded in Section 3.4.2 of Chapter 5.

3.3 Generate data

An interview protocol was developed as a guideline for the interviews. The interview protocol used was adapted from Creswell (2017), and the full interview structure is depicted in Annexure C. The researcher used non-verbal and verbal techniques, such as paraphrasing, reflecting, encouraging, acknowledging, clarifying, probing, and summarising, to help the interviewee feel comfortable and heard. These techniques helped the interviewees to explain their experiences in more depth.

As stated before, data were collected via semi-structured interviews with participants. The interviews took place at a place specified by the participant (in person). The interviews lasted between 30 and 60 minutes. The researcher also took notes on the participant and on what was said during the interview. These observations were used later for triangulation.

3.4 Analyse data inductively

Once the raw empirical data from the interviews had been gathered, it was transcribed and analysed. The analysis used a thematic analysis to determine units and codes. The aim was to use deductive inference later to categorise the units based on the ISEBoK codes. There is very little transdisciplinary collaboration between industrial engineering and red meat cattle production in the agriculture sector. This stage was used to identify overlaps between industrial engineering knowledge and cattle production approaches from the interviews, and these findings are presented in Chapter 5.

3.4.1 Thematic Analysis

The thematic analysis is done in 6 phases (Braun & Clarke, 2021):

- 1) Familiarisation with the data: As the researcher conducted the interviews herself, she was already quite familiar with the data. The data was read and re-read. Any initial ideas or analytical observations were noted.
- 2) Generating initial codes: Initial codes were produced from all the data by organising the data in a meaningful and systematic way.
- 3) Searching for themes: The codes were analysed to determine whether they fit into initial groups, named themes. A theme was seen as a meaningful and coherent pattern in the data.
- 4) Reviewing themes: The candidate themes from the previous phase were refined. The themes were checked against the full data set and the coded extracts to see if they worked. It was sometimes necessary to split a theme into two or three, or to collapse two or three into one.
- 5) Defining and naming of themes: The “essence” of each theme was captured, and the themes were given a precise name.
- 6) Producing the report: The final analysis and write-up were concise, logical, and coherent.

3.5 Analyse data deductively

After the initial inductive analysis, which identified themes within the interview data, a deductive analysis was conducted using the IISEBoK as codes. This was expanded on in Chapter 6 and forms the research artefact.

3.6 Verification, validation, and rigour

Quantitative research utilises reliability and validity to describe rigour, while qualitative research uses terms such as trustworthiness and transferability (Borrego, et al., 2009). The researcher used Guba and Lincoln’s criteria for trustworthiness to ensure data quality and integrity throughout the process (Lincoln & Guba, 1985). Therefore, the researcher used a combination of methods to ensure rigour. These techniques and strategies included (Merriam, 2009):

3.6.1 Credibility (Internal validity)

Credibility is the extent to which research findings match reality (Merriam, 2009). Methods to achieve credibility include:

- Triangulation – The researcher triangulated multiple data sources to confirm emerging findings. These data sources included interview recordings, the researcher's field notes, and transcriptions. Although recordings and transcripts are derived from the same interview, Tessier (2012) argues that field notes, transcripts, and tape recordings each capture different dimensions of the data and should be used together as complementary rather than redundant sources, with each contributing distinct analytical value to the triangulation process (Tessier, 2012).
- Prolonged engagement – Prolonged engagement with the data was maintained throughout the 2.5-month data collection period, spanning February 2025 to April 2025.
- Reflexive researcher journal – The essential theories and presumptions that led the researcher to formulate specific questions and findings were disclosed (Guba, 1981; Merriam, 2009). Although a reflexive researcher journal was maintained throughout the data collection process, the notes are not reproduced in this dissertation. Given the socioeconomic sensitivity of the topics raised during interviews (farm safety, theft, and politically charged land issues), showing the contextual reflexivity notes risked compromising participants' anonymity in a small, geographically bounded farming community. Participant confidentiality was therefore prioritised.
- Peer examination/peer evaluation - The research was sent to the researcher's supervisors after each completed stage for analysis of the work done (Merriam, 2009).

3.6.2 Dependability (Reliability)

Dependability revolves around how well the research can be replicated (Merriam, 2009). Methods to achieve dependability include:

- Triangulation – The researcher triangulated multiple data sources to confirm emerging findings. These multiple sources of data were the interview recordings, the researcher's field notes and transcriptions.
- Peer examination/peer evaluation - The research was sent to the researcher's supervisors after every completed stage to analyse the work done (Merriam, 2009).
- Audit trail – Documentation (specifically the interview notes taken) and a running journal of the process (the researcher's journal of the day) were collected (Guba, 1981; Merriam, 2009).

3.6.3 Transferability (External validity)

Transferability focuses on how well the findings can be applied to other situations (Merriam, 2009). Methods to achieve transferability include:

- Use of rich and thick descriptions - A full description of all contextual factors affecting the study was provided (Guba, 1981; Merriam, 2009).
- Maximum variation – This was achieved by selecting participants with the greatest variation (Merriam, 2009), specifically smallholder and commercial farmers.

3.6.4 Confirmability (Objectivity)

Confirmability refers to the extent to which the findings are grounded in the data and not influenced by the researcher's personal assumptions or bias (Lincoln & Guba, 1985). Strategies used to enhance confirmability include:

- Triangulation – The researcher triangulated multiple data sources to confirm emerging findings. These multiple sources of data were the interview recordings, the researcher's field notes and transcriptions.
- Audit trail – Documentation (specifically the interview notes taken) and a running journal of the process (the researcher's journal of the day) were collected (Guba, 1981; Merriam, 2009).
- Reflexive researcher journal – Used to document analytical decisions and reflections throughout the research process (Lincoln & Guba, 1985).

3.6.5 Ethics checklist

Ethical clearance was obtained from the Engineering Research Ethics Committee (ENG-REC) of the North-West University (ethics number NWU-00499-24-A3). To ensure ethical conduct, the following ethics checklist will be used (Patton, 2002):

1. The researcher explained the purpose of the inquiry and the methods to be used to the participants.
2. Confidentiality - The researcher did not publish any participant data. The researcher also verified that all relevant findings were disclosed and that no information was misrepresented for publication.

3. Informed consent: The researcher explained in detail what the study entailed, including its aims and objectives. All interviews were conducted after participants provided informed consent and permission. The researcher provided the participants with an informed consent form (Annexure B).
4. Data access and ownership - The data were uploaded to a cloud storage system and a computer for safekeeping. The computer was password-protected to protect the participants' information. The data will be saved for 5 years after the research is completed and then deleted.
5. Advice (counsellor on ethical matters) – The researcher's supervisors and the NWU code of ethics and conduct served as her counsellors on ethical matters.
6. Anonymity - The researcher respected all participants, their data, and their privacy. All participant information was kept anonymous; therefore, participant names were excluded from the study.
7. Publication - The researcher documented all findings in a master's dissertation publication. The researcher ensured that all relevant findings were communicated and that no information was misrepresented or altered for publication. The researcher ensured that the work was original and that sources were correctly referenced. The researcher also did not plagiarise any work and checked for plagiarism.
8. Declaration of interest - The researcher ensured transparency by including authors' and contributors' affiliations and interests. Sources of funding for research or publication were also disclosed. The researcher stated that they had no known competing financial interests or personal relationships that could have influenced the work reported in this study. The study was conducted in accordance with academic integrity and objectivity. The author had no financial, personal, or professional conflict of interest that could influence the design, execution, or interpretation of the research. Every effort was made to ensure that the research process remains unbiased and transparent.
9. Voluntary participation - The researcher informed the participants that they could withdraw from the study at any time. The researcher did not force a participant to participate in the study.
10. Ethical versus legal conduct – This study did not engage in any illegal activities and adhered to ethical principles in all situations.

3.6.6 Verification and validation

Verification and validation of this study happened throughout the entire research process. The overarching methodology, the case study design, demands thorough, rigorous methods. Therefore, this research rigorously adhered to the methodologies outlined. The verification and validation for this study were expanded in Chapter 7 and 8.

3.7 Chapter summary

This chapter explained the research design employed in this study. The chapters that follow discuss the detailed method and findings for the various stages of the research design.

CHAPTER 4 SCOPING LITERATURE REVIEW

This chapter presents a research paper that explores the intersection of industrial engineering and beef cattle production systems by examining the literature on applying industrial engineering knowledge to these systems, thereby achieving Research Objective 1. Figure 4-1 shows the current position in the research method.

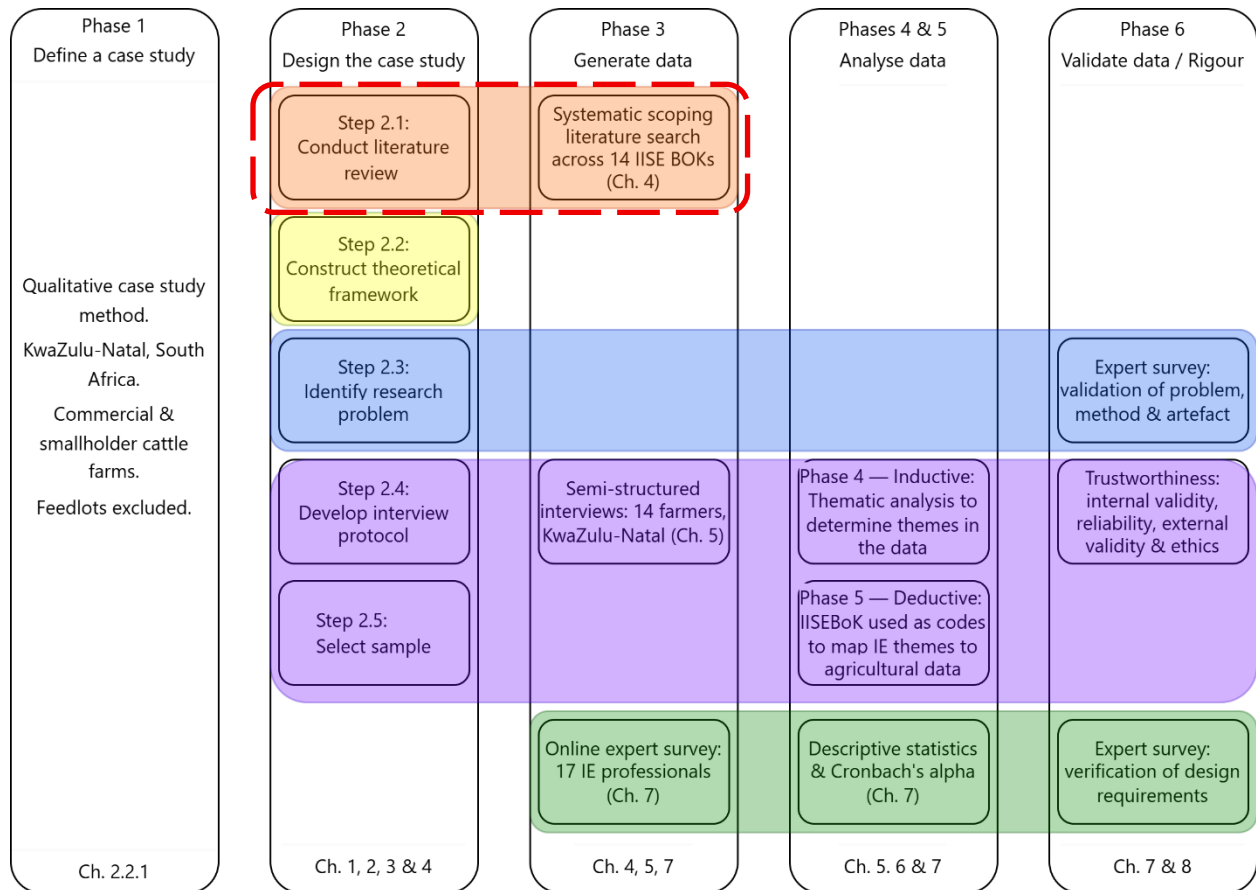


Figure 4-1: Research method

The Intersection of Industrial Engineering and Beef Cattle Production Systems: A Scoping Review

ABSTRACT

Food security is a global priority under the United Nations Sustainable Development Goals, particularly Goal 2: Zero Hunger. Beef cattle farmers contribute to the food production value chain but face challenges such as managing feed costs, animal health management, breeding efficiency, market access, and sustainability. Industrial engineering, with its focus on improving systems and processes, offers tools that may help address these challenges in agriculture. This study conducted a scoping review to explore the intersection of industrial engineering and beef cattle production systems. The review found that the existing literature is fragmented and largely discipline-bound, with most studies remaining theoretical or model-based. There was limited integration across the IISE Bodies of Knowledge and little translation into practical farm-level application. These findings highlight the need for more interdisciplinary research that links industrial engineering methods with real agricultural challenges in beef production.

Keywords: Industrial engineering; Beef cattle production systems; Cattle farming; Beef production; Scoping review; Agricultural systems

1 Introduction

Food security is part of the Sustainable Development Goals of the United Nations and falls under the Sustainable Development Goal 2 (SDG 2). SDG 2's focus is to end world hunger, achieve food security, improve nutrition, and promote sustainable agriculture (United Nations, 2015).

Agriculture, particularly livestock farming, plays a pivotal role in the global economy (Schrobbach, et al., 2023). In South Africa, the agricultural sector is a cornerstone of the economy, contributing substantially to job creation, foreign exchange, and food security (Mpundu & Bopape, 2022). Within this sector, beef cattle production is particularly significant, with millions of cattle contributing to the annual domestic meat supply in Africa (National Department of Agriculture, 2025). However, the agricultural sector faces challenges in productivity, sustainability, and resource management. Farmers face numerous challenges, including managing feed costs (Clune & Downey, 2022), ensuring animal health, optimising breeding practices, and addressing broader systemic issues such as market access (Alemneh & Getabalew, 2019) and sustainability. These challenges require innovative approaches to improve farming practices and profitability.

The Institute of Industrial and Systems Engineers (IISE) defines Industrial Engineering (IE) as "concerned with the design, improvement, and installation of integrated systems of people, material, information, equipment, and energy" (IISE, 2021). Industrial engineering (IE), a field focused on optimising systems and processes, offers a unique perspective that could potentially support agricultural methods. The comprehensive approach that IE offers to improve agricultural systems provides a toolkit that could possibly address many of the challenges facing farmers.

The IISE Body of Knowledge (BOK) outlines 14 core knowledge areas that collectively define the discipline of industrial engineering, as shown in Figure 1. Each Knowledge area has multiple subcategories and extends into a hierarchical structure with subheadings and sub-subheadings, often reaching down to the 6th level. This detailed framework ensures that each topic is thoroughly explored, allowing professionals and researchers to apply specific tools, methods, and principles to a wide range of contexts. Table 1 presents each IISE BOK, along with a summary that describes its focus and intended use.



Figure 1: Knowledge areas of Industrial and Systems Engineering (Adapted from IISE (2021))

These Bodies of Knowledge could potentially be applied to various aspects of cattle production in order to improve efficiency, sustainability, and overall farm profitability. A beef cattle farm can be likened to a factory, a manufacturer, or an organisation. In this analogy, cattle serve as raw material and beef at the end of the production line is the finished goods. If the production process does not work optimally, the quality and quantity of the finished product (meat) will be below the standard.

Table 1: IISE BOK summary

IISE Body of Knowledge	Summary
1. Work Design and Measurement	Focuses on structuring and analysing human-machine systems—tools, techniques, and environments—to create standardised, efficient work processes and measure output rates (Freivalds & Niebel, 2014; Groover, 2006).
2. Operations Research and Analysis	Applies mathematical models and computational methods—such as probability, statistics, and optimisation—to improve decision-making and system performance (Hillier & Lieberman, 2021).
3. Engineering Economics and Analysis	Evaluates the economic feasibility of engineering projects by comparing costs, benefits, and risks to guide investment and design choices (White, et al., 2020).
4. Facilities Engineering and Energy Management	Designs optimal layouts for equipment and personnel and plans energy use in buildings and plants to support efficient production and distribution (Tompkins et al., 2010; Roosa et al., 2020).
5. Quality and Reliability Engineering	Uses preventive and statistical methods to ensure that products and services meet specifications (quality) and perform continuously under expected conditions (reliability) (Montgomery, 2019; Elsayed, 2021).
6. Ergonomics and Human Factors	Designs tools, tasks, and environments to fit human physical, cognitive, and organisational needs, reducing fatigue and error (Lehto & Landry, 2013).

IISE Body of Knowledge	Summary
7. Operations Engineering and Management	Develops and optimises production and service processes—balancing throughput, cost, and quality—to meet customer requirements efficiently (Russell & Taylor, 2011).
8. Supply Chain Management	Coordinates the flow of materials and information from suppliers to customers, ensuring timely delivery and cost-effective inventory levels (Huang, 2013).
9. Engineering Management	Integrates engineering principles with business practices to lead technical teams, projects, and organisations toward strategic goals (Morse & Babcock, 2013).
10. Safety	Identifies, evaluates, and controls workplace hazards, and establishes protocols to prevent accidents and ensure regulatory compliance (Goetsch, 2015).
11. Information Engineering	Designs, implements and manages information systems and data processes to support effective decision-making and communication (Mallach, 2016).
12. Design and Manufacturing Engineering	Covers the entire product lifecycle—concept to production—by developing and standardising processes that efficiently transform raw materials into finished goods (Groover, 2019).
13. Product Design and Development	Guides idea generation, prototyping, and testing to create new products, applying IE methods to streamline development decisions (Ulrich & Eppinger, 2020).
14. Systems Design and Engineering	Integrates multidisciplinary perspectives to architect and manage complex projects, ensuring that all technical, economic, and human factors are aligned (Eisner, 2008).

Figure 2 uses the input–transformation–output process to explain beef cattle production. As Russell and Taylor (2011) describe, inputs are transformed through a series of activities into outputs of greater value, a concept common in manufacturing and business that also applies to agriculture.

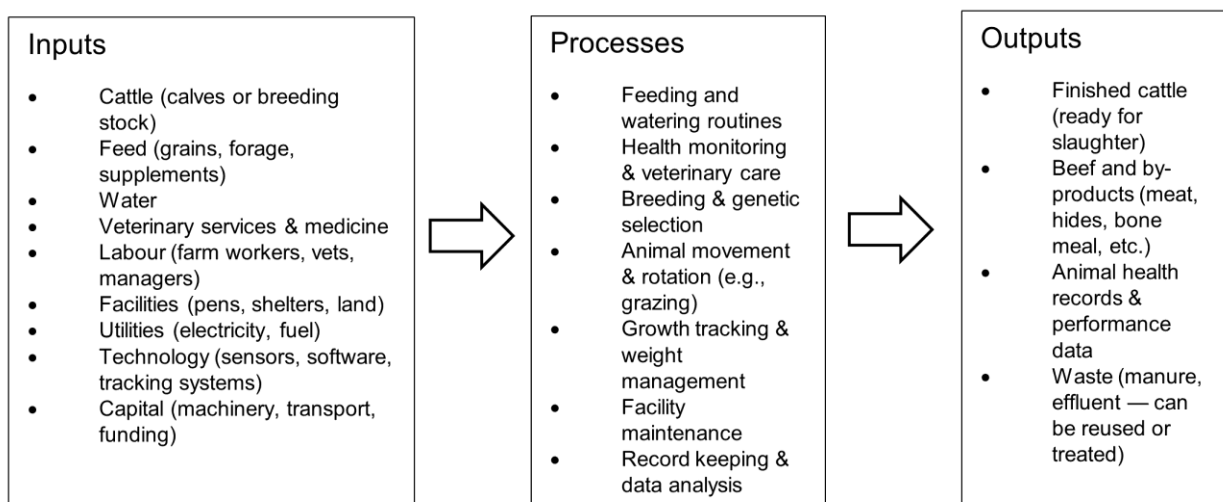


Figure 2: Beef cattle production system (Adapted from Russell & Taylor, 2011)

1. Inputs (Block 1):

Inputs are all the resources needed to initiate and sustain beef cattle production. These include cattle, food, and water, which are vital for the animals. Other essential inputs include veterinary care, medications, facilities, utilities, labour, and technology, which support the development and maintenance of animals. Capital resources, such as machinery, transportation, and money, also make it possible to acquire, grow, and manage these resources effectively.

2. Processes (Block 2):

The middle part of the model illustrates the primary production steps, where inputs are transformed into market-ready products. This includes daily operational tasks, such as feeding and cleaning, as well as technical work, including health checks and selecting breeding animals. In addition, it includes management tasks, including maintaining records and planning. These steps are both about animal biology and about running the farm as a business. The final step is to move cattle to markets or slaughterhouses, connecting the farm to the broader supply chain.

3. Outputs (Block 3):

The outputs are the results of the production system. The main outputs are finished cattle and beef products, like meat, hides and bone meal, which can be sold. Other outputs include performance and health data, which inform decision-making and drive continuous improvement, as well as waste products such as manure. Even waste can be beneficial if it is converted into fertiliser or energy, supporting more sustainable farming practices.

4. System Perspective:

All of these parts show that beef cattle farming is more than just raising animals. It is a complex system that combines resources, processes, and outcomes. Like a factory, problems at any stage, such as poor feeding or delays, can affect the amount or quality of the final products. However, utilising better technology or optimising resource utilisation can make the farm more productive and competitive.

The intersection of industrial engineering and agriculture, particularly in beef cattle production systems, represents a promising but little-known area of research. Therefore, the study aims to explore the intersection of industrial engineering and beef cattle production systems by investigating the available literature. The study will focus on farm-level operations rather than feedlots or processing facilities.

By systematically examining the current state of the literature and identifying gaps, this scoping review will lay the groundwork for future research studies and potential transdisciplinary collaborations. This work could benefit farmers and the agricultural industry, paving the way for more efficient and sustainable farming practices.

2 Research Methodology

A scoping review was conducted to investigate the intersection of industrial engineering and the cattle farming industry, with a focus on improving processes and systems.

Data were collected through a scoping review, as it enables the researcher to scope a body of literature through a systematic approach and clarify concepts by identifying key characteristics or factors related to the concept (Thomas, et al., 2017). Scoping reviews are not directed by a highly focused research question, but rather by a requirement to identify all relevant literature (Arksey & O'Malley, 2005). With a scoping review, as the researcher becomes more familiar with the data, they may want to refine the search terms (Arksey & O'Malley, 2005). Therefore, this study used Arksey and O'Malley's five-stage scoping review framework (Arksey & O'Malley, 2005):

- Stage 1: Identify the research question – Identify the research question, along with which aspects of the research question are the most important (Arksey & O'Malley, 2005).
- Stage 2: Identify relevant studies – Select the electronic databases that will be used, along with the keywords and their synonyms, and the type of literature (ex., Grey, white or brown literature) (Arksey & O'Malley, 2005).
- Stage 3: Study selection – Screen the titles and abstracts for the query and then match them against the inclusion and exclusion criteria (Arksey & O'Malley, 2005).
- Stage 4: Charting the data – Chart the key items of information obtained from the research reports through tables or graphs, etc. Key items include the year the report was published, study populations, outcome measures, and important results (Arksey & O'Malley, 2005)
- Stage 5: Collating, summarising, and reporting the results – Present all the material reviewed (Arksey & O'Malley, 2005). Organise the literature thematically according to key themes (Arksey & O'Malley, 2005).

2.1 Stage 1: Identify the research questions

The focus of the review was to explore the intersection between Industrial Engineering bodies of knowledge and beef cattle production systems, specifically focusing on identifying how these

knowledge areas have been applied within the existing literature. To ensure that the search produced an extensive range of literature relevant to the subject matter, the following preliminary research questions were selected to direct the search procedure:

- RQ - What literature exists at the intersection of industrial engineering and cattle farming?

2.2 Stage 2: Identify relevant studies

The researcher originally started with a broad search strategy (Arksey & O'Malley, 2005), using the keywords ("industrial engineer*") AND ("cattle farm*" OR "cattle product*"), but only 10 results were found. Arksey and O'Malley (2005) emphasise that "the process is not linear, but iterative". Therefore, 14 additional searches were conducted, each targeting a specific IISE BoK heading combined with agricultural keywords. Following the iterative approach, adjustments were made for one IISE Bok heading. Specifically, BOK 10 (Safety) returned 1,109 results, so it was refined to "occupational safety" to limit the number of results while specifically focusing on employee safety. The searches yielded 308 results in three databases, forming the complete literature of the study.

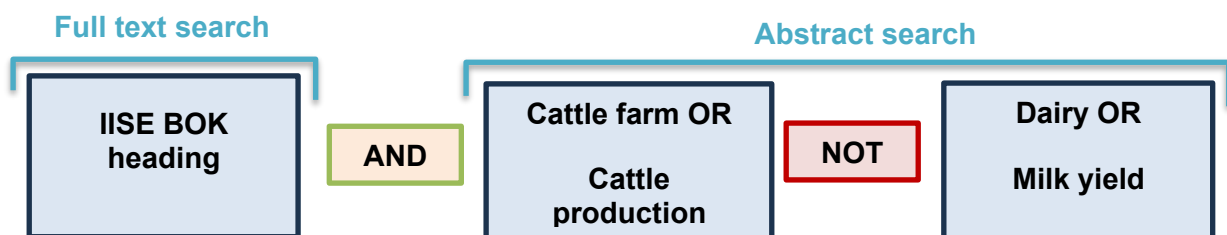


Figure 3: Keyword search strategy

Figure 3 illustrates the keyword search strategy, showing three components. A complete example of a search in EBSCO Host: TX ("Work design" OR "Work Measurement") AND AB ("cattle farm*" OR "cattle production") NOT AB (dairy OR "milk yield").

The search strategy was not limited by study design, language, or year; however, the results had to be peer-reviewed. The titles and abstracts were initially independently screened, followed by the full-text articles. The research protocol is presented in Table 2, and the search results are summarised in Table 3.

Table 2: Research Protocol

Purpose of the study	Explore the intersection of industrial engineering and beef cattle production systems by investigating the available literature on applying industrial engineering knowledge in beef cattle production systems.
Research question	What is the current research landscape for industrial engineering applications in beef cattle production systems?
Inclusion criteria	Cattle farming or cattle production. Any indication of an industrial engineering tool/method used
Exclusion criteria	• Dairy cattle production. • Industrial engineering terms used, but no actual industrial engineering method/tool applied (e.g., "production", "efficiency", etc). • Non-peer-reviewed materials, such as dissertations and manuscripts, were excluded. • Non-English results
Databases	• ScienceDirect • EBSCOHost • IEEE Explore
Keywords	The research keywords started with broad generalisation and were narrowed down to each of the IISE Body of Knowledge categories. The expansion of industrial engineering keywords is shown in Table 3.
Quality assessment criteria	The studies should also adhere to the following quality checklist (van Dinter, et al., 2021): 1. The article clearly states its aims and objectives. 2. The article provides an outline of the scope, design, and context of the study. 3. The variables in the study are reasonable and reliable. 4. The article sufficiently documents the research process. 5. The article answers all the study questions. 6. All the negative findings are presented. 7. The main findings are stated and verified as credible, valid and reliable. 8. The conclusions are reliable and relate to the purpose or purpose of the study.

2.3 Stage 3: Study Selection

For the initial abstract screening and the full-text screening, articles were included if they (1) were in English; (2) focused on beef cattle farming; and (3) were related to industrial engineering. No exclusion criteria were specified for sample size, age group, or location. Figure 4 displays the PRISMA flow diagram, which outlines the flow of information through the various review steps, including the number of records identified, included and excluded, along with the rationale behind their exclusion.

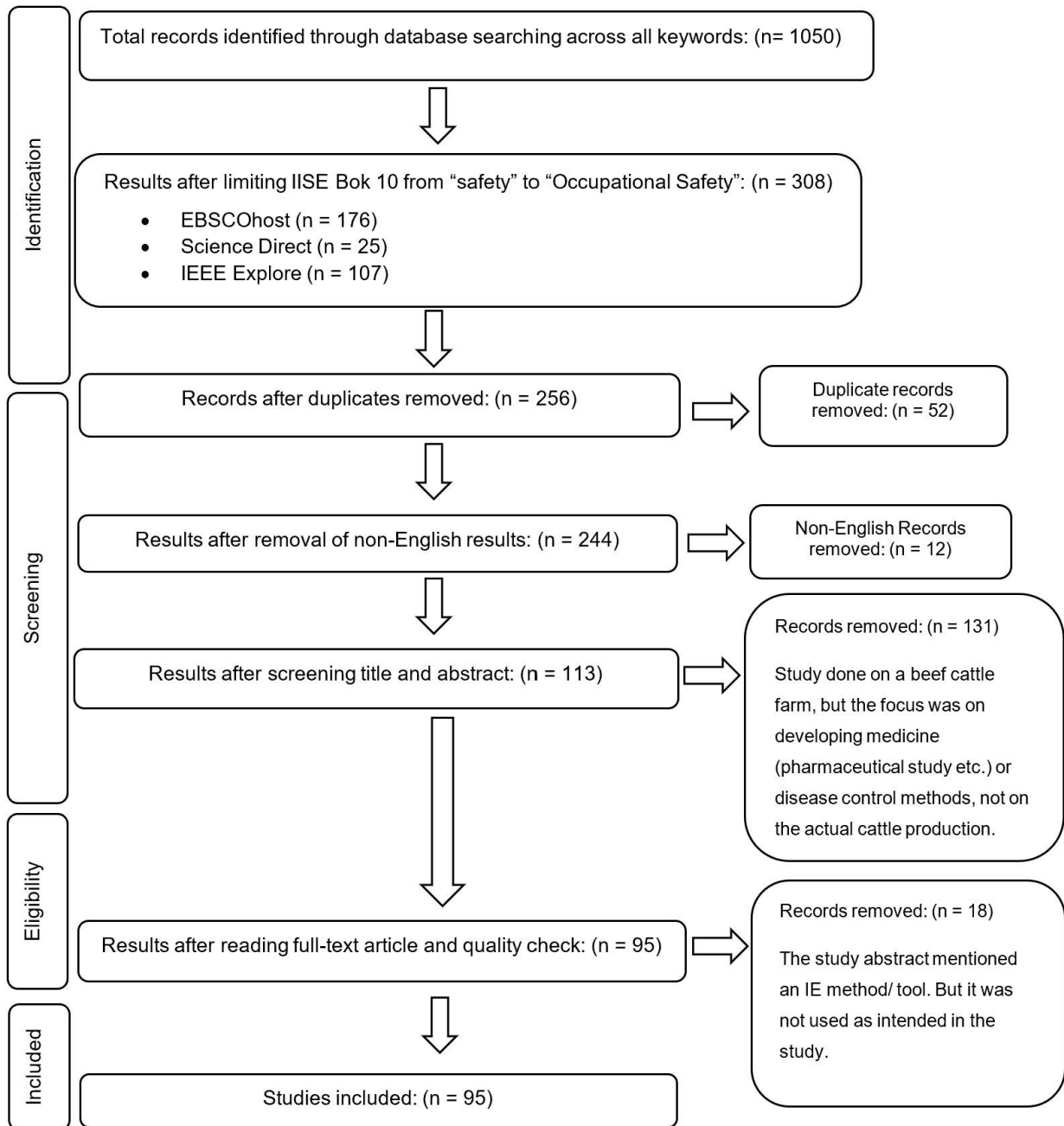


Figure 4: Selection flow chart

Table 3: Search results across databases

BOK	Search Keys	Databases		
		EBSCOHost	Science Direct	IEEE
	"Industrial engineer" AND ("cattle farm" OR "cattle product")	6	1	3
1	("Work design" OR "Work Measurement") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	4	0	0
2	("Operations Research OR "Operations Analysis") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	1	0	5
3	("economic analysis") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	96	2	55
4	("Facilities Engineering" OR "Energy Management") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	3	1	2
5	("Quality Engineering" OR "Reliability Engineering") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	1	1	0
6	("Ergonomics" OR "Human Factors Engineering") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	4	0	0
7	("Operations Engineering" OR "Operations Management") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	16	0	5
8	("Supply Chain Management") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	13	4	4
9	("Engineering Management") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	4	2	1
10	("Occupational Safety") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	10	0	1
11	("Information Engineering") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	9	2	3
12	("Design Engineering" OR "Manufacturing Engineering") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	1	0	1
13	("Product Design" OR "Product Development") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	3	1	3
14	("System Design" OR "System Engineering") AND ("cattle farm" OR "cattle production") NOT (dairy or "milk yield")	5	11	24
	Total for each database:	176	25	107
	Total results:	308		

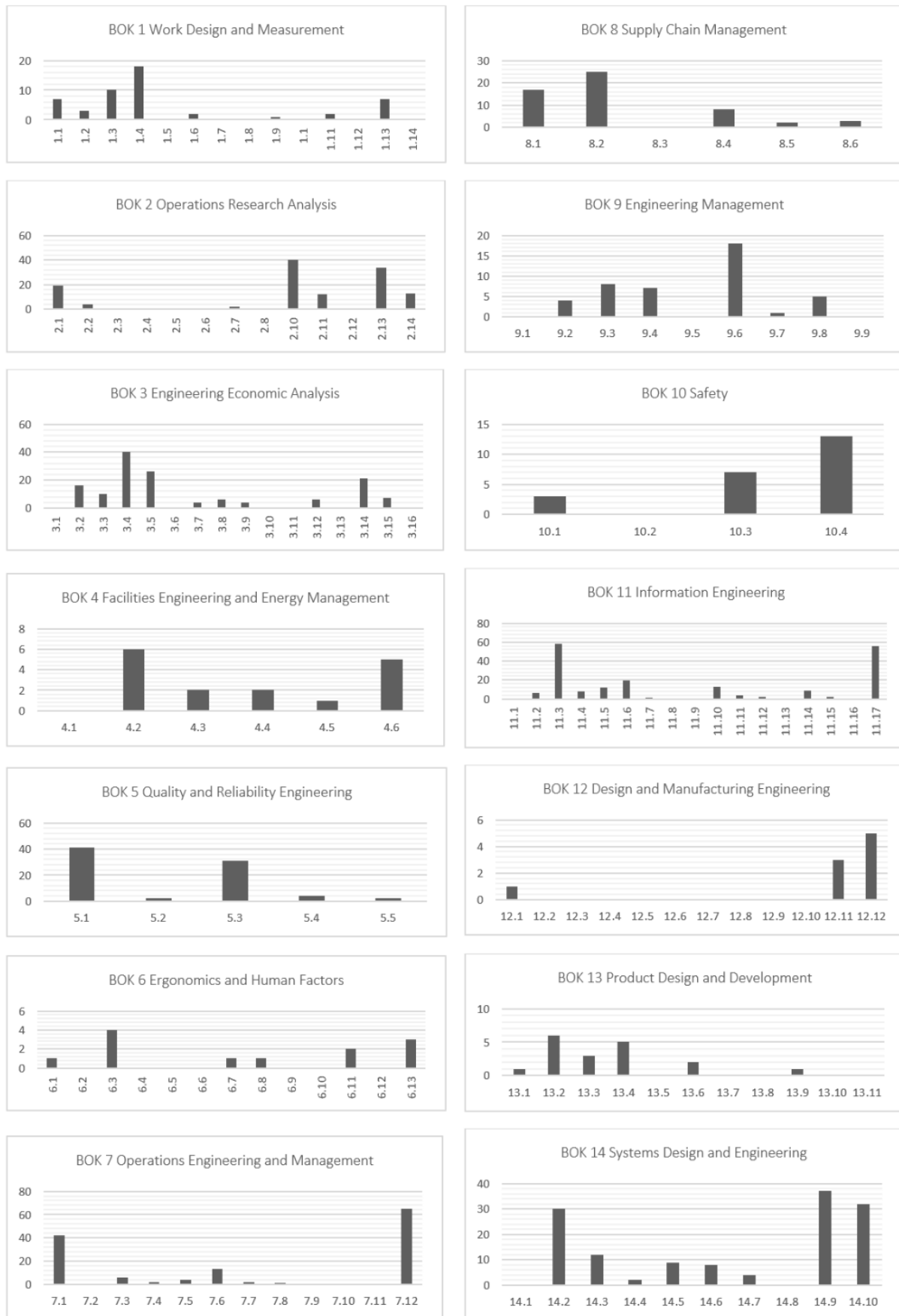


Figure 5: Institute of Industrial and Systems Engineers (IISE) BOK occurrence charts (x-axis: BOK sub-heading numbers; y-axis: number of studies in which that sub-heading was identified)

3 Findings

This section discusses all identified BOKs and their application in the studies. Each subheading that was found is summarised. Annexure A presents a complete reference mapping of the findings, showing each BOK sub-heading (e.g., 1.1, 1.2) with the peer-reviewed studies in which evidence of that sub-topic was identified.

3.1 Stage 4: Charting the data

The bar graphs in Figure 5 show each IISE BOK as a separate sub-chart. In each sub-chart, the horizontal (x) axis lists the BOK sub-headings (e.g., 1.1, 1.2, 1.3, corresponding to the numbered sub-topics within that BOK as defined by IISE (2021)), and the vertical (y) axis represents the number of studies (occurrences) in which evidence of that sub-heading was identified in the literature. A higher bar therefore indicates a greater number of studies that addressed that particular sub-topic

3.2 BOK 1 - Work Design and Measurement

3.2.1 Introduction to Work Systems

Seven studies used work systems to frame perspectives on the entire farm system—e.g., defining the “system” boundaries of grazing operations, linking cattle performance to inputs (forage, labour, capital), and integrating sustainability metrics such as greenhouse gas emissions into a unified view of the system.

3.2.2 Design System Process

Three studies applied design system process engineering methods to break down farm processes (feeding, handling, weighing), analyse labour organisation, and improve layouts or task workflows for improved animal health and smoother operation flow.

3.2.3 Performance Metrics and Exploratory Tools

Ten studies assessed animal growth and production efficiency. Performance metrics included average daily gain (ADG), body weight changes, and weaning rates. These performance indicators helped researchers and farmers evaluate the success of feeding regimes, supplements, and technologies.

3.2.4 Recording and Analysis Tools

Eleven studies used a recording method, such as video or IoT sensors, to capture real-time data. Flow or operational charts were used in seven studies to visualise tasks such as cattle handling and weighing procedures. These visual tools helped identify inefficiencies and simplify the process steps, especially in labour-intensive operations.

3.2.4 Performance Ratings and Allowances

Two studies used performance ratings to evaluate the labour demands of different approaches. The studies aimed to measure the time and effort needed per task and assess how new tools or systems could reduce human labour or make it more efficient.

3.2.6 Operations Analysis

An article used line-balancing models to simulate stocking rates (animals per hectare) as a flow-process system. In this framework, grass was considered the input, the cow served as the processing unit, and meat represented the output to identify capacity bottlenecks.

3.2.7 Workplace Equipment and Tool Design

Two studies examined how applying lean manufacturing principles to the design of feed-mixing stations and handling chutes can help ensure that raw feed is mixed in a way that maintains consistent ratios and reduces downtime and safety hazards.

3.2.8 Analytical Tools

Seven papers highlighted the importance of using technology to track what is going on. All kinds of sensors, Radio Frequency Identification (RFID) tags, and data-logging systems were used to collect information on more than 20 different performance metrics (e.g., intake rates, environmental conditions, and animal health indicators) on farms and packing plants.

3.3 BOK 2 - Operations Research Analysis

3.3.1 Operations Research

Nineteen studies framed farm systems as optimisation problems, using mathematical and agent-based models to capture interactions between grazing, feed intake, health monitoring (often through machine learning and object detection for individual cattle), and economic outputs.

3.3.2 Linear Programming (LP)

Four studies used LP to optimise resource allocation, breeding traits, and goal-programming alternatives to maximise profit margin constrained by policy or resource limits.

3.3.3 Integer Programming

Two studies used integer models to enforce discrete decisions, comparing breed composition and ensuring herd-size and activity constraints in the farm model.

3.3.4 Nonlinear Programming

One study used Nonlinear cost-profit functions to model price shock effects in production planning when there is uncertainty.

3.3.5 Decision Analysis and Game Theory

Forty studies used decision-analysis to help with cattle-farm management, using multi-criteria approaches to weigh economic, environmental, and welfare objectives. They also used decision analysis to evaluate trade-offs in feeding practices, breeding, and management strategies. Risk-based analysis evaluated scenarios such as price fluctuations, feedstock variations, and climate or disease-related issues to determine how the farm would respond.

3.3.6 Modelling Under Uncertainty

Twelve articles used stochastic processes and programming (including Markov chains) to model how markets, diseases, and feed price fluctuations would impact the farm and enable robust, informed decisions.

3.3.7 Simulation

Both Monte Carlo and discrete-event simulations were used in 34. The researchers used them to explore some of the more complex aspects of livestock farming, such as rotations of pastures, supply chain issues, and stakeholder interactions, allowing researchers to test “what if” scenarios without disrupting live herds.

3.3.8 Fundamentals of Systems Dynamics

System dynamics models were used in 13 articles, with feedback and balancing loops that capture how animal growth, resource replenishment, and market signals interact and evolve, giving researchers valuable insight into where they might be able to make a real impact.

3.4 BOK 3 - Engineering Economic Analysis

3.4.1 Classification of Cost

Sixteen studies categorised costs, breaking them down into fixed (e.g., buying land or fencing) and variable (for example, feeding and veterinary care) costs, first-cost (the big upfront expenses for infrastructure) and incremental (how much extra it costs to add an extra head of cattle) categories, and even marginal (the cost of one more calf). This exposed misconceptions about sunk costs that led farmers to hesitate when switching breeds.

3.4.2 Interest and Interest Formulas

Ten studies applied time-value of money concepts, including compounding and discounting, to evaluate equipment financing options and to calculate the similarity between lump-sum investments in machinery and annual lease payments.

3.4.3 Cash Flow Analysis

Forty studies used cash flow techniques like present value, future value, payback period, IRR, and benefit-cost ratios to evaluate the financial viability of herd expansion, pasture improvements, vaccination programmes, and technology adoption. They compared the profitability, costs, and returns of various production systems, reproductive strategies, and disease control methods. The studies also assessed the economic efficiency and long-term sustainability of the cash flow.

3.4.4 Financial Decision Making Among Alternatives

Twenty-six studies used financial decision-making to compare proposals when funds were limited and showed criteria to choose between competing feed supplement, breeding, or housing options.

3.4.5 Break-Even and Minimum Cost Analysis

Break-even analysis was used in four articles to compare the cost of feed supplementation with the opportunity cost of grazing and crop-livestock integration depending on market conditions.

3.4.6 Evaluation of Public Activities

Six studies applied benefit-cost analyses, including vaccination campaigns and public subsidies programmes, evaluating economic impacts on small-scale farmers, national investment decisions, and environmental impact, including assessing the loss of community welfare due to lower livestock production and resource allocation for public health purposes.

3.4.7 Accounting and Cost Accounting

Four studies focused on cost accounting methods for livestock farming, using profit margin analysis for farm profitability, including direct and indirect costs for the beef industry, and incorporating disease risk probability.

3.4.8 Estimating Economic Elements

Six studies estimated the economic impacts of livestock injuries, diseases, theft, herd mobility, crop and livestock integration, and the profitability of different production strategies. They also compared the cost-effectiveness of different livestock monitoring systems.

3.4.9 Decision Making Involving Risk

Probability methods and decision trees were used in 21 studies to determine disease outbreaks, price fluctuations, and weather conditions, including the estimation of the expected value of vaccination and insurance programs.

3.4.10 Decision Making Under Uncertainty

Seven studies applied uncertainty-based decision-making techniques using payoff matrices to compare economic outcomes, system dynamics for the analysis of the beef value chain, and benefit-cost analysis for different weather and price conditions. The studies also evaluated policies, the economic viability of agritourism during the uncertainty of COVID-19, and the economic returns for fluctuating exchange rates and the evaluation of genetic traits.

3.5 BOK 4: Facilities Engineering and Energy Management

3.5.1 Facilities Sizing

Six studies have used the application of facility sizing to meet the needs of the herd and the processes, including the analysis of peak seasonal throughput to calculate the capacity of pens, silos, and equipment. Studies have also used the application of animal flow rate and service level objectives to match the capacity of barns, feed bins, and dosing equipment.

3.5.2 Facilities Layout

Two studies applied layout principles to improve farm processes, using strategic placement of pens and feed troughs to optimise workflow and wagon-wheel paddock designs to manage cow-feed interactions.

3.5.3 Material Handling

Two studies used material-handling principles to improve feed delivery systems using mix-trailers and silos, while treating cattle movement through paddocks as material flow for efficient forage use.

3.5.4 Storage, Warehousing, and Distribution

One study used warehouse design principles to optimise storage and animal movement, designing spaces that could allow one to efficiently collect data from livestock movement.

3.5.5 Plant and Facilities Engineering

Five studies examined energy and facility systems, focusing on building automation, facility maintenance modelling, biogas system design, and sanitation systems (like waste removal methods and controlled hygiene protocols).

3.6 BOK 5 - Quality and Reliability Engineering

3.6.1 Quality Definition and Fundamentals

Forty-one studies used descriptive statistics, probability distributions, regression analysis, analysis of variance (ANOVA), and hypothesis testing to analyse livestock data. This included injury rates, productivity metrics, herd performance, and beef quality indicators, and compared treatments and validated management practices using different statistical tests.

3.6.2 On-line Quality Engineering Methods

Two studies applied quality control methods, where one used $\bar{X}$ charts to monitor consistency in weight recording, and the other implemented error-proofing techniques using standardised feed protocols to minimise process variability.

3.6.3 Off-line Quality Engineering Methods

Thirty-one studies applied the design of experiments and regression analysis, where ANOVA was used to compare grazing and feeding treatments, and simple and multiple linear regression models were used to predict and identify significant factors for cattle weight gain. These studies also applied appropriate model validation and statistical inference techniques.

3.6.4 Quality Management and Training

Four studies were based on data-driven decision-making, using data surveillance and modelling to guide national strategies, compare system architectures, and verify the use of automated weighing. They were also based on the DMAIC methodology for sustainable farm practices.

3.6.5 Reliability Engineering

Two studies were based on the fundamentals of reliability, using precision, recall, and metrics to measure the recognition capabilities of the models, and applying probability and statistics to track deforestation rates, emissions, and compliance for reliable reporting systems.

3.7 BOK 6 - Ergonomics and Human Factors

3.7.1 Ergonomic Basics

One study applied work-system ergonomics to automate cattle monitoring, using deep pose-estimation networks to eliminate the need for manual observation.

3.7.2 Anthropometric Principles

Four studies used body-dimension data to inform the design of equipment and tags, identify musculoskeletal risk factors, apply joint-detection modelling, size chutes and weighing platforms according to cattle proportions, and evaluate the fit across population variability.

3.7.3 Design of Manual Handling Tasks

One study identified farm tasks (e.g., herding, administering medical treatment) that increase the risk of injury to guide prevention measures.

3.7.4 Design for Standing and Sitting

A study evaluated the ergonomic design of a standing-worker workstation, designing touch-screen interfaces to reduce worker fatigue and optimise posture.

3.7.5 Human Information Processing, Skill, and Performance

Two studies were based on cognitive ergonomics. The first used structured information processing to support human decision-making from automated model outputs. The other used deep-learning modules to identify behaviour patterns in cattle and, therefore, reduced the cognitive workload of the workers.

3.7.6 Human-Machine Interaction, Human Error, and Safety

Three studies assessed human-machine interaction by analysing the relationships between accidents at work and the way operators used equipment. The studies developed user-interfaces for AI visual tools, enhancing the accuracy of posture detection and developing an intuitive touchscreen design to prevent operator errors.

3.8 BOK 7 - Operations Engineering and Management

3.8.1 Operations Planning

Forty-two studies used operations planning (market analysis and forecasting) to examine trade policy that affects international trade, dynamic patterns of beef markets, effects of price volatility on profitability, seasonal forecasting of herd performance, pasture biomass and cattle movement to optimise production timing and allocation of resources.

3.8.2 Planning and Control for Manufacturing Systems/Projects

Six studies used production scheduling techniques. The studies implemented feeding schedules, grazing rotations, breeding and weaning windows, hay harvest timing, and seasonal grazing programmes to optimise resource utilisation and align production activities with capacity constraints and seasonal availability.

3.8.3 Production Scheduling

Production scheduling was used in two studies to place steers in calf-fed, summer yearling, or fall yearling positions and to show cattle movements between ranch, stocker, and feedlot as a job shop flow.

3.8.4 Inventory Management & Control

Four studies looked at inventory control through herd modelling by age and sex class for sales planning, balancing livestock under capacity constraints, and aligning feed supply with cattle demand.

3.8.5 Capacity Management

Thirteen articles assessed farm capacity, evaluating labour, equipment and land throughput to identify bottlenecks in herd growth, machinery use, and pasture capacity.

3.8.6 Materials Requirements Planning

Two studies developed master production schedules for the calving-finishing pipeline, treating farm systems as production processes with defined timing and inputs and outputs, supporting production flow planning across different phases, such as cow-calf, backgrounding and finishing operations.

3.8.7 Purchasing/Supply Chain

One study examined supply chain management by accounting for purchasing decisions on different farms.

3.8.8 Operational Metrics

Sixty-five studies tracked operational metrics that included cost analysis (per-unit production costs, profit per animal), quality measures (weight accuracy, feed conversion efficiency), productivity indicators (throughput, herd performance) and throughput metrics (cattle processed, breeding success rates) to benchmark performance and support continuous improvement.

3.9 BOK 8 - Supply Chain Management

3.9.1 Supply Chain Management Fundamentals

Seventeen studies studied main supply chain management processes by tracking cattle flows from pasture to plate, assessing supply chain effectiveness through performance indicators, implementing risk management strategies for disease outbreaks and biosecurity threats, and evaluating purchasing decisions, including direct marketing channels and diversification strategies.

3.9.2 Building Competitive Operations, Planning, and Logistics

Twenty-five studies explored supply chain network design, analysing cattle flows, feed sourcing decisions (on-farm vs. purchased), vaccine distribution logistics, market strategies, and supply chain resilience through network modelling.

3.9.3 Managing Product Flow

Eight studies assessed livestock and input flows, using metrics like demand met and distance travelled by cattle, while simulating vehicle routing and IoT-based transport optimisation. They integrated material handling systems, silos, and inventory control to manage cattle flow and transport logistics in different sizes and conditions of the herd.

3.9.4 Managing Customer Relationships

Two studies analysed customer relationship management by identifying the different customer segments (feedlots, processors, retailers, exporters) and their specific requirements. The research emphasised CRM practices, such as on-time delivery, to maintain relationships and the collaboration between agritourism and direct meat sales to build customer loyalty.

3.9.5 Managing Supplier Relationships

Three studies focused on supplier management and risk management. The articles evaluated Strategic Supply Partner (SSP) models, highlighting trust, coordination, and joint problem solving. The studies focused on feed, veterinary, and logistics providers and described situations where investors and ranchers share risk, resources, and offspring to improve supply chain flexibility.

3.10 BOK 9 - Engineering Management

3.10.1 Leadership, Teamwork, and Organisation

Four studies analysed teamwork and organisational structure. The studies analysed how different disciplines work together in labelling and system design, described the roles and communication

patterns in family farms, and showed that miscommunication in the supply chain can distort information.

3.10.2 Shared Knowledge Systems

Eight studies developed farm information systems, including infrastructure for outbreak notification, IoT, and sensor networks integrated with ERP (Enterprise Resource Planning), GIS (Geographic Information System) platforms, and cloud-based RFID data repositories with centralised dashboards. The research also implemented simulation frameworks for planning strategies and survey instruments to capture consumer quality cues for visibility and decision support.

3.10.3 Business Processes

Eight of the studies looked at how different parts of the system (like upstream agribusiness and farm activities) connect and flow. The studies also prototyped rapid weighing solutions and mapped value chain processes. The research used simulation frameworks to better understand the system when preparing for disruptions by integrating economic, technical, and organisational elements. The studies used process controls, like soil analyses and electric fencing, to compare perceived versus actual consumer needs and identify gaps.

3.10.4 Strategic Management

Eighteen studies used strategic management tools to support decision-making on farms. This included environmental scanning to assess factors like market conditions and climate impacts, as well as SWOT (Strengths, Weaknesses, Opportunities, and Threats) analyses of farm operations. Some studies also applied formal planning processes to develop multi-year herd and grazing plans. In general, the research focused on guiding longer-term decisions, such as technology adoption, policy responses, and diversification.

3.10.5 Human Resource Management

An article measured the percentage of farmers with education after high school as a social indicator.

3.10.6 Project Management

Five studies used project management approaches to organise activities such as pilot IoT implementations, staged farm expansions, and the development of AI tools. They also examined the financial implications of various decisions (e.g., comparing strategies considering the potential impact of disease outbreaks). In addition, the studies considered risks related to drought, import competition, and disease control programmes.

3.11 BOK 10 – Safety

3.11.1 Perspective and Overview

Three studies took a high-level view of safety within livestock systems. The studies identified broad areas of risk, such as threats from disease to pastoralists and injuries related to cattle-handling practices. In some cases, tools like SWOT analysis were used to highlight biosecurity risks and possible mitigation strategies, helping to frame where the main safety concerns lie.

3.11.2 Hazard Recognition, Evaluation, and Control

Seven studies focused on identifying specific hazards and how they can be managed. These included equipment-related risks (e.g., tractor use and manual handling), environmental hazards (such as flooding and unstable ground), and biological threats (like tick-borne diseases). The studies also described practical control measures, including regular health checks and vaccination programmes to prevent disease outbreaks.

3.11.3 Safety and Health Management

Thirteen studies looked at how safety is managed on an ongoing basis within livestock systems. This included formal risk assessments assessing issues like disease outbreaks, unsafe practices, and contaminated equipment. Some studies also analysed accident reports and approaches that encourage safer practices, such as responsible pesticide use and improved cattle management.

3.12 BOK 11 - Information Engineering

3.12.1 Systems Concepts

Six studies designed cloud and IoT architectures that integrate RFID tags, sensor networks, blockchain nodes, and cloud databases for real-time cattle monitoring. These systems enabled oestrus prediction, spatial mapping, and remote tracking of herd health and pasture conditions through web and mobile platforms.

3.12.2 Information Requirements for Organisations

Fifty-eight studies identified key data requirements for cattle management and decision-making, including herd health, feed, forage, prices, climate, and disease information. The researchers used data models, surveys, and interviews to classify information needs, structure farm simulations, and address gaps in reporting and predictive modelling.

3.12.3 Designing Information Outputs

Eight studies developed real-time dashboards, agent-based models, and interactive visualisations to present KPIs (e.g., daily weight gain, feed conversion ratios), alert trigger points, and strategic summaries for farm managers.

3.12.4 Data Processing Overview

Twelve studies used big data frameworks, R and Python scripts, and spreadsheet tools to collect, clean, and transform large volumes of sensor, production, and financial data for downstream analysis.

3.12.5 Database Concepts

Nineteen studies applied relational database principles, including designing schemas, writing SQL queries with joins, and using Database Management Systems (DBMSs) (e.g., MySQL, PostgreSQL) to store and retrieve historical farm data.

3.12.6 Logical Data Organisation

A study developed a conceptual framework that structures information resources (by medium, origin, and content) within organisational and processing subsystems, organising how data are filtered, capitalised, and exploited to support farm decision-making.

3.12.7 System Analysis

Thirteen studies used approaches, such as the Unified Modelling Language (UML), causal diagrams, and process models, to better understand how farm systems operate, define system requirements, and support decision-making. This included mapping how information moves through the system, using farm and disease data in simulations, and representing different management strategies or types of farming systems.

3.12.8 System Design

Four studies developed detailed design specifications for decision-making components (e.g. disease-detection algorithms) with a focus on making the systems easier to expand and adapt over time.

3.12.9 System Evaluation and Justification

Two studies evaluated models through sensitivity testing of biological and production factors. The studies also checked whether the models behaved as expected under different conditions, including extreme scenarios, to make sure the results were reliable.

3.12.10 Forms, Programs, and Procedures

Nine studies developed standardised forms, surveys, and templates to improve the consistency of data collected on farms. Some also built software and simple hardware systems to capture, send and validate field and laboratory data, in real-time.

3.12.11 System Implementation

Two studies used the FARMASIM model to run “what-if” scenarios and explore different results. They verified results with herd and steer trial data using sensitivity analyses and structural behaviour reproduction tests.

3.12.12 Data Analytics

Fifty-six studies used a range of data analysis methods. These included identifying trends, grouping animals with similar growth patterns, classifying disease risk, predicting outcomes like weight gain, and suggesting actions such as feed optimisation, using both statistical and machine learning approaches.

3.13 BOK 12 - Design and Manufacturing Engineering

3.13.1 Engineering Design

One study used computer-aided design (CAD) to create custom sensor housings precisely shaped to cattle anatomy, therefore securing sensors comfortably.

3.13.2 Manufacturing Planning

Two studies tested cattle detection models using standard performance metrics and hardware trials in both laboratory and real-time settings.

3.13.3 Manufacturing Systems

Five studies focused on automation and system integration. They developed end-to-end platforms that linked AI models, PLCs, sensor networks, data storage, and cloud dashboards to support real-time herd monitoring and decision-making.

3.14 BOK 13 - Product Design and Development

3.14.1 Design Process

A study performed a feasibility analysis to determine whether standard RFID, weighing scales, and Total Mixed Ration (TMR) systems could be integrated on a local farm. The analysis showed that the availability of feed and the costs of the project supported a positive return on investment within a single fattening cycle.

3.14.2 Design Process Steps

One study defined breeding objectives by weighting traits to balance genetic progress with economic return. Five studies created annotated video datasets to train vision models, compared their systems with commercial tools, and assessed the trade-offs between vaccination and detection.

3.14.3 Design Project

Two studies built low-cost IoT prototypes, including ear tags and edge-ML devices, under tight budget constraints. One study also carried out a replicated feeding trial to measure weight gain, feed conversion, blood safety parameters, and tick reduction, to test both the devices and the management approach.

3.14.4 Economic Decision Making/Cost Evaluation

Five studies used life-cycle analysis to assess the environmental and economic impacts of cattle production systems. They analysed energy use, emissions, land and water impacts, and performed cost-benefit evaluations for disease control.

3.14.5 Risk and Opportunity Management

One study used risk analysis to compare performance variability between IoT-based weighing systems and traditional static scales under operational conditions. Another study modelled input-cost shocks, like sudden increases in feed prices, to evaluate the resilience of the system and the financial viability of the farm.

3.14.6 Design for Manufacturability

This study focused on sourcing locally available components to build weighing units and sensor assemblies. This reduced reliance on imports, made repairs easier, and lowered unit costs, which supported wider on-farm use.

3.15 BOK 14: Systems Design and Engineering

3.15.1 Requirements Analysis and Allocation

Thirty studies used structured requirements analysis to identify the needs of farmers and veterinarians and translate them into system requirements. Some also used sensitivity analysis and trade-off studies to determine which requirements would provide the greatest economic and on-farm benefit.

3.15.2 System Architecting

Twelve studies described the overall structure of AI and IoT-based cattle-monitoring platforms. These studies showed how data moved from sensors through edge and cloud processing, and in some cases included blockchain or governance features as part of system design.

3.15.3 Subsystem Design

Two studies focused on how different parts of the system fit together. One organised farm variables into four modules to clarify data flow, while the other defined control rules across six sectors to support communication between sub-models.

3.15.4 System Construction

Nine studies described how systems were built by combining hardware, firmware, and user interfaces. These included IoT prototypes using cameras, RFID tags, and weather sensors, as well as embedded machine learning models and assembly testing before on-farm trials.

3.15.5 Verifying and Validating Requirements

Eight studies described verification processes used to verify that the systems met their requirements. This included linking requirements to test cases, setting performance targets, planning test protocols, calibrating models, and using design-of-experiments to test difficult scenarios. The studies also generated compliance reports to show that the systems met both technical and user needs.

3.15.6 Design Iteration

Four studies showed how the models were refined over time when problems or inconsistencies were found. In these cases, sub-models for diet, mortality, and economic parameters were adjusted, and farm classifications were refined to improve consistency and fit.

3.15.7 Role of Models in Systems Design Process

Thirty-seven studies used models to better understand cattle farming systems. These studies treated farms as systems with inputs (like feed, land, and labour), processes (including metabolism, reproduction, and disease treatment), and outputs (such as calving rates and weight gain). The models were used for simulation, scenario testing, and a more general economic and environmental analysis, and the results were compared with real-world data to support decisions for individual farms.

3.15.8 Completing the Systems Engineering Process

Thirty-two studies completed the system engineering process by including configuration management, performance measurement, lifecycle costing, and risk analysis. They tracked changes, compared costs and benefits between project stages, and assessed schedule and performance risks to support the long-term use of the solution.

4 Discussion

Although the studies were academically focused, their findings were reviewed to identify practical applications for beef cattle farming. The following discussion therefore provides practical suggestions on-farm operations for integrating these principles into farming operations.

4.1 Work Design & Measurement (BOK 1)

Work Design & Measurement can help beef cattle producers break down daily tasks such as feeding, herd checks, and calving into clear, measurable steps. Simple flow charts and tracking

key operations in logbooks or digital forms can help spot bottlenecks and inefficiencies. Time-study and statistical methods could support realistic planning of labour, equipment, and schedules.

4.2 Operations Research (BOK 2)

The use of Operations Research can give beef cattle producers practical tools to make efficient, data-driven decisions. Simple mathematical models, like spreadsheets, can help optimise feed rations and grazing schedules to increase weight gain and lower costs. Dynamic programming can guide decisions about animal replacement, and integer models can help select optimal batch sizes for vaccinations or sales. Decision-tree and multi-criteria methods can balance profit, risk, and animal welfare, while Monte Carlo simulations explore different scenarios.

4.3 Engineering Economic Analysis (BOK 3)

Engineering Economic Analysis can be used for investment and budgeting choices on the farm. It can be applied to differentiate between fixed and variable costs, project cash flows, and apply break-even or benefit–cost criteria to capital purchases or new practices. Simple decision trees can help plan for disease events or volatile markets, and economic frameworks can be integrated into spreadsheets or farm-management tools to make trade-offs clear.

4.4 Facilities Engineering and Energy Management (BOK 4)

Facilities Engineering and Energy Management can be used to optimise the layout, infrastructure, and maintenance of a farm. Using simple flow diagrams, throughput data and storage design (e.g., covered FIFO bins) can help align capacity with demand, while preventive maintenance schedules can reduce operating costs and improve reliability. Integrating these practices in spreadsheet tools or lightweight farm management software - transforms decisions into cost-effective, data-informed operations.

4.5 Quality and reliability engineering (BOK 5)

When quality and reliability engineering principles are applied, they can improve operational performance and resilience on the farm. This includes using control charts, basic statistics, and regression analysis to monitor weight gain trends and disease occurrences. The design of Experiments can support the structured testing of feeds or vaccines.

4.6 Ergonomics and Human Factors (BOK 6)

Ergonomics and Human Factors can help improve safety and efficiency. Ergonomics principles can be applied to align equipment, chutes, and workstations with the measurement of handlers and animal behaviour. Therefore, reducing fatigue and errors. Human factors can also be considered when introducing new equipment or systems to ensure that they are safe and easy for workers to use. When human factors are integrated into management protocols, fatigue and injury are reduced, operational safety is improved, and animal welfare is improved.

4.7 Operations Engineering and Management (BOK 7)

Operations Engineering and Management can help farmers better organise production activities around key seasonal events like calving, weaning, and selling. Planning labour, equipment, and resources around these periods can ease workload pressure and improve daily coordination. Keeping track of key measures such as feed conversion, weight gain, equipment use, and costs can help farmers make more informed decisions over time. Tools such as spreadsheets or farm management applications can support this process simply and practically.

4.8 Supply Chain Management (BOK 8)

Supply Chain Management (SCM) can help farmers keep a better track of inputs like feed and medicines, as well as outputs such as cattle and by-products. Understanding these flows makes it easier to spot potential risks, such as unreliable suppliers or delays. Planning transport and logistics with more care can improve efficiency and reduce disruptions. It can also help farmers better meet the needs of their customers. Building and maintaining strong relationships with customers further supports market stability. Simple tools like spreadsheets or basic SCM apps can help organise and manage this information.

4.9 Engineering Management (BOK 9)

Engineering Management principles can help farmers organise their operations better by ensuring that everyone understands their roles and responsibilities. Clear communication and simple ways of sharing information, such as tracking pasture growth, feed levels, and animal health, can support better daily decision-making. Improving routine activities like feeding and handling cattle can also save time, reduce labour effort, and limit stress on animals. In general, this can lead to more organised and efficient farm management.

4.10 Safety (BOK 10)

Safety engineering methods can be used to identify and mitigate mechanical, environmental, and biological hazards through risk assessment, incident investigation, and safety programmes. Integrating these safety engineering principles helps reduce hazards, lower accident rates, and ultimately protects both people and cattle.

4.11 Information Engineering (BOK 11)

Information Engineering can help farmers identify which information is important to track, such as animal performance and health data, and how to record it consistently. Using simple systems to store and organise this information makes it easier to monitor trends and support daily decisions. Basic databases or digital tracking tools can help bring these data together and, where possible, allow more real-time monitoring of key indicators. This information can then be used to predict trends.

4.12 Design and Manufacturing Engineering (BOK 12)

Design and Manufacturing Engineering can help farmers improve or adapt equipment to their specific needs, like handling facilities or feeding systems. Trying small changes or prototypes first can help reduce risk and ensure that the final design is safe, durable, and appropriate for local conditions.

4.13 Product Design and Development (BOK 13)

Product development methods can help farmers test new ideas in a structured way, such as feed mixes, supplements, housing changes, or simple monitoring technologies. Considering both costs and potential environmental impacts can also support better decision-making. Exploring different scenarios, such as changes in feed prices, disease outbreaks, or equipment failures, can help farmers plan and prepare contingency plans, buffer-stock decisions, and robust product/process design.

4.14 Design and Engineering (BOK 14)

Systems Design can help farmers structure the analysis of the requirements to determine what they need from new technologies, like monitoring animal health, improving feed efficiency, or strengthening biosecurity. These needs can then guide the selection of appropriate tools and systems that fit existing farm operations. Introducing new technologies in a simple and flexible

way can reduce disruption and make it easier to adjust over time. Considering factors such as seasonal changes, herd size, costs, and potential risks can also help ensure that these systems remain practical, reliable, and suitable for the farm over the long term.

Across the 14 BOKs reviewed, the level of alignment differed across the 14 BOKs. Areas such as Operations Research, Engineering Economic Analysis, and Supply Chain Management showed stronger and more consistent overlap with beef cattle production systems and were supported by more studies. In contrast, BOKs such as Ergonomics and Design and Manufacturing Engineering showed more limited and indirect connections, with fewer studies and less explicit application of the relevant tools and methods.

5 Conclusions

To the best of the researcher's knowledge, this study is the first to systematically explore the overlap between the Industrial Engineering body of knowledge and beef cattle production systems. Through a scoping review, the study identified literature aligned with the IISE Bodies of Knowledge. The review showed that several concepts and methods associated with industrial engineering principles have appeared in cattle production research, although they are seldom presented within an explicit industrial engineering framework. The findings further indicate conceptual overlap across multiple BOK domains.

The review highlighted an important gap between Industrial Engineering theory and its practical application in beef cattle production. As noted in the findings, the strength of alignment varied across the 14 BOKs, with some domains showing well-evidenced overlap and others more limited connections. Most of the literature was found to be model-based, technical, or focused on isolated problems, with limited proof of integrated farm-level implementation. At the same time, the review revealed clear opportunities for Industrial Engineering methods to support decision-making, efficiency, resource use, safety, quality, supply chain coordination, and system resilience in cattle production.

A further key takeaway is that the IISE Bodies of Knowledge provide a useful framework for understanding cattle production as a complex system of inputs, processes, and outputs. Therefore, this study contributes not only by mapping existing overlaps but also by showing where the strongest opportunities for transdisciplinary collaboration lie. In doing so, it lays the foundation for future work that can move beyond theory toward practical applications in real farming contexts.

6 Future research

Future research should build on this study in several directions. First, the contextualisation of Industrial Engineering methods should be tested in other livestock production systems, such as sheep, goats, poultry, and pig production, to determine whether similar overlaps and opportunities exist across different animal production contexts. Second, the IISE BOK should be explored in non-animal agricultural systems, such as crop production, horticulture, and mixed-farming systems, to assess whether the Industrial Engineering body of knowledge can be adapted more broadly within agriculture.

Future studies should also investigate the same issue in different geographic and institutional contexts, including other provinces in South Africa and other countries, to determine how the context influences the relevance and implementation of Industrial Engineering methods in agriculture. In addition, future reviews could extend beyond peer-reviewed journal articles to include grey literature, industry reports, extension publications, and practitioner documentation, as these sources may capture applied knowledge that is not visible in academic databases.

More importantly, future research should focus on the practical implementation of the methods identified in this study. Rather than only identifying theoretical overlaps, future studies should examine how specific Industrial Engineering tools can be adapted, implemented, and sustained under real farm conditions. Further work could also compare the methods identified in this review with the practical challenges uncovered in interviews, in order to test how well the literature aligns with real farm realities.

7 Conflicts of Interest Declaration

All authors declare that they have no conflicts of interest.

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The authors declare the use of artificial intelligence tools in the preparation of this article. ChatGPT (OpenAI) was used to help improve the flow and readability of selected paragraphs. Claude (Anthropic) was used to assist with checking and formatting references in accordance with journal guidelines. The authors take full responsibility for the accuracy and integrity of all content, including those sections where these tools were utilised.

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Annexure A

Annexure A presents a complete reference mapping of the scoping review findings. Each row corresponds to a specific sub-heading within an IISE Body of Knowledge (BOK), identified by its hierarchical number (e.g., 1.1, 1.2). The citations listed in each row are the peer-reviewed studies in which evidence of that particular BOK sub-topic was identified during the review. A study may appear under multiple BOK sub-headings if it addressed more than one area.

BoK 1: Work Design & Measurement	
1.1	(Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Makiya & Fraisse, 2015), (Esmaeilzadeh, et al., 2022),
1.2	(Mysko, et al., 2024), (Popp, et al., 2021), (Hagg, et al., 2024)
1.3	(Arias, et al., 2019), (Sorang, et al., 2023), (Van Heerden, et al., 2024), (Rótolo, et al., 2007), (Veysset, et al., 2010), (Vogel, et al., 2021), (Ogino, et al., 2021), (Jobirov, et al., 2022), (Vegosen, et al., 2012), (Adams, et al., 2010)
1.4	(Masoud, et al., 2023), (Li, et al., 2023), (Brooks-Pollock & Keeling, 2009), (Meyer, et al., 2018), (Piramuthu, 2022), (Shaw, et al., 2020), (Živković, et al., 2015), (Aloo, et al., 2024), (da Costa Jr, et al., 2019), (Panin & Monkhei, 1999), (Armando, et al., 2023), (Leme, et al., 2020), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Adams, et al., 2010), (Ekowati, et al., 2018), (Noinan, et al., 2022)
1.6	(Quiroga, et al., 2009), (Li, et al., 2023)
1.9	(Senft & Tharel, 1989)
1.11	(Senft & Tharel, 1989), (Živković, et al., 2015)
1.13	(Zaloshnja, et al., 2011), (Jibat, et al., 2016), (Susanty, et al., 2021), (Abassa, et al., 1987), (Ekowati, et al., 2018), (Noinan, et al., 2022), (Hagg, et al., 2024)
BoK 2: Operations Research	
2.1	(Cloete, et al., 2007), (Bommel, et al., 2014), (Lei, et al., 2024), (Dizyee, et al., 2017), (Martin, et al., 2011), (Tanure, et al., 2015), (Jemberu, et al., 2016), (Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2019), (Sy, et al., 1997), (Yang, et al., 2020), (Jibat, et al., 2016), (Vegosen, et al., 2012), (McCuistion, et al., 2011), (Abassa, et al., 1987), (Popp, et al., 2021), (Ekowati, et al., 2018), (Salmon, et al., 2018)
2.2	(dos Reis, et al., 2020), (Rewe, et al., 2006), (Veysset, et al., 2010), (Brečko, et al., 2024)
2.7	(Cloete, et al., 2007), (Brečko, et al., 2024),
2.8	(Brečko, et al., 2024)
2.10	(Magne, et al., 2010), (Jiménez, et al., 2024), (Jones & Langemeier, 2010), (Perillat, et al., 2004), (Ojeda-Rojas, et al., 2022), (MacLeod, et al., 2007), (Masoud, et al., 2023), (Li, et al., 2022), (dos Reis, et al., 2020), (Piña, et al., 2023), (Tanure, et al., 2015), (Renault, et al., 2021), (Rewe, et al., 2006), (Browning, et al., 2013), (Suleiman, et al., 2015), (Houessou, et al., 2019), (Hessle, et al., 2017), (Randela, 2005), (Jemberu, et al., 2016), (Li, et al., 2024), (Fernández-Perea & Alenda Jiménez, 2004), (Rótolo, et al., 2007), (Veysset, et al., 2010), (Vogel, et al., 2021), (Ogino, et al., 2021), (Bouyer, et al., 2014), (Mysko, et al., 2024), (Senft & Tharel, 1989), (Piramuthu, 2022), (Baker, et al., 2025), (Susanty, et al., 2019), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Makiya & Fraisse, 2015), (Esmaeilzadeh, et al., 2022), (Adams, et al., 2010), (Salmon, et al., 2018), (Noinan, et al., 2022), (Hagg, et al., 2024)
2.11	(Masoud, et al., 2023), (Li, et al., 2022), (Alizadeh, et al., 2020), (Tanure, et al., 2015), (Renault, et al., 2021), (Browning, et al., 2013), (Suleiman, et al., 2015), (Houessou, et al., 2019), (Li, et al., 2019), (Meyer, et al., 2018), (Levine & Hohenboken, 1981), (Esmaeilzadeh, et al., 2022)
2.13	(Quiroga, et al., 2009), (Sieng, et al., 2022), (Bommel, et al., 2014), (Jiménez, et al., 2024), (Dizyee, et al., 2017), (Jones & Langemeier, 2010), (Perillat, et al., 2004), (Martin, et al., 2011), (Ojeda-Rojas, et al., 2022), (MacLeod, et al., 2007), (Masoud, et al., 2023), (dos Reis, et al., 2020), (Tanure, et al., 2015), (Rewe, et al., 2006), (Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2019), (Li, et al., 2024), (Van Heerden, et al., 2024), (Veysset, et al., 2010), (Vogel, et al., 2021), (Bilotto, et al., 2021), (Brooks-Pollock & Keeling, 2009), (Yang, et al., 2020), (Meyer, et al., 2018), (López-González, et al., 2020), (Senft & Tharel, 1989), (Susanty, et al., 2021), (Itty, 1996), (Senft, 1988), (Popp, et al., 2021), (Levine & Hohenboken, 1981), (Pitrova, et al., 2020), (Itty, et al., 1995)
2.14	(MacLeod, et al., 2007), (Alizadeh, et al., 2020), (Tanure, et al., 2015), (Van Heerden, et al., 2024), (Ogino, et al., 2021), (dos Reis, et al., 2021), (López-González, et al., 2020), (Senft & Tharel, 1989), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Ekowati, et al., 2018)
BoK 3: Engineering Economic Analysis	
3.2	(Sieng, et al., 2022), (Jones & Langemeier, 2010), (Martin, et al., 2011), (Jemberu, et al., 2016), (Romanzini, et al., 2020), (Sunu W, 2023), (Jobirov, et al., 2022), (Bouyer, et al., 2014), (Zaloshnja, et al., 2011), (Jibat, et al., 2016), (Susanty, et al., 2021), (Živković, et al., 2015), (Brečko, et al., 2024), (Panin & Monkhei, 1999), (Yap, et al., 2023), (Itty, et al., 1995),
3.3	(Jemberu, et al., 2016), (Romanzini, et al., 2020), (Sunu W, 2023), (Fernández-Perea & Alenda Jiménez, 2004), (Zaloshnja, et al., 2011), (Panin & Monkhei, 1999), (Pitrova, et al., 2020), (Itty, et al., 1995), (Hagg, et al., 2024), (Merry, et al., 2004)
3.4	(Quiroga, et al., 2009), (Cloete, et al., 2007), (Sieng, et al., 2022), (Dizyee, et al., 2017), (Jones & Langemeier, 2010), (Perillat, et al., 2004), (Martin, et al., 2011), (Ojeda-Rojas, et al., 2022), (MacLeod, et al., 2007), (Masoud, et al., 2023), (dos Reis, et al., 2020), (Tanure, et al., 2015), (Randela, 2005), (Jemberu, et al., 2016), (Romanzini, et al., 2020), (Sunu W, 2023), (Fernández-Perea & Alenda Jiménez, 2004), (Arias, et al., 2019), (Sorang, et al.,

	2023), (Rótolo, et al., 2007), (Veyssset, et al., 2010), (Jobirov, et al., 2022), (Bouyer, et al., 2014), (Mysko, et al., 2024), (Zaloshnja, et al., 2011), (Jibat, et al., 2016), (Meyer, et al., 2018), (dos Reis, et al., 2021), (Živković, et al., 2015), (Baker, et al., 2025), (Brečko, et al., 2024), (Itty, 1996), (Panin & Monkhei, 1999), (Pitrova, et al., 2020), (Drugova, et al., 2021), (Itty, et al., 1995), (Ekowati, et al., 2018), (Salmon, et al., 2018), (Noinan, et al., 2022), (Merry, et al., 2004)
3.5	(Cloete, et al., 2007), (Sieng, et al., 2022), (Dizyee, et al., 2017), (Perillat, et al., 2004), (MacLeod, et al., 2007), (Masoud, et al., 2023), (Li, et al., 2022), (dos Reis, et al., 2020), (Tanure, et al., 2015), (Renault, et al., 2021), (Rewe, et al., 2006), (Jemberu, et al., 2016), (Romanzini, et al., 2020), (Rótolo, et al., 2007), (Veyssset, et al., 2010), (Vogel, et al., 2021), (Ogino, et al., 2021), (Senft & Tharel, 1989), (Baker, et al., 2025), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Ekowati, et al., 2018), (Salmon, et al., 2018), (Hagg, et al., 2024), (Merry, et al., 2004)
3.7	(dos Reis, et al., 2020), (Bilotto, et al., 2021), (Živković, et al., 2015), (Noinan, et al., 2022)
3.8	(Randela, 2005), (Jemberu, et al., 2016), (Vogel, et al., 2021), (Meyer, et al., 2018), (Drugova, et al., 2021), (Itty, et al., 1995)
3.9	(Jobirov, et al., 2022), (Brooks-Pollock & Keeling, 2009), (Makiya & Fraisse, 2015), (Adams, et al., 2010)
3.12	(Browning, et al., 2013), (Suleiman, et al., 2015), (Houessou, et al., 2019), (Hessle, et al., 2017), (Randela, 2005), (Armando, et al., 2023)
3.14	(Perillat, et al., 2004), (Ojeda-Rojas, et al., 2022), (MacLeod, et al., 2007), (Li, et al., 2022), (Tanure, et al., 2015), (Rewe, et al., 2006), (Suleiman, et al., 2015), (Houessou, et al., 2019), (Hessle, et al., 2017), (Randela, 2005), (Romanzini, et al., 2020), (Fernández-Perea & Alenda Jiménez, 2004), (Senft & Tharel, 1989), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Makiya & Fraisse, 2015), (Pitrova, et al., 2020), (Itty, et al., 1995), (Salmon, et al., 2018), (Merry, et al., 2004)
3.15	(Masoud, et al., 2023), (Alizadeh, et al., 2020), (Renault, et al., 2021), (Romanzini, et al., 2020), (Fernández-Perea & Alenda Jiménez, 2004), (Pitrova, et al., 2020), (Itty, et al., 1995)
BoK 4: Facilities Engineering & Energy Management	
4.2	(Veyssset, et al., 2010), (Vogel, et al., 2021), (Ogino, et al., 2021), (Mysko, et al., 2024), (Živković, et al., 2015), (Hagg, et al., 2024)
4.3	(Živković, et al., 2015), (Senft, 1988)
4.4	(Živković, et al., 2015), (Senft, 1988)
4.5	(Li, et al., 2023)
4.6	(Li, et al., 2023), (Veyssset, et al., 2010), (Ogino, et al., 2021), (TEnu, et al., 2024), (Hagg, et al., 2024)
BoK 5: Quality & Reliability Engineering	
5.1	(Magne, et al., 2010), (Jones & Langemeier, 2010), (Perillat, et al., 2004), (Browning, et al., 2003), (Browning, et al., 2013), (Suleiman, et al., 2015), (Houessou, et al., 2019), (Hessle, et al., 2017), (Randela, 2005), (Jemberu, et al., 2016), (Li, et al., 2019), (Arias, et al., 2019), (Sorang, et al., 2023), (Jobirov, et al., 2022), (Bouyer, et al., 2014), (Kibona & Yuejie, 2021), (Brooks-Pollock & Keeling, 2009), (Mysko, et al., 2024), (Yang, et al., 2020), (Zaloshnja, et al., 2011), (Jibat, et al., 2016), (Meyer, et al., 2018), (dos Reis, et al., 2021), (López-González, et al., 2020), (Senft & Tharel, 1989), (Shaw, et al., 2020), (Susanty, et al., 2021), (Vegosen, et al., 2012), (McCustion, et al., 2011), (Susanty, et al., 2019), (Itty, 1996), (da Costa Jr, et al., 2019), (Robinson, et al., 2021), (Armando, et al., 2023), (Senft, 1988), (Popp, et al., 2021), (Esmaeilzadeh, et al., 2022), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
5.2	(Li, et al., 2023), (Hagg, et al., 2024)
5.3	(Quiroga, et al., 2009), (Jiménez, et al., 2024), (Perillat, et al., 2004), (Martin, et al., 2011), (Ojeda-Rojas, et al., 2022), (Masoud, et al., 2023), (Li, et al., 2022), (Piña, et al., 2023), (Browning, et al., 2013), (Suleiman, et al., 2015), (Houessou, et al., 2019), (Hessle, et al., 2017), (Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2019), (Sy, et al., 1997), (Bilotto, et al., 2021), (Jobirov, et al., 2022), (Kibona & Yuejie, 2021), (Senft & Tharel, 1989), (McCustion, et al., 2011), (Aloo, et al., 2024), (da Costa Jr, et al., 2019), (Robinson, et al., 2021), (Senft, 1988), (Popp, et al., 2021), (Drugova, et al., 2021), (Ekowati, et al., 2018), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019)
5.4	(Jemberu, et al., 2016), (Li, et al., 2019), (Li, et al., 2023), (Makiya & Fraisse, 2015)
5.5	(Li, et al., 2024), (Makiya & Fraisse, 2015)
BoK 6: Ergonomics & Human Factors	
6.1	(Li, et al., 2019)
6.3	(Browning, et al., 2013), (Li, et al., 2019), (Li, et al., 2023), (Aloo, et al., 2024)
6.7	(Browning, et al., 2013)
6.8	(Li, et al., 2023)
6.11	(Li, et al., 2019), (Li, et al., 2024)
6.13	(Browning, et al., 2013), (Li, et al., 2019), (Li, et al., 2023)
BoK 7: Operations Engineering & Management	
7.1	(Dizyee, et al., 2017), (MacLeod, et al., 2007), (Masoud, et al., 2023), (Li, et al., 2022), (Alizadeh, et al., 2020), (dos Reis, et al., 2020), (Piña, et al., 2023), (Tanure, et al., 2015), (Renault, et al., 2021), (Houessou, et al., 2019), (Hessle, et al., 2017), (Randela, 2005), (Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2019), (Rótolo, et al., 2007), (Veyssset, et al., 2010), (Bilotto, et al., 2021), (Jobirov, et al., 2022), (Bouyer, et al., 2014), (Kibona & Yuejie, 2021), (Brooks-Pollock & Keeling, 2009), (Zaloshnja, et al., 2011), (Meyer, et al., 2018), (Senft & Tharel, 1989), (Piramuthu, 2022), (Guéneau, 2018), (Živković, et al., 2015), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Levine & Hohenboken, 1981), (Jie & Parton & Mustafid, 2016), (Makiya & Fraisse, 2015), (Esmaeilzadeh, et al., 2022), (Pitrova, et al., 2020), (Ekowati, et al., 2018), (Salmon, et al., 2018), (Noinan, et al., 2022), (Merry, et al., 2004), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
7.3	(Živković, et al., 2015), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Levine & Hohenboken, 1981), (Pitrova, et al., 2020)
7.4	(Yang, et al., 2019), (Adams, et al., 2010)
7.5	(Živković, et al., 2015), (Pitrova, et al., 2020), (Itty, et al., 1995), (Toro-Mujica, et al., 2019)

7.6	(Alizadeh, et al., 2020), (dos Reis, et al., 2020), (Browning, et al., 2013), (Suleiman, et al., 2015), (Houessou, et al., 2019), (Hessle, et al., 2017), (Yap, et al., 2023), (T̂enu, et al., 2024), (Jie & Parton & Mustafid, 2016), (Itty, et al., 1995), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019)
7.7	(Veysset, et al., 2010), (Vogel, et al., 2021)
7.8	(Yang, et al., 2019)
7.12	(Quiroga, et al., 2009), (Cloete, et al., 2007), (Sieng, et al., 2022), (Jiménez, et al., 2024), (Dizyee, et al., 2017), (Jones & Langemeier, 2010), (Perillat, et al., 2004), (Martin, et al., 2011), (Ojeda-Rojas, et al., 2022), (MacLeod, et al., 2007), (Masoud, et al., 2023), (dos Reis, et al., 2020), (Piña, et al., 2023), (Tanure, et al., 2015), (Renault, et al., 2021), (Rewe, et al., 2006), (Browning, et al., 2013), (Suleiman, et al., 2015), (Houessou, et al., 2019), (Hessle, et al., 2017), (Randela, 2005), (Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2019), (Arias, et al., 2019), (Rótolo, et al., 2007), (Veysset, et al., 2010), (Vogel, et al., 2021), (Ogino, et al., 2021), (Jobirov, et al., 2022), (Bouyer, et al., 2014), (Brooks-Pollock & Keeling, 2009), (Mysko, et al., 2024), (Yang, et al., 2020), (dos Reis, et al., 2021), (López-González, et al., 2020), (Senft & Tharel, 1989), (Piramuthu, 2022), (Shaw, et al., 2020), (Susanty, et al., 2021), (Guéneau, 2018), (Vegosen, et al., 2012), (Živković, et al., 2015), (Baker, et al., 2025), (McCuistion, et al., 2011), (Aloo, et al., 2024), (Brečko, et al., 2024), (da Costa Jr, et al., 2019), (Panin & Monkhei, 1999), (Armando, et al., 2023), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Yap, et al., 2023), (T̂enu, et al., 2024), (Jie & Parton & Mustafid, 2016), (Esmaeilzadeh, et al., 2022), (Adams, et al., 2010), (Ekowati, et al., 2018), (Salmon, et al., 2018), (Noinan, et al., 2022), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
BoK 8: Supply Chain Management	
8.1	(Alizadeh, et al., 2020), (Renault, et al., 2021), (Hessle, et al., 2017), (Randela, 2005), (Yang, et al., 2019), (Rótolo, et al., 2007), (Piramuthu, 2022), (Susanty, et al., 2021), (Susanty, et al., 2019), (Leme, et al., 2020), (Makiya & Fraisse, 2015), (Pitrova, et al., 2020), (Itty, et al., 1995), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
8.2	(Cloete, et al., 2007), (Dizyee, et al., 2017), (MacLeod, et al., 2007), (Masoud, et al., 2023), (Alizadeh, et al., 2020), (dos Reis, et al., 2020), (Tanure, et al., 2015), (Rewe, et al., 2006), (Houessou, et al., 2019), (Hessle, et al., 2017), (Jemberu, et al., 2016), (Li, et al., 2023), (Yang, et al., 2019), (Li, et al., 2024), (Rótolo, et al., 2007), (Mysko, et al., 2024), (Yang, et al., 2020), (Susanty, et al., 2021), (Guéneau, 2018), (Živković, et al., 2015), (Brečko, et al., 2024), (Senft, 1988), (Yap, et al., 2023), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
8.4	(Yang, et al., 2019), (Yang, et al., 2020), (Piramuthu, 2022), (Živković, et al., 2015), (Yap, et al., 2023), (Adams, et al., 2010), (Pitrova, et al., 2020), (Mancilla & Sepúlveda, 2017)
8.5	(Jie & Parton & Mustafid, 2016), (Pitrova, et al., 2020)
8.6	(Jie & Parton & Mustafid, 2016), (Makiya & Fraisse, 2015), (Merry, et al., 2004)
BoK 9: Engineering Management	
9.2	(Li, et al., 2019), (Li, et al., 2023), (Živković, et al., 2015), (Mancilla & Sepúlveda, 2017)
9.3	(Yang, et al., 2020), (Piramuthu, 2022), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Makiya & Fraisse, 2015), (Noinan, et al., 2022), (Mancilla & Sepúlveda, 2017)
9.4	(Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2019), (Živković, et al., 2015), (Ekowati, et al., 2018), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
9.6	(Li, et al., 2019), (Li, et al., 2023), (Rótolo, et al., 2007), (Mysko, et al., 2024), (Zaloshnja, et al., 2011), (Susanty, et al., 2021), (Guéneau, 2018), (Brečko, et al., 2024), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (T̂enu, et al., 2024), (Jie & Parton & Mustafid, 2016), (Makiya & Fraisse, 2015), (Pitrova, et al., 2020), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019)
9.7	(Susanty, et al., 2021)
9.8	(Li, et al., 2019), (Esmaeilzadeh, et al., 2022), (Pitrova, et al., 2020), (Noinan, et al., 2022), (Toro-Mujica, et al., 2019)
BoK 10: Safety	
10.1	(Renault, et al., 2021), (Browning, et al., 2013), (Suleiman, et al., 2015)
10.3	(Li, et al., 2019), (Li, et al., 2023), (Zaloshnja, et al., 2011), (Vegosen, et al., 2012), (T̂enu, et al., 2024), (Hagg, et al., 2024), (Merry, et al., 2004)
10.4	(Sieng, et al., 2022), (Dizyee, et al., 2017), (Browning, et al., 2003), (Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2020), (Zaloshnja, et al., 2011), (Jibat, et al., 2016), (Susanty, et al., 2021), (Vegosen, et al., 2012), (Makiya & Fraisse, 2015), (Hagg, et al., 2024), (Merry, et al., 2004)
BoK 11: Information Engineering	
11.2	(Cho & Kim, 2023), (Shaw, et al., 2020), (Armando, et al., 2023), (Leme, et al., 2020), (Makiya & Fraisse, 2015), (Noinan, et al., 2022)
11.3	(Quiroga, et al., 2009), (Cloete, et al., 2007), (Magne, et al., 2010), (Sieng, et al., 2022), (Bommel, et al., 2014), (Dizyee, et al., 2017), (Jones & Langemeier, 2010), (Martin, et al., 2011), (Browning, et al., 2003), (MacLeod, et al., 2007), (Masoud, et al., 2023), (Li, et al., 2022), (Alizadeh, et al., 2020), (dos Reis, et al., 2020), (Piña, et al., 2023), (Tanure, et al., 2015), (Renault, et al., 2021), (Rewe, et al., 2006), (Jemberu, et al., 2016), (Li, et al., 2023), (Yang, et al., 2019), (Arias, et al., 2019), (Rótolo, et al., 2007), (Ogino, et al., 2021), (Jobirov, et al., 2022), (Bouyer, et al., 2014), (Kibona & Yuejie, 2021), (Yang, et al., 2020), (Meyer, et al., 2018), (dos Reis, et al., 2021), (Piramuthu, 2022), (Susanty, et al., 2021), (Guéneau, 2018), (Vegosen, et al., 2012), (Živković, et al., 2015), (Brečko, et al., 2024), (Itty, 1996), (da Costa Jr, et al., 2019), (Panin & Monkhei, 1999), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Levine & Hohenboken, 1981), (Yap, et al., 2023), (T̂enu, et al., 2024), (Jie & Parton & Mustafid, 2016), (Makiya & Fraisse, 2015), (Esmaeilzadeh, et al., 2022), (Pitrova, et al., 2020), (Drugova, et al., 2021), (Itty, et al., 1995), (Ekowati, et al., 2018), (Salmon, et al., 2018), (Noinan, et al., 2022), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
11.4	(Yang, et al., 2019), (Li, et al., 2024), (Arias, et al., 2019), (Sorang, et al., 2023), (Rótolo, et al., 2007), (Senft & Tharel, 1989), (Piramuthu, 2022), (Shaw, et al., 2020)
11.5	(Piramuthu, 2022), (da Costa Jr, et al., 2019), (Panin & Monkhei, 1999), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (T̂enu, et al., 2024), (Jie & Parton & Mustafid, 2016), (Salmon, et al., 2018), (Hagg, et al., 2024), (Merry, et al., 2004), (Mancilla & Sepúlveda, 2017)

11.6	(Quiroga, et al., 2009), (Bommel, et al., 2014), (Dizyee, et al., 2017), (MacLeod, et al., 2007), (Masoud, et al., 2023), (Jemberu, et al., 2016), (Li, et al., 2019), (Li, et al., 2023), (Sy, et al., 1997), (Brooks-Pollock & Keeling, 2009), (Yang, et al., 2019), (Aloo, et al., 2024), (Susanty, et al., 2019), (Leme, et al., 2020), (Popp, et al., 2021), (Yap, et al., 2023), (Makiya & Fraisse, 2015), (Esmaeilzadeh, et al., 2022), (Ekowati, et al., 2018)
11.7	(Magne, et al., 2010)
11.10	(Bommel, et al., 2014), (Lei, et al., 2024), (Martin, et al., 2011), (Ojeda-Rojas, et al., 2022), (Van Heerden, et al., 2024), (Veyssset, et al., 2010), (Levine & Hohenboken, 1981), (Makiya & Fraisse, 2015), (Esmaeilzadeh, et al., 2022), (Pitrova, et al., 2020), (Drugova, et al., 2021), (Itty, et al., 1995), (Toro-Mujica, et al., 2019)
11.11	(Bommel, et al., 2014), (Lei, et al., 2024), (Van Heerden, et al., 2024), (Toro-Mujica, et al., 2019)
11.12	(Van Heerden, et al., 2024), (Salmon, et al., 2018)
11.14	(Jobirov, et al., 2022), (Bouyer, et al., 2014), (Kibona & Yuejie, 2021), (Vegosen, et al., 2012), (Živković, et al., 2015), (Armando, et al., 2023), (Leme, et al., 2020), (Makiya & Fraisse, 2015), (Noinan, et al., 2022)
11.15	(Levine & Hohenboken, 1981), (Pitrova, et al., 2020)
11.17	(Cloete, et al., 2007), (Sieng, et al., 2022), (Li, et al., 2022), (Jiménez, et al., 2024), (Lei, et al., 2024), (Dizyee, et al., 2017), (Jones & Langemeier, 2010), (Perillat, et al., 2004), (Martin, et al., 2011), (Browning, et al., 2013), (Cho & Kim, 2023), (Ojeda-Rojas, et al., 2022), (MacLeod, et al., 2007), (Masoud, et al., 2023), (Houessou, et al., 2019), (Hessle, et al., 2017), (Jemberu, et al., 2016), (Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2019), (Li, et al., 2024), (Romanzini, et al., 2020), (Sorang, et al., 2023), (Rótolo, et al., 2007), (Veyssset, et al., 2010), (Vogel, et al., 2021), (Ogino, et al., 2021), (Sy, et al., 1997), (Bilotto, et al., 2021), (Brooks-Pollock & Keeling, 2009), (Mysko, et al., 2024), (Yang, et al., 2020), (Zaloshnja, et al., 2011), (Jibat, et al., 2016), (Senft & Tharel, 1989), (Piramuthu, 2022), (Shaw, et al., 2020), (Susanty, et al., 2021), (Baker, et al., 2025), (Aloo, et al., 2024), (Susanty, et al., 2019), (Robinson, et al., 2021), (Senft, 1988), (Abassa, et al., 1987), (Popp, et al., 2021), (Yap, et al., 2023), (Jie & Parton & Mustafid, 2016), (Esmaeilzadeh, et al., 2022), (Adams, et al., 2010), (Pitrova, et al., 2020), (Drugova, et al., 2021), (Itty, et al., 1995), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
BoK 12: Design & Manufacturing Engineering	
12.1	(Aloo, et al., 2024)
12.11	(Li, et al., 2019), (Li, et al., 2023), (Hagg, et al., 2024)
12.12	(Li, et al., 2022), (Lei, et al., 2024), (Li, et al., 2019), (Li, et al., 2023), (Armando, et al., 2023)
BoK 13: Product Design & Development	
13.1	(Noinan, et al., 2022)
13.2	(Li, et al., 2022), (Lei, et al., 2024), (Rewe, et al., 2006), (Jemberu, et al., 2016), (Li, et al., 2019), (Li, et al., 2023)
13.3	(Aloo, et al., 2024), (Armando, et al., 2023), (Hagg, et al., 2024)
13.4	(Jemberu, et al., 2016), (Rótolo, et al., 2007), (Veyssset, et al., 2010), (Vogel, et al., 2021), (Ogino, et al., 2021)
13.6	(Li, et al., 2023), (Veyssset, et al., 2010)
13.9	(Li, et al., 2023)
BoK 14: Systems Design & Engineering	
14.2	(Quiroga, et al., 2009), (Cloete, et al., 2007), (Sieng, et al., 2022), (Jiménez, et al., 2024), (Dizyee, et al., 2017), (Jones & Langemeier, 2010), (Perillat, et al., 2004), (Martin, et al., 2011), (Ojeda-Rojas, et al., 2022), (Jemberu, et al., 2016), (Li, et al., 2019), (Li, et al., 2023), (Yang, et al., 2019), (Van Heerden, et al., 2024), (Yang, et al., 2020), (Guéneau, 2018), (Aloo, et al., 2024), (Susanty, et al., 2019), (Leme, et al., 2020), (Senft, 1988), (Levine & Hohenboken, 1981), (Yap, et al., 2023), (TEnu, et al., 2024), (Makiya & Fraisse, 2015), (Pitrova, et al., 2020), (Itty, et al., 1995), (Noinan, et al., 2022), (Hagg, et al., 2024), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
14.3	(Lei, et al., 2024), (Cho & Kim, 2023), (Li, et al., 2024), (Piramuthu, 2022), (Armando, et al., 2023), (Leme, et al., 2020), (Senft, 1988), (Yap, et al., 2023), (Makiya & Fraisse, 2015), (Pitrova, et al., 2020), (Itty, et al., 1995), (Toro-Mujica, et al., 2019)
14.4	(Van Heerden, et al., 2024), (Toro-Mujica, et al., 2019)
14.5	(Alizadeh, et al., 2020), (Li, et al., 2024), (Bouyer, et al., 2014), (Piramuthu, 2022), (Armando, et al., 2023), (Leme, et al., 2020), (Yap, et al., 2023), (Noinan, et al., 2022), (Hagg, et al., 2024)
14.6	(Li, et al., 2019), (Li, et al., 2023), (Van Heerden, et al., 2024), (Piramuthu, 2022), (Levine & Hohenboken, 1981), (Pitrova, et al., 2020), (Itty, et al., 1995), (Toro-Mujica, et al., 2019)
14.7	(Levine & Hohenboken, 1981), (Pitrova, et al., 2020), (Itty, et al., 1995), (Toro-Mujica, et al., 2019)
14.9	(Magne, et al., 2010), (Bommel, et al., 2014), (Li, et al., 2022), (Jiménez, et al., 2024), (Lei, et al., 2024), (Dizyee, et al., 2017), (Li, et al., 2019), (Yang, et al., 2019), (Rótolo, et al., 2007), (Veyssset, et al., 2010), (Ogino, et al., 2021), (Bilotto, et al., 2021), (Kibona & Yuejie, 2021), (Brooks-Pollock & Keeling, 2009), (Yang, et al., 2020), (Meyer, et al., 2018), (dos Reis, et al., 2021), (López-González, et al., 2020), (Senft & Tharel, 1989), (Guéneau, 2018), (Živković, et al., 2015), (Baker, et al., 2025), (McCuistion, et al., 2011), (Senft, 1988), (Levine & Hohenboken, 1981), (TEnu, et al., 2024), (Makiya & Fraisse, 2015), (Esmaeilzadeh, et al., 2022), (Adams, et al., 2010), (Pitrova, et al., 2020), (Itty, et al., 1995), (Ekowati, et al., 2018), (Salmon, et al., 2018), (Noinan, et al., 2022), (Merry, et al., 2004), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)
14.10	(Cloete, et al., 2007), (Sieng, et al., 2022), (Houessou, et al., 2019), (Hessle, et al., 2017), (Randela, 2005), (Jemberu, et al., 2016), (Li, et al., 2023), (Yang, et al., 2019), (Van Heerden, et al., 2024), (Rótolo, et al., 2007), (Veyssset, et al., 2010), (Vogel, et al., 2021), (Ogino, et al., 2021), (Mysko, et al., 2024), (Zaloshnja, et al., 2011), (Jibat, et al., 2016), (Meyer, et al., 2018), (Piramuthu, 2022), (Susanty, et al., 2021), (Guéneau, 2018), (Senft, 1988), (Levine & Hohenboken, 1981), (Makiya & Fraisse, 2015), (Esmaeilzadeh, et al., 2022), (Pitrova, et al., 2020), (Itty, et al., 1995), (Ekowati, et al., 2018), (Salmon, et al., 2018), (Hagg, et al., 2024), (Merry, et al., 2004), (Toro-Mujica, et al., 2019), (Mancilla & Sepúlveda, 2017)

CHAPTER 5 INTERVIEWS AND FINDINGS

This chapter explains the interview process and findings, thereby addressing Research Objective 1, which explores the challenges and their root causes in cattle production. This chapter focused on the inductive component of the data analysis, using thematic analysis to identify recurring themes and patterns from the interviews. The subsequent deductive analysis, which maps these themes against the IISE Bodies of Knowledge, is presented in the following chapter. Figure 5-1 shows the current position of the research method.

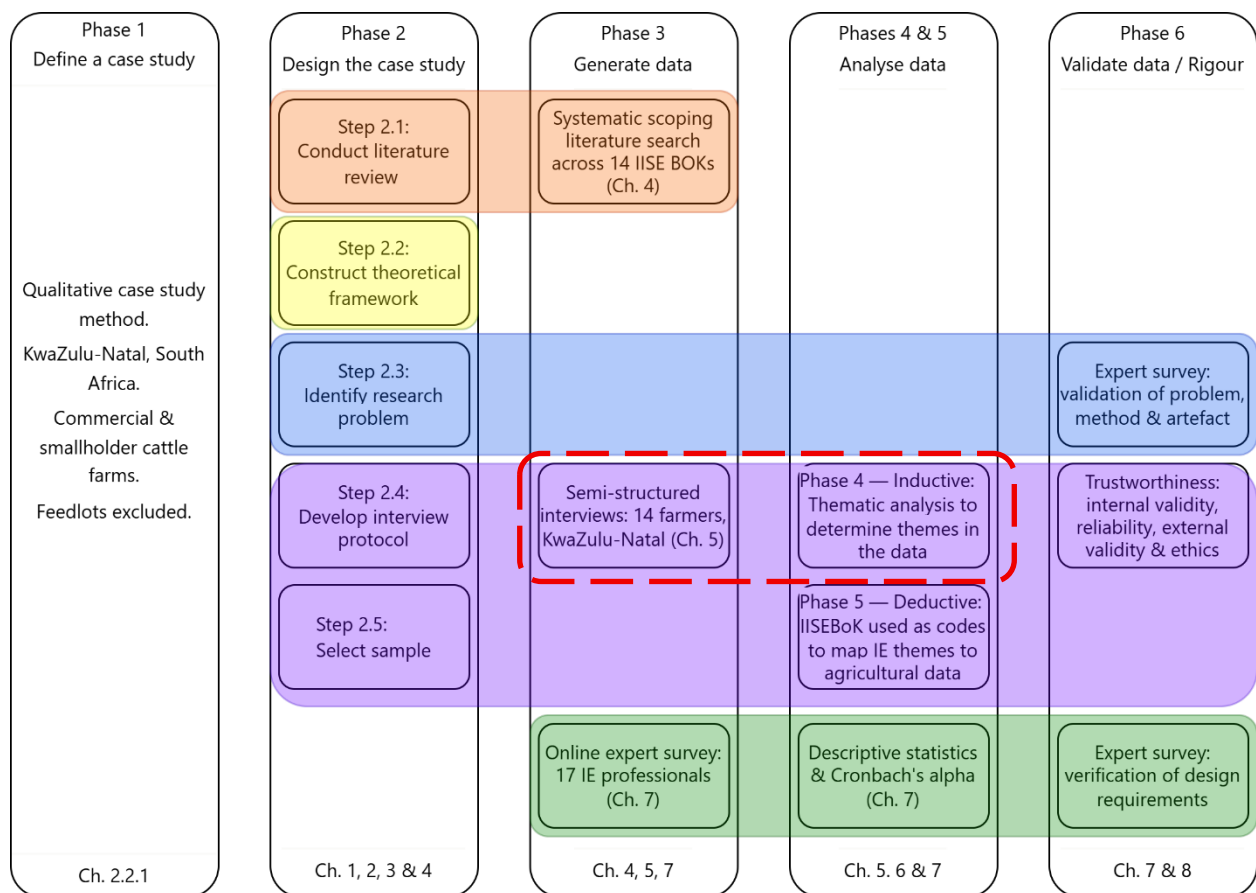


Figure 5-1: Research method

CHALLENGES IN KWAZULU-NATAL BEEF PRODUCTION: A SYSTEMS APPROACH

Beef cattle production in South Africa contributes significantly to food security, employment, and local economies. However, farmers operate in a complex environment shaped by various challenges, many of which fall outside their direct control yet significantly affect farm performance. This study identifies and discusses the key challenges faced by cattle farmers in KwaZulu-Natal and explores how these challenges are interconnected from a systems perspective. Participants were selected through purposive sampling across the Highveld and Midlands regions, and data were analysed using a thematic analysis. Eight themes and 22 subthemes were identified. The analysis shows that challenges rarely occur in isolation — they trigger cascading effects converging on shared outcomes, with reinforcement loops where responses to one problem can unintentionally worsen others. The study demonstrates that pressures on beef producers are systemic, highlighting the need to understand cattle production as an interconnected operating system rather than a set of independent problems.

Keywords: Cattle production; Interconnected systems; Thematic analysis; Feedback loops; Systems perspective; Beef farming

1. INTRODUCTION

Beef cattle production plays an important role in the South African economy, contributing to employment and food security. An estimated 22,000 commercial farms employ 138,000 people, while 3 million emerging and community farmers employ 9 million people (DALRRD, 2023). With 2,125,000 people dependent on the cattle sector, the beef industry is a significant source of income. In 2022, South Africa exported more than 28,000 tonnes of beef, valued at R2.5 billion.

Despite its significance, research indicates that farmers face a range of challenges that shape their daily production decisions. Several South African studies report problems such as disease and feed shortages, limited access to production and management support services, and low reproductive performance, suggesting that cattle farmers commonly face multiple overlapping constraints rather than a single isolated problem (Makombe et al., 2025; Nkadameng et al., 2022; Malusi et al., 2011; Mbatha, 2021; Mdiya et al., 2025).

KwaZulu-Natal (KZN) represents a significant region in South Africa for the study of beef production. It is one of South Africa's main livestock provinces, with a diverse mix of commercial, emerging, and small-scale producers (Agribook Digital, 2024; National Department of Agriculture, 2025). The Midlands and Highveld have good rainfall and varied terrain, which support a range of cattle systems and farm sizes (Hitayezu et al., 2014; Agribook Digital, 2024). That variety is useful because different farms face different combinations of environmental, operational, and market pressures. KZN is well placed to explore how these constraints play out in real life.

Technical disciplines such as animal science and agronomy provide essential knowledge for cattle production, but many farmers' problems go beyond purely biological issues. Questions about how people, information, feed, and equipment are organised (decisions about timing, labour, stock flow, and resource allocation) are just as important.

Although various studies have reported technical and socio-economic challenges faced by beef cattle farmers, these issues are often examined in isolation. As a result, little is known about how multiple constraints interact within the daily operations of a cattle production system. Little attention has been paid to interpreting beef cattle production through a systems approach that considers the farm as an integrated system of people, processes, resources, and information. This creates a gap in the literature in the KwaZulu-Natal context, where diverse production systems offer an opportunity to systematically examine cattle production challenges.

Therefore, this study aims to identify the key challenges faced by cattle farmers who contribute to food production and food security. Furthermore, it is explored how these challenges are interconnected and how they are interpreted at a systems level.

2. LITERATURE REVIEW

The State of Food Security and Nutrition in the World report estimated that 673 million people experienced hunger worldwide in 2024 (FAO, IFAD, UNICEF, WFP, & WHO, 2024). The 1996 World Summit defined food security as "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2008; CFS, 2012).

The United Nations Sustainable Development Goal 2 (SDG 2) aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture (United Nations, 2015). SDG 2 focuses on increasing the productivity and incomes of small-scale food producers, improving the sustainability and resilience of agricultural systems, and reducing food losses along value chains (United Nations, 2015).

Livestock systems contribute to food security in several ways. Livestock convert low-value biomass and materials that are often inedible to humans into foods like meat, milk, and eggs, which are rich in high-quality protein and essential micronutrients needed for human health and development (Davis & White, 2020). Beyond direct food production, livestock also support rural livelihoods through income generation, asset growth, and the supply of inputs like manure and draft power in mixed farming systems (van Wijk et al., 2018; Banda & Tanganyika, 2021)

Farmers face a range of constraints, including access to land and markets, training, technology, labour, and business skills (Rangarajan & Chitja, 2020). These challenges affect production decisions and highlight the need to understand cattle farming within a broader operational context.

By viewing farming operations as a production system, a beef cattle farm can be compared to a factory, manufacturer, or organisation. The cattle are the raw material, and the beef at the end of the production line is the finished goods. If the production process is not functioning optimally, the quality and quantity of the finished product (meat) will be below the standard.

To explore how farmers in KwaZulu-Natal experience these multiple, interconnected challenges, this study adopted a qualitative, interview-based approach.

3. RESEARCH DESIGN

3.1. Research Setting

The interviews were conducted with farmers to collect data on their lived experiences with the challenges of cattle production. The inclusion and exclusion criteria for participants are expanded in Section 5. Participants were identified via purposive and snowball sampling. The researcher conducted the interviews with professionalism. The data were then analysed via a thematic analysis.

3.2. Entrée and Establishment of Researcher Roles

The researcher obtained permission from the institutional research ethics committee before conducting the interviews. The researcher used an independent person to ask participants to participate in the research. The researcher obtained participants' consent before beginning the investigation.

The researcher developed the interview questions and conducted semi-structured interviews with the support of the supervisors. Thereafter, the researcher analysed and interpreted the data gathered.

3.3. Population

The study population consisted of participants from the KwaZulu-Natal Midlands and Highveld.

3.4. Sampling

3.4.1. Sampling technique

Non-probability sampling was used to explore the common and unique instances (Sandelowski, 2000). The sampling techniques used were purposive and snowball sampling. Snowball sampling required the researcher to rely on participants to identify additional potential participants (Naderifar, et al., 2017).

3.4.2. Sampling size

Various studies state that no fixed sampling size should be adhered to; rather, a flexible approach can be used, provided rich, voluminous data are collected, and population integrity is maintained during recruitment (De Vos et al., 2011). This study aimed to reach data saturation with the participants. According to Hennink & Kaiser, data saturation can be reached in a narrow range of interviews (9-17 interviews) (Hennink & Kaiser, 2022). Therefore, the researcher aimed to conduct at least 15 interviews or until saturation was reached. As the study focused on smallholder and commercial beef farmers, data saturation was reached for both groups after 14 interviews.

Qualitative case studies usually require two levels of purposive sampling (Merriam, 2009). The first level is to choose the case to be studied, and the second is to sample within the case (Merriam, 2009). The first level of

purposive sampling for this study involved selecting the case to be studied. This study used clear inclusion criteria for ethical and practical reasons. The participants could be male or female and were selected according to the following criteria:

- The participant's farm had to be in the Highveld or Midlands area of KwaZulu-Natal. The case study was geographically restricted to the Midlands and Highveld regions of KwaZulu-Natal, as these areas produce the most cattle in the province.
- The participant had to be producing beef cattle. This study focused on beef as a product and not milk; therefore, it targeted beef cattle producers/farmers.
- The participant had to be a smallholder or commercial farmer (i.e., not a subsistence farmer) to ensure the case was as close as possible to traditional industrial engineering systems (such as manufacturing and production lines). A subsistence farmer farms for their own consumption, whereas smallholder and commercial farmers farm for market consumption. Choosing smallholder and commercial farmers enabled more comprehensive data, as farms of different sizes and herd sizes might face different challenges.

Limiting the sample to this specific group ensured the data were complete and accurate. It also aligned the data with the study's purpose and objectives. The second level of purposive sampling was snowball sampling. After identifying key participants who met the study's criteria, the researcher asked the early participants to refer others who met the criteria (Merriam, 2009). Participants were excluded according to the following criteria:

- The participant was excluded if they were not red meat cattle producers, e.g., dairy cattle producers.
- The participant was excluded if they were unwilling to provide informed consent.

Table 1 captures the distribution of the sample. Eight of the farmers' production systems consisted solely of selling weaner calves, while six farmers have diversified their income streams by selling other products or services. Six farmers were classified as smallholders and eight as commercial farmers.

Table 1: Characteristics of the sample

Category	Production System	Frequency	Percentage
Smallholder farmer	Selling of Weaner calves (and old cows)	5	35.7 %
	Diversified system (Selling of Weaner calves and crops)	1	7.1 %
Commercial farmer	Selling of Weaner calves (and old cows)	3	21.4 %
	Diversified system (Selling of Weaner calves and sheep/stud cattle/slaughter of cattle/wildlife hunting operation)	5	35.7 %

3.5. Recruitment of participants

The researcher used an independent person to ask participants who met the criteria to participate in the investigation. The independent person was someone from the farming community who already knew of possible candidates. The independent person explained the aims and objectives of the research along with the roles of the participants. The independent person also explained to the participants that their participation was completely voluntary and that they could withdraw at any time. After obtaining the participants' consent, the independent person shared their contact details with the researcher. Thereafter, the researcher contacted the participant and scheduled an interview date, time, and location.

After the interview, the researcher asked the participant to suggest another possible participant (the snowball technique). The independent person then contacted the potential participants named by the previous participant to explain the study's objectives and goals and obtain their consent. The researcher then contacted the participants. The researcher contacted the participants to introduce herself and suggest an interview date, time, and location.

3.6. Process of obtaining informed consent

Participants received the informed consent form through an independent person electronically (via email or WhatsApp). After the participants had been recruited and contacted, the researcher and the participant met for the interview. The researcher explained in detail what the study entails, the aim and objectives, and the contents of the informed consent form. Ideally, the participant had already signed the electronic consent form, but the researcher brought a hard copy along to the interview just in case. If the participant had not yet signed the electronic consent form, the researcher left the participant to sign the hard-copy informed consent form. The researcher left to avoid placing any pressure on the participant, then returned. The participant was then reminded that they could stop the interview at any time and leave the study. The informed consent forms were backed up on Google Cloud and OneDrive.

3.7. Data generation (Data collection)

The study used semi-structured interviews as the data-gathering method, as this allowed interviewees greater flexibility to express themselves fully (Sandelowski, 2000). It was also an effective method for providing reliable, comparable qualitative data (Sandelowski, 2000). All interviews were conducted in person on the participants' farms, allowing the researcher to engage directly with farmers within their operational context. The interviews were structured according to the interview protocol outline in Annexure B, and probing questions were asked to deepen the investigation of each question. The researcher also gathered field notes, including location notes, descriptive observations on who, where, when, why, and how data were gathered (Patton, 2002).

3.8. Data Recording

The semi-structured interviews were recorded with the participants' permission and transcribed and analysed afterwards. The data were uploaded to a cloud storage system and a computer for safekeeping. The computer was password-protected to protect the participants' information. The data will be saved for 5 years after the research is

completed and then deleted. The researcher will send the results and discussion, or a copy of the dissertation, to the participants by email.

3.9. Rigour

The researcher used the trustworthiness criteria of Guba and Lincoln to ensure data quality and integrity throughout the process (Forero, et al., 2018). Therefore, the researcher used a combination of methods to ensure rigour. These methods included:

- Internal validity - the extent to which research findings match reality (Merriam, 2009).
- Reliability and consistency - Reliability and consistency refer to how well the research can be replicated (Merriam, 2009).
- External validity focuses on how well the findings can be applied to other situations (Merriam, 2009).

3.10. Data Analysis

This study adopted the six-phase cycle for data analysis as described by Braun & Clarke (2021):

- 1) Familiarisation with the data: Since the researcher conducted the interviews herself, she was already quite familiar with the data and had read the interview transcripts.
- 2) Generating initial codes: Initial codes were produced from all the data by organising the data in a meaningful and systematic way.
- 3) Searching for themes: Codes were analysed to determine whether they fit into the initial groups, named themes. A theme was seen as a coherent and meaningful pattern in the data.
- 4) Review themes: The candidate themes of the previous phase were refined. The themes were checked against the full data set and the coded extracts to see if they worked. Sometimes necessary to split a theme into two or three different themes or to collapse two or three themes into one.
- 5) Defining and naming themes: The "essence" of each theme was captured, and each theme was given a precise name.
- 6) Production of the report: The final phase involved compiling the analysis into a concise, logical, and coherent report, which is presented in this chapter.

4. FINDINGS

The 14 participants shared their own experiences, challenges, and solutions for their farms. Many of these difficulties overlapped. The analysis identified eight themes, which were further separated into subthemes as listed in Table 2.

Figure 1 presents a thematic map that visualises the themes and sub-themes. The colours used in Table 2 correspond to the colours found in Figure 1 and Figure 10.

The challenges are later viewed systemically, and their relationships are explored in Figure 10. The following sections discuss the findings for each theme.

Table 2: Themes of the thematic analysis

Theme	The first-level subtheme	2 nd level subtheme
Theme 1: Disease & veterinary health	1A. Tick-borne diseases	- Gall sickness, Redwater, Heartwater
	1B. Controlled/notifiable diseases	- Foot-and-Mouth Disease, Brucellosis, Lumpy skin disease
	1C. Other health issues	- Abscesses, Black quarter, Diarrhoea, Foot rot, Poisonous plant effects, Burnt grass effects
Theme 2: Theft, crime & security	2A. Direct theft	- Cattle theft, Fence theft
	2B. Other crimes	- Snares for illegal wildlife hunting, Fires of malicious arson
Theme 3: Environmental & natural factors	3A. Predators	- Jackals
	3B. Climate & weather	- Drought, Lightning, Unpredictable high rainfall
	3C. Terrain & vegetation	- Bush encroachment, Grazing Palatability
Theme 4: Market access & pricing	4A. Price challenges	- Low/ fluctuating prices, Market manipulation
	4B. Market structure and access	- Single-channel market, Export market closure, Distance to Market
Theme 5: Operational & production	5A. Labour challenges	- Labour availability & competence, Labour costs
	5B. Disease management costs	- Blocking costs, Dipping costs, Other medical costs
	5C. Reproductive challenges	- Older cow problems, Low calving rate
	5D. Input costs	- Various high input costs
	5E. Feed production	- Production of cattle feed
Theme 6: Political & institutional failure	6A. Law enforcement failure	- Stock theft unit corruption, police ineffectiveness
	6B. State service collapse	- State veterinary collapse
	6C. Political threats	- Land claims, Expropriation threats
Theme 7: Infrastructure challenges	7A. Water availability	- Water availability across camps
	7B. Road conditions	- Government road conditions
Theme 8: Financial challenges	8A. Financing/interest rates	- Bank interest rates
	8B. Cash flow management	- Yearly cash flow management

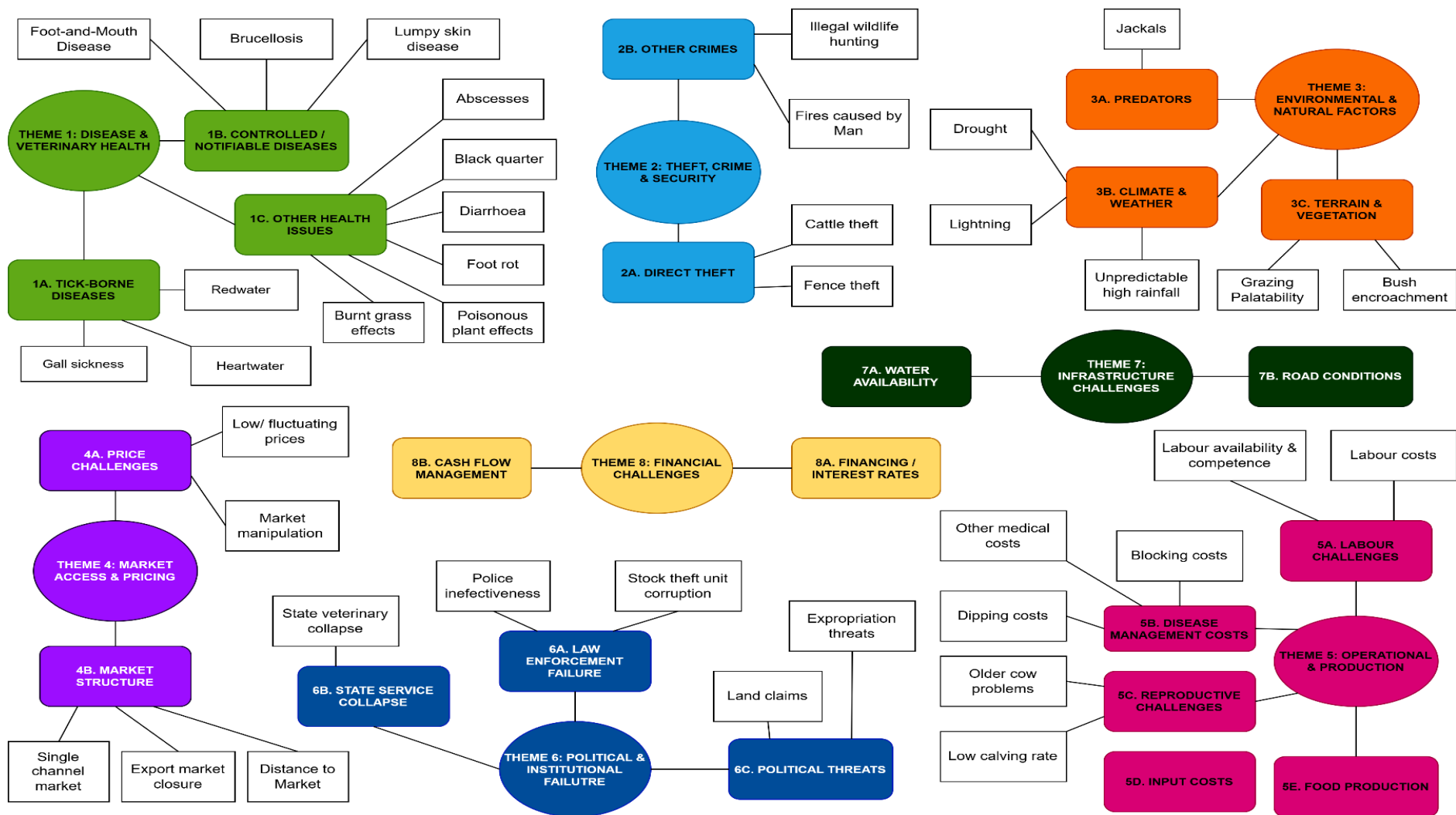


Figure 1: Thematic map of challenges and themes

4.1. Theme 1: Health and Diseases

Animal health challenges were among the most serious and frequently reported issues raised by the participants in this study. Of the 14 participants, 12 reported experiencing challenges with cattle health and disease. Seven participants indicated that this was the most frequent challenge they faced, while five noted that it required constant intervention. Four farmers stated that disease control was the most expensive operation they dealt with, which was related to Theme 5B, Disease Management Costs. Figure 2 illustrates the number of farmers who struggle with cattle health and disease, highlighting the most common diseases and challenges.

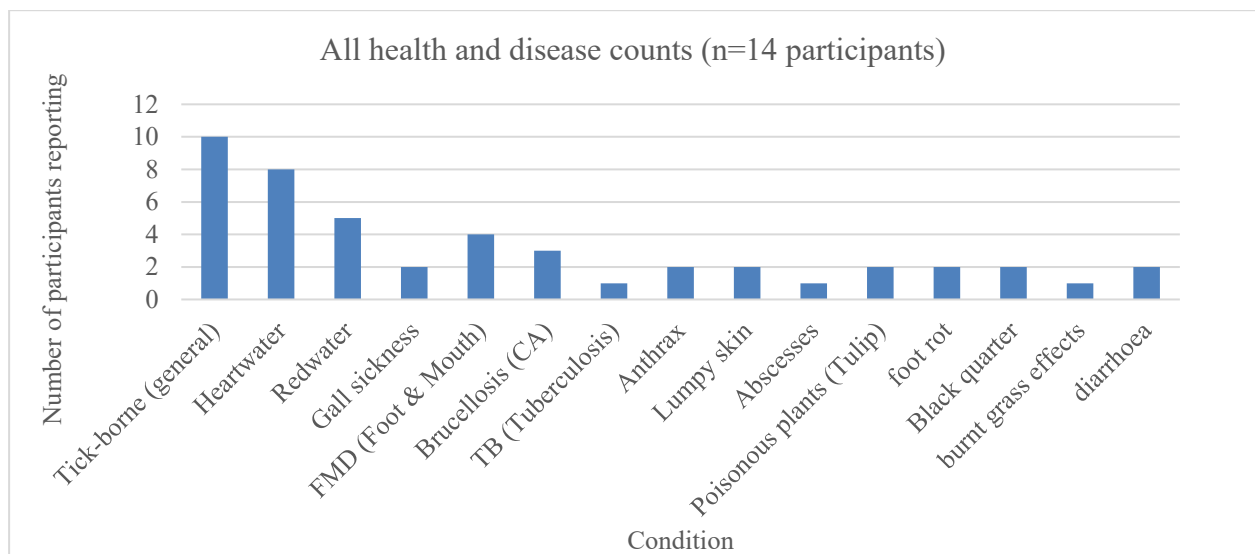


Figure 2: Number of farmers who struggle with cattle health and diseases

The participants emphasised that disease outbreaks could have severe and sometimes catastrophic consequences for herd productivity and farm profitability. Illness-related losses were described as sudden, difficult to control, and capable of removing large portions of a herd in short periods. Farmers also highlighted the long recovery times required to replace breeding animals, thereby extending production lead times and reducing effective herd capacity.

4.1.1. Tick-borne diseases (1A)

Ten participants mentioned tick-borne diseases as a challenge. The three tick-borne diseases included redwater, heartwater, and gall sickness. These diseases are more common in summer than in winter, as ticks are more prevalent in higher temperatures and after high rainfall (3B Climate and Weather). Farmers' control measures differ. Farmers reported using different tick-control strategies, ranging from visual monitoring and selective dipping to scheduled, seasonal, and more natural approaches:

- Seasonal approach: Farmers dipped more often in summer than in winter, moving from once every 6 weeks to once every 3 weeks (Participant 12).

- **Scheduled preventive programme:** Some farmers used specific schedules, following a veterinary-approved program, usually ranging between 7 and 10 days between each dip (Participant 9). Farmers also acted before the heartwater season starts or with long-acting ingredients.
- **Natural approach:** Some farmers have moved away from traditional dip medicines because ticks in the area have developed resistance to certain chemicals. Therefore, farmers only dip when they can visibly see ticks on the cattle. The rest of the time, the farmers use a natural ingredient, specifically an aloe-based lick to help keep ticks away (Participant 7).

Together, the participants' experiences demonstrated a mix of control strategies (from scheduled dips to seasonal and natural strategies), each with different implications for cost, labour, chemical resistance, and herd health outcomes. The participants have also explained that the ticks can become resistant to treatment, making the challenge even harder to solve.

4.1.2. Controlled/notifiable diseases (1B)

Controlled and notifiable diseases are infectious conditions that participants identified as subject to statutory control and reporting. This included Foot-and-Mouth Disease (FMD), Brucellosis (CA), Tuberculosis (TB), Anthrax, and Lumpy Skin. The participants reported that these diseases had serious regulatory and economic consequences. Outbreaks of these diseases often trigger compulsory reporting and, in some cases, culling or carcass disposal, further reducing farmers' income. Farmers explained that these outbreaks also led to market restrictions, including being forced to quarantine their animals or being limited to a single abattoir in their area. These constraints reduced market prices and forced the slaughter of valuable genetics (Participant 10).

The participants attributed the spread of these diseases to loss of state veterinary control, poor enforcement, and the movement of neighbouring cattle (Participant 14). They noted that movement permits and strict checks had fallen away, once limiting disease spread. Therefore, animals could be brought from disease-prone areas: "A person can bring an animal from the thornveld and bring it here and come and give me diseases... it has just been an absolute breakdown of State control or veterinary control" (Participant 10).

4.1.3. Other health issues (1C)

In addition to tick-borne and notifiable diseases, the participants reported some other health problems affecting their cattle. These problems included abscesses, poisonous plants, foot rot, black quarter, diarrhoea, and the effects of burnt grass. Some of these conditions, like abscesses, black quarter, diarrhoea, and foot rot, were described as treatable with timely medical care. In contrast, the consumption of burnt grazing and poisonous plants was viewed as more severe and difficult to manage. Participant 14 stated that the consumption of burnt grass could cause miscarriage, while Participant 12 mentioned that tulip consumption can lead to the loss of cattle.

Participants linked foot rot, black quarter, and diarrhoea to periods of high rainfall (Participant 5, 4, 9). Kraaling (penning) practices were also associated with increased cases of foot rot and diarrhoea, which then led to the loss of two to three calves per season for Participant 9.

4.2. Theme 2: Theft, crime, and security

Participants frequently reported theft, crime, and security challenges as major threats to farm operations. Of the 14 participants, 8 reported experiencing theft or security-related challenges in various forms. Three participants described theft as their most frequent challenge, while two noted that policing failures required the most intervention. For five farmers, security-related expenses (particularly labour costs for guards, daily cattle monitoring, and fencing materials) were their most expensive operational challenge. Figure 3 illustrates the distribution of theft, crime, and security challenges across the participant group, showing the frequency of different security threats.

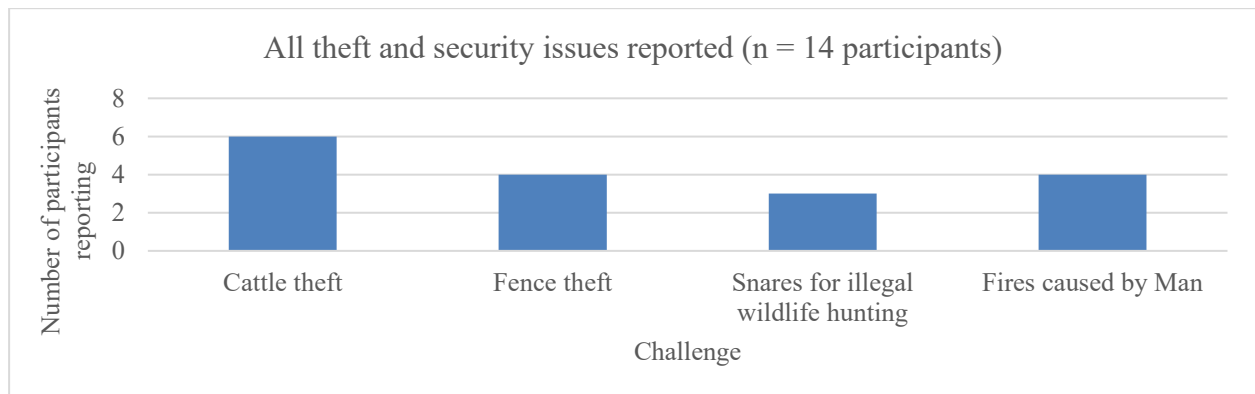


Figure 3: Number of farmers who struggle with security issues

Participants described these challenges as having severe consequences for both farm productivity and personal well-being. The theft caused direct financial losses through the loss of animals and breeding stock. The ongoing security threats caused stress, disrupted normal farming routines, and took time and labour away from productive activities. The need for constant vigilance and additional security measures added pressure to already-constrained agricultural systems.

4.2.1. Direct theft (2A)

Seven farmers (50%) specifically reported cattle theft as a challenge. Theft typically results in a complete loss for the farmer, as stolen animals are rarely recovered. Participants described two main forms of theft: first, slaughter theft, where animals are taken to be slaughtered quickly; and second, theft for resale, in which animals are moved through criminal markets (Participant 8).

Thieves usually operate in organised groups, and the scale of a single theft event can be large. A farmer explained that they can lose 10 to 15 cattle per theft case (Participant 10), while another lost up to 17 animals at once (Participant 14). Beyond immediate capital loss, theft reduces herd productivity and destroys breeding programmes, making recovery slow and costly.

Three farmers experienced repeated fence theft, which weakened biosecurity and allowed neighbouring animals to enter their farms (Participants 14, 9, 11). Continuous fence replacement is expensive, and to reduce losses,

some farms employ guards and herd boys and adopt constant monitoring routines (Participant 9, 11). These protective measures create ongoing labour and operational costs and also take up time from productive farming tasks.

The human risks and the follow-up costs of theft are significant. Some farmers described dangerous recovery attempts when cattle are taken: "they are armed, and you are not armed... then you have to pay for very expensive advocates to come and protect you and keep you out of jail" (Participant 10). Several participants linked cattle theft to broader social factors such as unemployment and weak police service; the policing issue is addressed in Theme 6 (Law enforcement failure).

4.2.2. Other crimes (2B)

Four participants reported losses and damage caused by artificial fires, while three described illegal hunting and poaching as recurring problems. Farmers said that fires damaged grazing resources and caused unexpected feed costs to compensate for lost pastures (Participant 11). Several farmers noted that fire risk required daily monitoring, particularly during dry (winter) seasons, adding to the usual labour demands and operating costs.

Illegal hunting and poaching caused multiple operational impacts. On mixed game-and-cattle farms, poaching was often accompanied by cutting fences, which aggravated the biosecurity and stock-escape problems discussed in 2A direct theft. The hunters' dogs also chased livestock, causing stress, injuries, and occasional losses, while traps set for wild game sometimes trapped cattle. A farmer reported losing four cows to snares in a single year (Participant 11). Poaching incidents also meant that farmers had to abandon other tasks to attend to them (Participant 11).

Some of the security measures implemented to combat theft created their own operational challenges. Some farmers resorted to kraaling (penning) cattle at night to prevent theft. However, this defensive measure unintentionally created a vicious cycle: overnight penning in muddy, manure-laden conditions led to foot rot among cattle, creating additional disease management challenges and veterinary costs (see Theme 1, Other health problems).

4.3. Theme 3: Environmental and natural factors

Many farmers struggled with environmental and natural factors. Of the 14 participants, nine reported experiencing challenges related to wildlife, climate, weather, or terrain. Three participants specifically identified predators as a recurring problem, while eight farmers reported difficulties related to climate and weather conditions, including drought, excessive rainfall, and lightning. In addition, four farmers emphasised terrain and challenges like steep or inaccessible topography, bush encroachment, and seasonal changes in grazing quality. Figure 4 illustrates the distribution of environmental and natural factor challenges across the participant group, highlighting the range and frequency of constraints experienced.

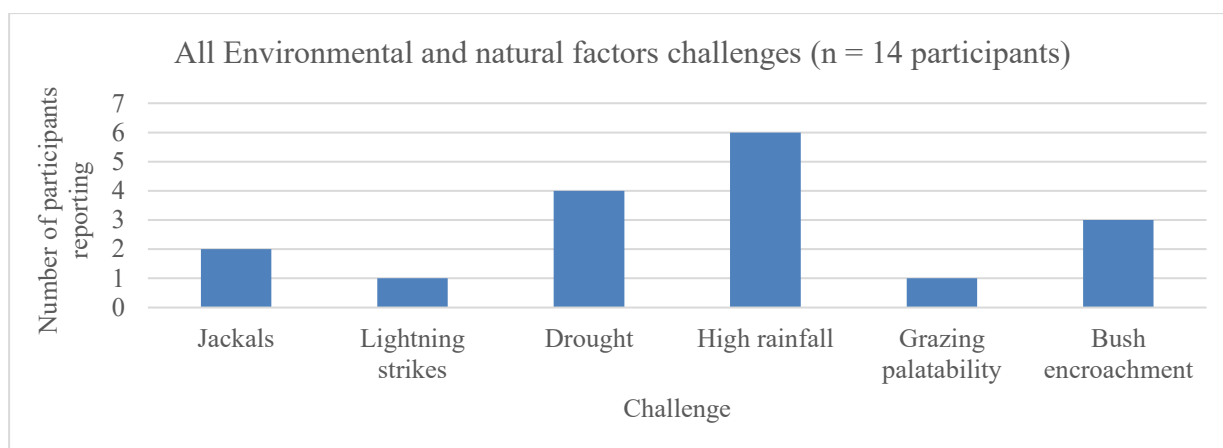


Figure 4: Number of farmers who struggle with environmental issues

Participants described these environmental challenges as usually unavoidable and sometimes unsolvable. The terrain challenges could not be altered, requiring farmers to adapt their operations rather than eliminate the problem. Weather-related challenges, including drought and lightning, are entirely beyond farmers' control. Even predator management, while mitigated through culling, was an ongoing battle rather than a solvable problem.

4.3.1. Predators (3A)

Three participants identified predators as a challenge, with two farmers specifically mentioning jackals. Cattle losses occurred primarily during the calving season, typically between August and December, when young calves were most vulnerable. A farmer explained that jackals target calves during this period because cows are often lying down and unable to defend themselves effectively (Participant 1).

Although the losses caused by jackals were not described as constant, they contributed to larger annual rates of cattle mortality of approximately 3 to 5 % reported by farmers. Each calf lost was a significant economic setback, with farmers emphasising that it takes two to three years for a calf to reach productive age. As a result, predator losses were viewed not only as immediate stock losses but also as long-term setbacks to herd growth and productivity.

The participants explained that it is hard to handle the jackals and that their options were limited. Lethal control through culling was described as the primary (and often the only) available response: "There is no other way, you just cull them" (Participant 1). Farmers noted that while culling could temporarily reduce losses, predators remained a persistent challenge.

4.3.2. Climate and weather (3B)

Eight participants reported climate- and weather-related challenges, including lightning strikes, drought, and periods of heavy rainfall. These factors were described as uncontrollable, forcing farmers to adapt their operations rather than prevent losses altogether.

Lightning strikes, although rare, sometimes killed cattle on the spot, causing sudden and catastrophic losses when they occurred (Participant 14). These incidents were considered unavoidable and beyond the farmer's control.

Four participants reported severe drought, which affected herd size, productivity, and recovery time. A farmer explained that drought conditions forced him to reduce herd numbers to maintain the farm's grazing capacity (Participant 2). Reduced stock levels, combined with declining calving percentages, caused significant production losses: "Drought is terrible... you have to cut your numbers right down, and your calving percentage goes right down, so you lose quite a bit in a drought" (Participant 5).

Another farmer explained that drought increased input costs because they had to buy additional feed and hire labour to distribute the bales (Participant 6). Recovery from drought-related losses was described as slow, often taking two to three years.

High rainfall also created operational challenges. Six participants linked seasons of heavy rainfall to increased disease, particularly tick-borne diseases, and to other health issues discussed earlier in Theme 1. Rain also disrupted normal farm operations, limiting farmers' ability to work in the fields or monitor cattle. Although rainfall was necessary for grazing and crop production, its timing and intensity created trade-offs between production benefits and operational disruption.

4.3.3. Terrain and Vegetation (3C)

Four participants reported terrain and vegetation constraints, which were described as persistent area-specific challenges that limited how farming operations could be carried out. Unlike weather-related events, these challenges were seen as permanent features of the farm environment, forcing farmers to adapt their operations to the terrain.

In the farming systems typical of the KwaZulu-Natal Midlands and Highveld, cattle generally graze freely across large pieces of land with minimal daily supervision, often covering hundreds of hectares. This means that locating and gathering cattle requires farmers or labourers to travel across the entire farm on foot or horseback. Difficult terrain increased labour and time requirements. A farmer explained that steep, inaccessible areas made it impossible to use vehicles or horses, requiring cattle to be gathered on foot, a process that could take up to 2 days (Participant 13). This increased labour demands and reduced the time available for other farming activities.

The changes in Vegetation also reduced the efficiency and carrying capacity of grazing. Several participants mentioned bush encroachment as a growing problem that limited available pasture. One farmer described bush clearing as necessary but labour-intensive (Participant 4). Although deforestation could restore grazing over time, it would add to the workload.

Seasonal changes in grazing quality also affected cattle performance. A farmer noted that changes in pasture palatability during different seasons required nutritional supplementation (Participant 13). This led to higher input costs and greater management complexity.

4.4. Theme 4: Market access and pricing

Market access and pricing challenges represented the challenges farmers faced when selling cattle. Of the 14 participants, six had experienced market-related constraints. Four farmers identified low or fluctuating prices as a major challenge, while two described market manipulation or buyer dominance. Other challenges included the distance to markets, export closures, and quarantine-imposed restrictions that limited farmers to single marketing channels. Figure 5 illustrates the distribution of market access and pricing challenges between the participant group, showing the frequency of different market-related constraints.

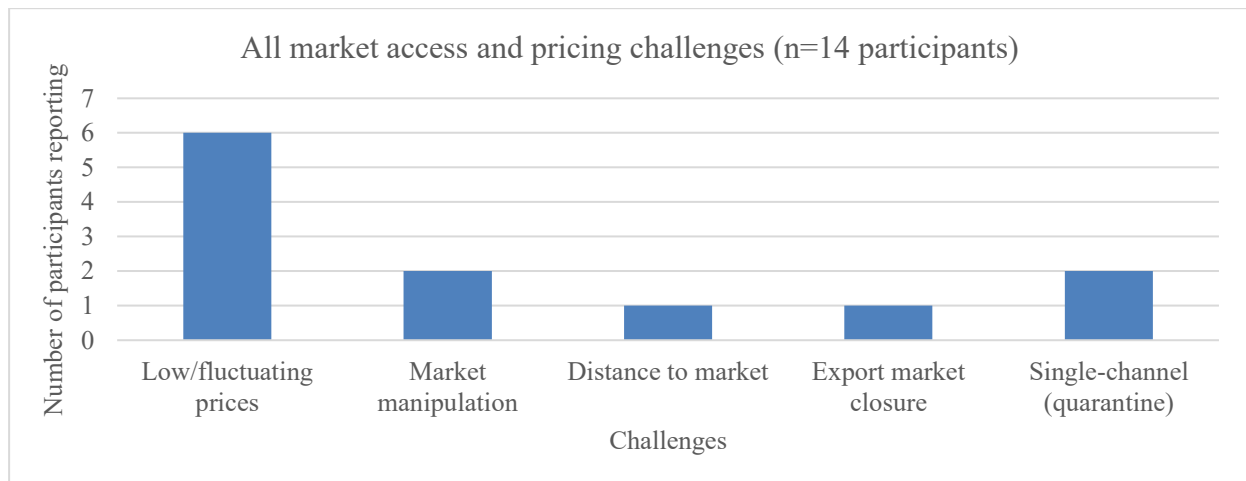


Figure 5: Number of farmers who struggle with market issues

Two participants indicated that the decline in prices was their most frequent challenge, with prices dramatically declining from previous years. The participants described buyer manipulation and the loss of traditional pricing structures that had provided stability. Quarantines and export restrictions caused by diseases compounded these challenges by limiting market access and forcing farmers to poor sales.

4.4.1. Price challenges (4A)

Six farmers (29%) struggled with low or fluctuating market prices. One farmer noted that heifer prices dropped from R30/kg to R23-26/kg following a Foot-and-Mouth Disease outbreak (Participant 8), demonstrating how quickly disease outbreaks could crash market values.

The root causes for the low prices varied. One farmer explained that market control played an important role: "Company X monopolised the beef industry now. They bought a triple-A feedlot in New Hanover... they have about 60% of the weaner market. So, they pushed the price down hugely two years ago" (Participant 2). Another farmer explained that demand for red meat has been declining, as it is seen more as a luxury, and that people would rather buy cheaper meat like poultry (Participant 1).

4.4.2. Market structure and access (4B)

The structure and accessibility of the market also made it harder for farmers to secure fair prices. One farmer struggled with the distance to the market, noting that the nearest markets were about 70 km away, with high transport costs, and that the distance to alternative markets was twice as far. Therefore, the farmer was limited to accepting the prices in that market. Poor road conditions worsened this problem by increasing travel time and vehicle wear (Participant 3).

Transport distance also affected animal welfare and product quality. One farmer explained that long journeys exposed cattle to stress, bruising, and physical damage, which then reduced meat quality and value: "Any animal that is transported undergoes bumps and knocks... and that affects the quality of the meat eventually" (Participant 3).

Disease-related quarantines also severely restricted access to markets, as markets and abattoirs closed for that period. A stud farmer described being limited to a single abattoir during quarantine, eliminating price competition (Participant 10). For stud operations, this meant high-value animals and genetics were forced into normal slaughter markets, where farmers received much less than the animals were originally worth, resulting in financial losses. Export restrictions further reduced market opportunities. One participant noted that the Foot-and-Mouth Disease epidemic in South Africa prevented exports of cattle and embryos to other countries. This eliminated access to premium international markets and decreased revenue potential (Participant 10).

4.5. Theme 5: Operations and production

The challenges of operations and production were the most common and financially significant theme identified in this study. Among the 14 participants, 13 reported operational challenges in multiple categories. Specifically, 11 farmers (78.6%) identified disease management, labour, feed production, reproductive performance, and rising input costs as their largest operational expenses. Figure 6 illustrates the distribution of operations and production challenges across the participant group, showing the frequency and types of operational cost pressures faced.

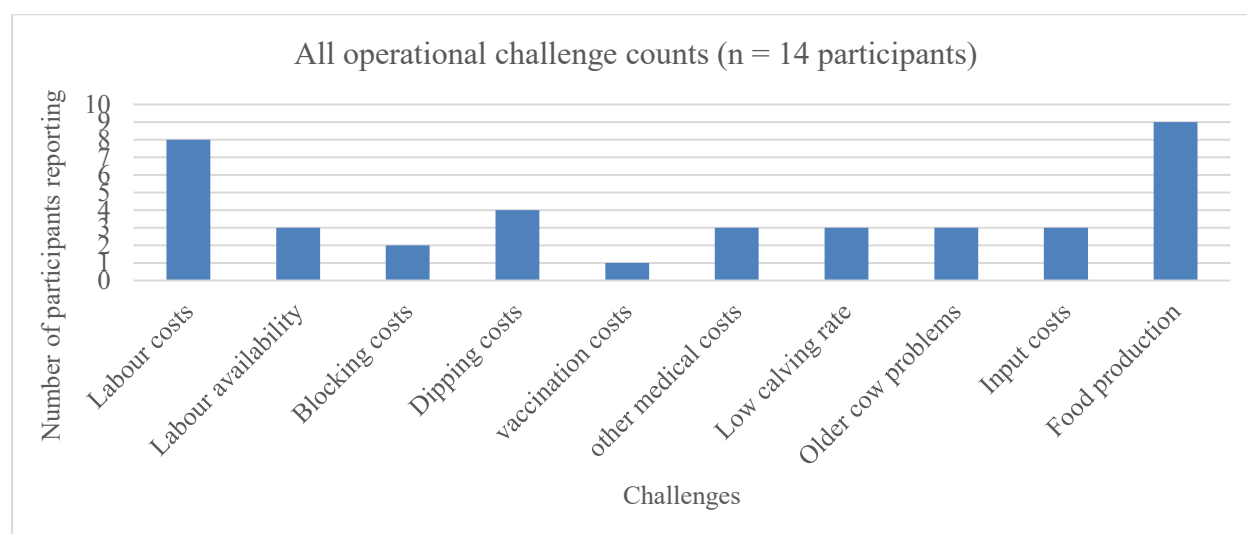


Figure 6: Number of farmers who struggle with operational and production issues

The financial impact of these operational challenges was severe and often overwhelming. The severity of the challenges stemmed from their financial burden, as well as their snowballing and continuous nature. Disease management and labour costs were a regular and constant expense, while reproductive challenges and feed limitations reduced productive output (the number of calves and the weight of cattle) and delayed financial recovery. Rising input costs worsened cash flow stress, especially when output prices remained stagnant or declined.

4.5.1. Labour challenges (5A)

Five farmers noted labour as their most expensive operational challenge. For several participants, high labour costs were due to the addition of security guards rather than to routine farming activities. One farmer explained that he employed six guards to protect cattle and game, with additional expenses including fuel for their vehicles, maintenance, etc (Participant 11). These labour demands were directly related to theft, fires, and poaching, with farmers explaining that security needs had become a permanent part of their operating costs.

The availability of labour also limited the farms' operations. A smallholder farmer reported being unable to find workers in his area, limiting his capacity to carry out everyday farming activities (Participant 4). For other farmers, labour regulations further increased cost pressures. One participant noted that minimum wage increases outpaced inflation while beef prices declined (Participant 10), leaving farmers in a position where costs increased faster than income.

Some farmers explained the loss of flexibility in labour management. Due to regulatory laws, seasonal employment was no longer possible. Therefore, forcing farmers to employ staff permanently regardless of seasonal work patterns (Participant 10). This meant that labour costs became fixed rather than adjustable, increasing costs during periods of low production or poor market conditions.

4.5.2. Disease management costs (5B)

Farmers repeatedly identified disease management costs as their most expensive operational costs. Several participants described dip, vaccination, and blocking as their single largest recurring expense. A farmer explained that "to block a whole herd of 200 cows, 300 cows, is going to cost you anything from R20 000 to R30 000" (Participant 1), highlighting the high cost required for basic disease prevention. For many farmers, these already high disease control costs were worsened by the failure of state veterinary services. A farmer explained that government vaccine production could not meet demand, forcing farmers to purchase vaccines privately at significantly higher prices (Participant 10).

Some farmers compared South African disease control costs with those of neighbouring countries. One participant noted that vaccination against Foot-and-Mouth disease in Botswana cost much less than what South African farmers were required to pay per animal (Participant 10). These price differences place South African farmers at a competitive disadvantage and increase operating costs.

In general, the participants described disease management as an unavoidable expense. Even when market prices were low or cash flow was limited, disease control could not be reduced without risking major losses.

4.5.3. Reproductive challenges (5C)

Three farmers reported reproductive challenges that directly affected herd productivity and long-term profitability. The main issue was older breeding cows, particularly udder problems that limited milk availability for calves, which could cause calves to starve because they were not getting enough milk (Participant 13).

The participants noted that a cow's productive lifespan was limited, with a farmer explaining that a cow typically produces between 9 and 11 calves before it needs to be replaced (Participant 14). When cows did not calve annually or lost calves due to age-related issues, the financial consequences were immense.

These reproductive losses were particularly expensive given the time required to replace breeding animals. Farmers explained that raising a replacement heifer to a productive age takes between two and three years. During these years, farmers again spent money on inputs without any production returns. Therefore, reproductive challenges reduced effective herd output while simultaneously increasing long-term cost exposure.

4.5.4. Feed production (5D)

Feed production and supplementation costs varied across farming systems. For example, a small farmer managing an intensive system with approximately 50 cows on 30 hectares identified feed production as both the most frequent and the most expensive challenge (Participant 7). Maintaining this stocking rate required annual feed production from both summer and winter crops to support the herd. One farmer noted that planting feed was expensive, and with the price of electricity, fertiliser, and fuel rising every year, it made feed production even more difficult to maintain (Participant 7). This was made worse, particularly since the price of beef did not increase by the same percentage as their input costs (Participant 7). This mismatch between rising input costs and stagnant market prices continues to put pressure on cash flow and overall profitability.

For farmers operating larger systems, feed challenges were less, but could become severe during environmental hazards. For example, farmers had to buy additional feed after their grazing was destroyed by fires or drought (Participant 11). Supplementary feeding also increased labour requirements, as more time and workers were needed to distribute the feed, further adding to operational costs.

4.5.5. Input Costs (5E)

The high input costs compressed farmers' cash flow margins. Farmers repeatedly stated that input costs had increased significantly over time, while beef prices had not. A farmer noted that input costs had doubled since 2015 (Participant 7). Energy, fertilisers and fuel have been repeatedly identified as major contributors to rising costs. This was made worse, particularly since the price of beef did not increase by the same percentage as their input costs (Participant 7). This imbalance meant that even when production levels were maintained, profit margins continued to shrink.

4.6. Theme 6: Political and state institutional failure

This theme includes the state's governance and institutional failures, which created challenges beyond farmers' control. Of the 14 participants, 8 had experienced challenges stemming from political or institutional failures in various forms.

Six farmers (43%) identified poor law enforcement as a major problem; three reported a collapse of state veterinary services; and four described political threats, such as fears of land expropriation and labour tenant claims. Figure 7 illustrates the distribution of political and institutional failure challenges between the participant group, showing the frequency and types of governance failures experienced.

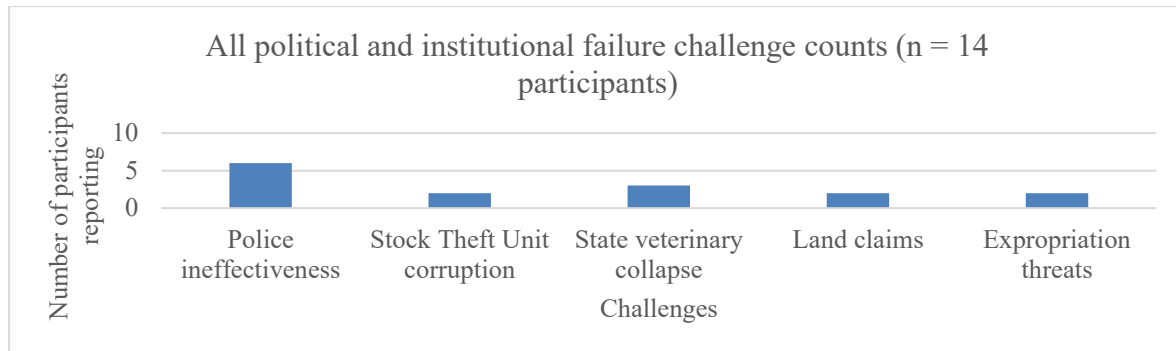


Figure 7: Number of farmers who struggle with political and institutional issues

Farmers described situations in which basic state functions (such as law enforcement, disease control, and protection of property rights) were lacking. These failures increased exposure to crime, facilitated the spread of disease, restricted market access, and created deep uncertainty about land tenure and long-term planning. Several farmers emphasised that even well-run farms became vulnerable when the institutional systems around them failed.

4.6.1. Law enforcement failure (6A)

Six farmers (43%) reported police ineffectiveness, specifically simple incompetence or active corruption. A farmer explained that sometimes, when they contacted the police, the police did not come, and therefore farmers took the work upon themselves (Participant 14). Another farmer mentioned bluntly that when he reported theft, the police did nothing about it (Participant 9).

According to the participants, corruption extended to specialised units that should have provided support to farmers. Two farmers identified corruption within the Stock Theft Unit, one explaining that he had to do the work that the SAPS Stock Theft Unit should have done. The farmer also stated that, in many cases, some of those stock theft members are part of the problem (Participant 10). Another participant reported that "the last people you tell are stock theft units. If they know you are going to look for cattle, then the cattle disappear" (Participant 11), suggesting that in some cases, police were not simply failing to help, but actively participating in the theft.

These law enforcement issues forced farmers to become their own police force by conducting investigations, tracking stolen cattle, and confronting armed thieves (Participant 10). The result was that farmers employed private guards, conducted armed recovery operations, and built reputations for violence as preventive measures.

4.6.2. State service collapse (6B)

Several participants described that the collapse of state veterinary services directly affected disease control and market access. Three farmers identified this collapse as a critical institutional failure that damaged their operations. Farmers reported that state bodies could not reliably produce vaccines, could not conduct necessary tests, and had effectively lost control over animal movement and disease containment.

A common challenge concerned the supply and quality of vaccines. A farmer in the study argued that the state supplier could not keep up with demand for vaccine production (Participant 10). That failure pushed farmers into private markets for vaccines, which are much more expensive (Participant 10). This challenge affects both vaccine availability and cost.

The participants also explained the collapse of the testing and permit systems that once controlled animal movement. Without working testing laboratories and movement controls, farmers said that disease spread became harder to trace and contain. A farmer described how disease strains could travel long distances unchecked, noting that Foot-and-Mouth Disease DNA tracking showed that a strain had moved from Limpopo to the Eastern Cape (Participant 10). Farmers explained that the collapse of these systems meant cattle could move between regions without proper control, thereby increasing the spread of disease.

The market consequences were immediate and severe. A farmer mentioned that neighbouring countries have stopped exporting live cattle and embryos from South Africa due to South Africa's Foot-and-mouth disease status (Participant 10). Quarantine measures (to contain diseases) also forced farmers into limited local markets. One stud farmer explained that for producers of high-value breeding stock, that meant animals worth far more on the open market were reduced to normal stock prices under quarantine conditions.

Farmers noted that while strong farm biosecurity could reduce some of the risks, individual measures could not fully compensate for national failure. In other words, without effective state veterinary control, market opportunities, and national biosecurity remained at risk regardless of what a single farm did.

4.6.3. Political threats (6C)

Four farmers described political threats that created ongoing uncertainty and fear. Two farmers mentioned threats of land seizure, while the others reported land claims and pressure from local land authorities. Farmers explained how these threats affected day-to-day decisions about investment, land use, and long-term planning.

The participants gave examples of how the legal and political environment could be used against landowners. One farmer explained how easy it was for claims to be made: "The legal qualifications are so low that... anyone can just come on and claim they have got a legal right on your property. And they do not even have to come along with any documentation" (Participant 10). The participant also said that a new law allowed ownership to transfer on the day a notice was served. Therefore, the person claiming the farm has the right to make changes on the farm immediately (Participant 10). The farmer explained that the long delays and legal costs made it unrealistic for many farmers to rely on the courts (Participant 10).

Land claims from labour tenants and pressure from large neighbouring communities also created challenges. A farmer described sharing a 25 km border with a communal trust and feeling constant pressure to move or share his grazing (Participant 2). Another farmer used a proactive strategy, selling 70 hectares to 5 of his labourer families to eliminate future claims (Participant 10).

4.7. Theme 7: Infrastructure challenges

Infrastructure limitations affected a small number of participants but had clear operational consequences for those farmers. Of the 14 participants, only two reported infrastructure problems. One farmer struggled with water availability and distribution between camps, while another farmer mentioned poor road conditions that worsened their market access problems. Although these issues were not mentioned often in the sample, they created additional costs and increased labour and time requirements. Figure 8 illustrates the distribution of infrastructure challenges in the participant group, showing the frequency and types of challenges experienced.

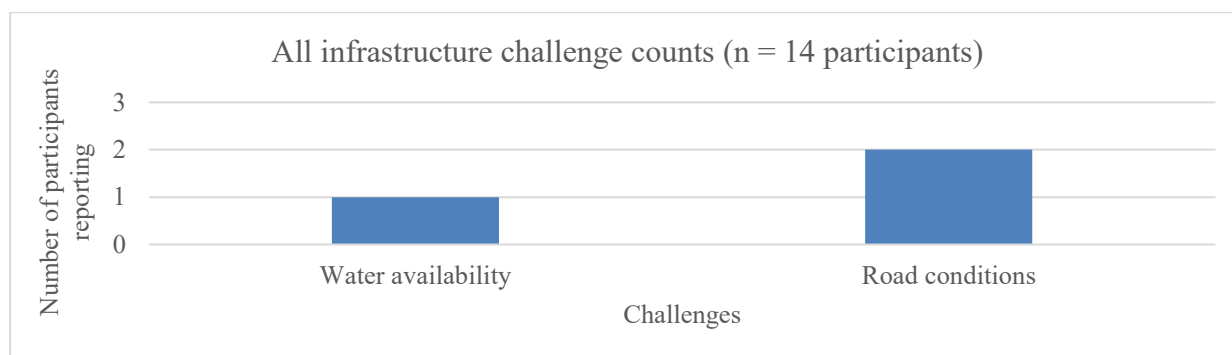


Figure 8: Number of farmers who struggle with infrastructure issues

4.7.1. Water availability (7A)

A farmer whose farm was at a higher elevation (in the mountains) described the water system he needed to supply multiple camps. The operation relied on three sources, specifically wells (solar-powered), rainwater dams, and a river to ensure that there was enough water supply between the camps (Participant 4). Installing and maintaining the wells, pipes, and pumps was expensive, and the farmer described it as a recurring cost (Participant 4). The farmer noted that the water infrastructure remained an ongoing cost that increased annually (Participant 4).

Water problems also impacted animal safety. The farmer had multiple calf drownings caused in two ways, namely, larger animals pushing calves into drinking troughs and calves becoming trapped in clay or mud around dams. To reduce these losses, the farmer made practical modifications. He created partition walls in stone troughs and fenced off dangerous dam edges, which reduced drownings, but added further labour and capital costs (Participant 4).

4.7.2. Road conditions (7B)

Two participants linked poor road conditions to higher transport costs and reduced market access. Poor roads increased travel times and vehicle wear, increasing the cost of bringing stocks to market (Participant 3). A farmer noted that

rough transport also affected animal condition, causing bruises and stress that affected meat quality: "any animal that is transported undergoes bumps and knocks... and eventually affects the quality of the meat" (Participant 3). In these cases, poor roads worsened the market-distance challenges already described in Theme 4, adding both direct transport costs and indirect product-quality losses.

4.8. Theme 8: Financial challenges

A small number of participants mentioned problems with finance and access to capital. Four of the 14 participants faced financial challenges. Three farmers specifically mentioned struggles with cash-flow patterns, while two were severely affected by financing and high interest rates. A farmer explained the importance of finance bluntly: "Of all things, finance makes or breaks you" (Participant 8). Therefore, when financial challenges arose, they threatened the viability of the entire operation rather than being merely a minor operational inconvenience. Figure 9 illustrates the distribution of financing challenges in the participant group, showing the frequency and types of challenges experienced.

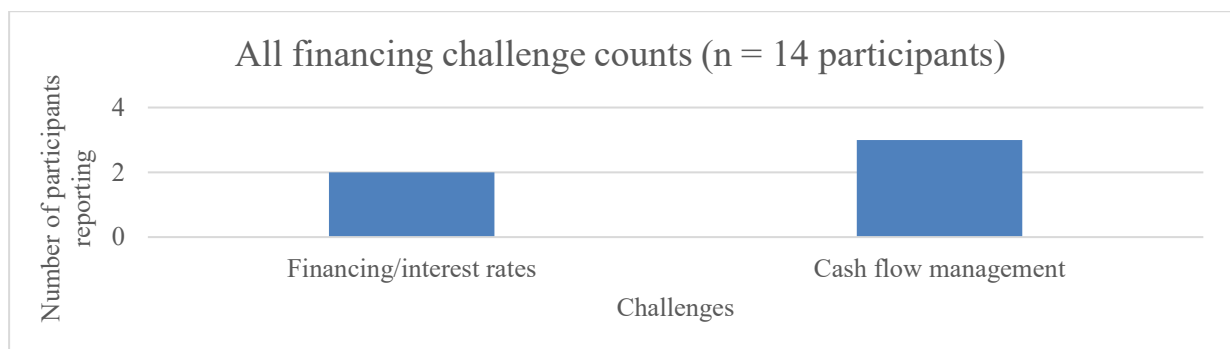


Figure 9: Number of farmers who struggle with financing issues

4.8.1. Cash flow management (8A)

Three farmers said cash flow was a constant worry when they only sell weaners once or twice a year. The problem is with timing: a farmer explained that farmers traditionally sell once or twice a year when doing weaners, and still have to manage their cash flow in between sales (Participant 5).

Some farmers moved to other enterprises for the steady cash flow. A participant explained that some farmers will swing to dairy just because of these cash flow constraints (Participant 8). Those who stayed used careful planning to manage their cash flows. One farmer kept monthly cash flow updates using Pastel accounting software and bank templates (Participant 2). Others tried to increase sales frequency by selling smaller lots locally or running monthly sales to smooth income (Participant 8). This meant that the farmer had to choose between "monthly sales vs twice yearly where possible" and selling "undesirable products (heifers) monthly to locals" while "feeding and growing oxen for additional sales" (Participant 8).

4.8.2. Financing/ Interest rates (8B)

Two farmers described how the loans had changed and become much harsher. One farmer said his bond rate rose from 8% to 12.75% over 18 months, adding about R80,000 per month in repayments (Participant 2). That kind of jump makes a big difference in a farm's cash flow.

Farmers also said that long-term (e.g., 25-year) affordable loans have largely disappeared, and commercial banks now lend for shorter terms and require larger cash deposits, specifically 30-40% cash security upfront (Participant 8). Because beef farming is capital-intensive, some farmers sought alternatives, namely, share arrangements, investors seeking tax write-offs, or renting land instead of buying (Participant 8). A farmer explained that it is not really possible to purchase a farm, buy cattle, and try to make a living, as it would be too expensive (Participant 8).

5. DISCUSSION

The analysis revealed clear differences in the frequency and intensity of challenges, as well as in how strongly they affected cattle production across the eight themes. Some challenges were widespread and had major operational and financial consequences, while others were less common and more situational. Significantly, the findings showed that these challenges rarely occurred in isolation. Instead, problems in one area often triggered knock-on effects in others, meaning that actions taken to address a single issue could influence several parts of the red meat production system, sometimes in unintended ways.

Figure 10 illustrates the relationships between subthemes and the farmers' responses, demonstrating how challenges and decisions spread throughout the production system.

Each subtheme appears in a small, coloured bubble, with its name and number (e.g., 1A Tick-borne diseases). The colours of the subtheme bubbles correspond to the subtheme colours of the thematic map in Figure 1. The only subtheme that was not shown is Theme 8B, Cash-flow management, as this theme occurs throughout the system at every stage. It is important to note that no farmer experienced all these challenges simultaneously. The diagram groups the experiences of all 14 participants to present the full range of pressures influencing cattle production.

The map demonstrates that various challenges lead to a small number of specific outcomes: cattle loss, production loss, higher costs, reduced profit, and negative impact on farmer well-being. These outcomes are marked in larger bubbles. This pattern indicates that the primary issue is not a single problem, but rather the cumulative impact of multiple interconnected challenges that create financial and operational pressure. The two main effects of these challenges were a negative impact on farmers' well-being (black bubble) and reduced profits (large green bubble), as all other challenges eventually lead to these two bubbles, with no arrows extending beyond them.

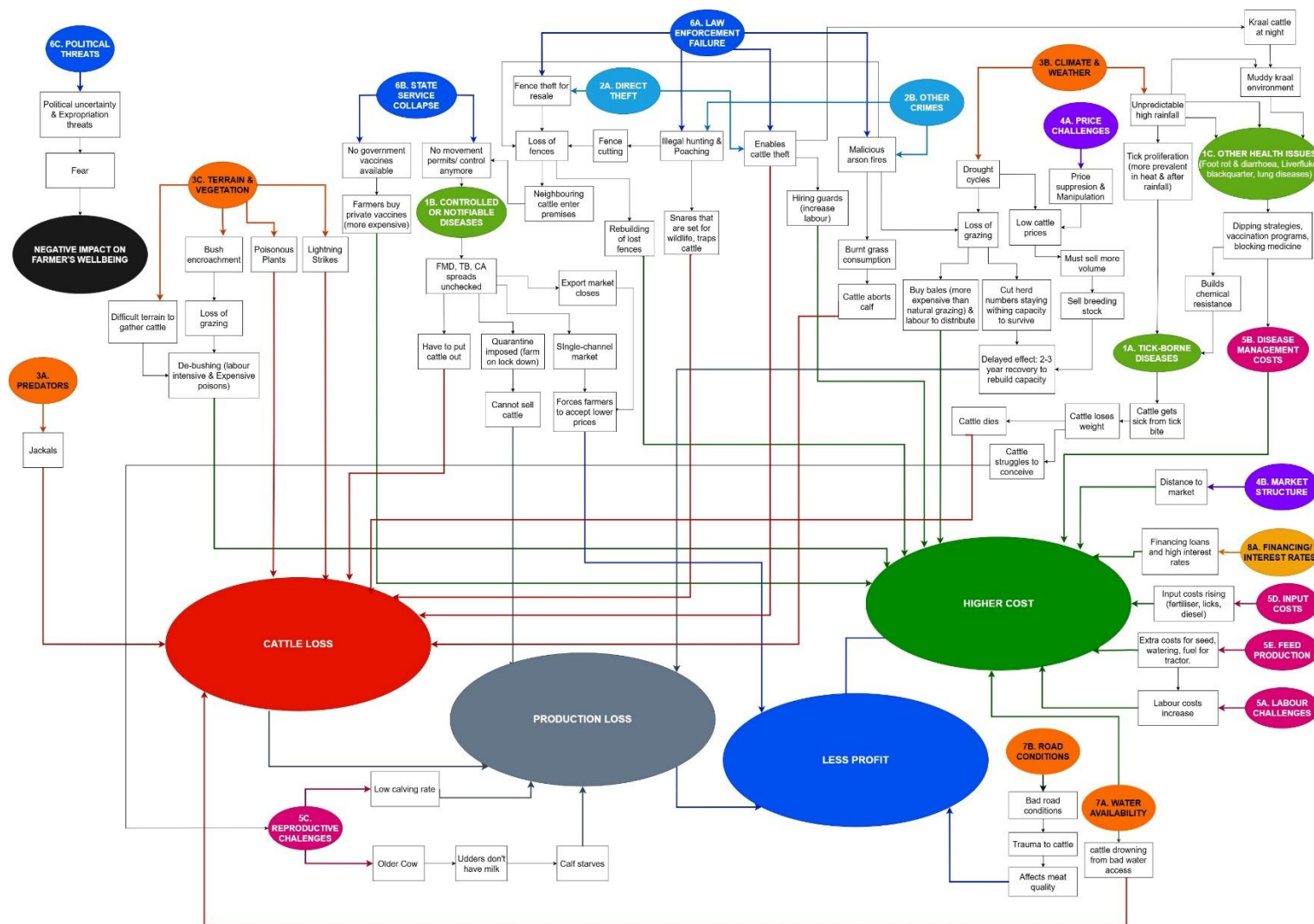


Figure 10: Relational diagram illustrating cascading challenges within the cattle production system

Some relationships created loops and worsened and reinforced the theme's overall effect. When police were failing, theft increased, and farmers lost cattle. Those losses cut income, making it harder to pay for fence repairs, guards, or other preventive measures, so the farm becomes easier to steal from, and the cycle repeats. This loop crossed three themes: Theme 6, Law-enforcement failure; Theme 2, Theft & security; and Theme 5, Labour/costs.

A disease outbreak forces farmers to cull cattle, quarantine, or incur heavy treatment costs. These losses reduce revenue and make it difficult to fund regular prevention next season, increasing the risk of another outbreak. Because rebuilding herds takes years, a single bad outbreak can have a lasting effect for many seasons. This loop crossed over three themes: Theme 1: Health & diseases; Theme 5: Disease management costs; Theme 3: Climate/Weather, where rainfall increases tick populations.

Another loop occurs when drought or fire destroys grazing, forcing farmers to buy feed. The spending reduces profits and leaves little money to invest in water, feed, or storage for the next dry spell, therefore making the farm more vulnerable to the next drought. This loop crossed over two themes: Theme 3, Climate & weather; Theme 5, Feed production; and Input costs.

If the disease spreads or veterinary testing breaks down, quarantines and export bans follow. Those market losses reduce the funds farmers can allocate to biosecurity, increasing the likelihood of further outbreaks and keeping markets closed. This loop crossed three themes: Theme 1: Health & diseases; Theme 6: State veterinary collapse; and Theme 4: Market access & pricing.

Lastly, losing breeding stock or facing low calving rates means fewer productive animals and lower income. With lower income, farmers delay buying replacement cattle, leading to low herd size and output for years. Because it takes two to three years to raise a replacement, the effect is long and cumulative. This theme crossed over three themes, namely, Theme 5: Reproductive challenges, Theme 1: Health & diseases, and Theme 4: Market/pricing, indirectly.

In summary, red meat cattle farmers make a significant contribution to food security. However, the findings show that the pressures in red meat production systems do not stem from a single constraint but rather from the interaction of multiple challenges that create cascading effects. The cascading effects mean that the efforts made to mitigate one constraint may, in fact, affect other parts of the system, thereby accentuating the very constraint being controlled. Viewing cattle production through a systems lens, therefore, highlights that the main problem is not a single challenge but the cumulative impact of interconnected constraints that affect farm profitability and farmer well-being.

6. CONCLUSION

To alleviate food security challenges, the origins and root causes need to be understood. Therefore, this study aimed to identify the key challenges faced by cattle farmers, examine how these challenges are interconnected, and consider how they can be understood at a systems level. The findings show that cattle farmers in KwaZulu-Natal do not face isolated problems, but rather a web of challenges that reinforce one another through eight themes.

Although farmers continually adapt through practical and strategic decisions, these decisions often entail trade-offs. Short-term solutions to immediate problems can reduce resilience later, specifically when breeding cycles, disease control, or financial commitments are involved.

Not every farmer experienced every challenge, and the impacts varied in intensity. However, when all the challenges are combined, the patterns show that they lead to the same outcomes: cattle loss, production loss, rising costs, reduced profitability, and strain on farmer well-being.

By mapping these interconnections, the study contributes to a broader understanding of how challenges occur within cattle farming systems. Recognising these links is essential to interpret farmer decision-making, assess support mechanisms, and understand why problems can escalate into long-term operational and financial strain.

7. FUTURE RESEARCH

Future research should build on these findings by situating cattle production challenges within a production-system framework. This could include identifying the practical methods, benchmarks, and tools currently employed by farmers to address these challenges and systematically linking them to the themes identified in this study. This approach would facilitate a structured understanding of how specific practices relate to challenges, how they fit into larger farm operations, and where opportunities exist to improve farm performance and resilience.

Future research should also be conducted across other provinces, production systems, or livestock sectors to determine whether the patterns observed in KwaZulu-Natal are unique to this context or reflect broader trends in cattle production.

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CHAPTER 6 IISE-BOK Cattle Production Contextualisation Matrix

Figure 6-1 shows the current position of the research method.

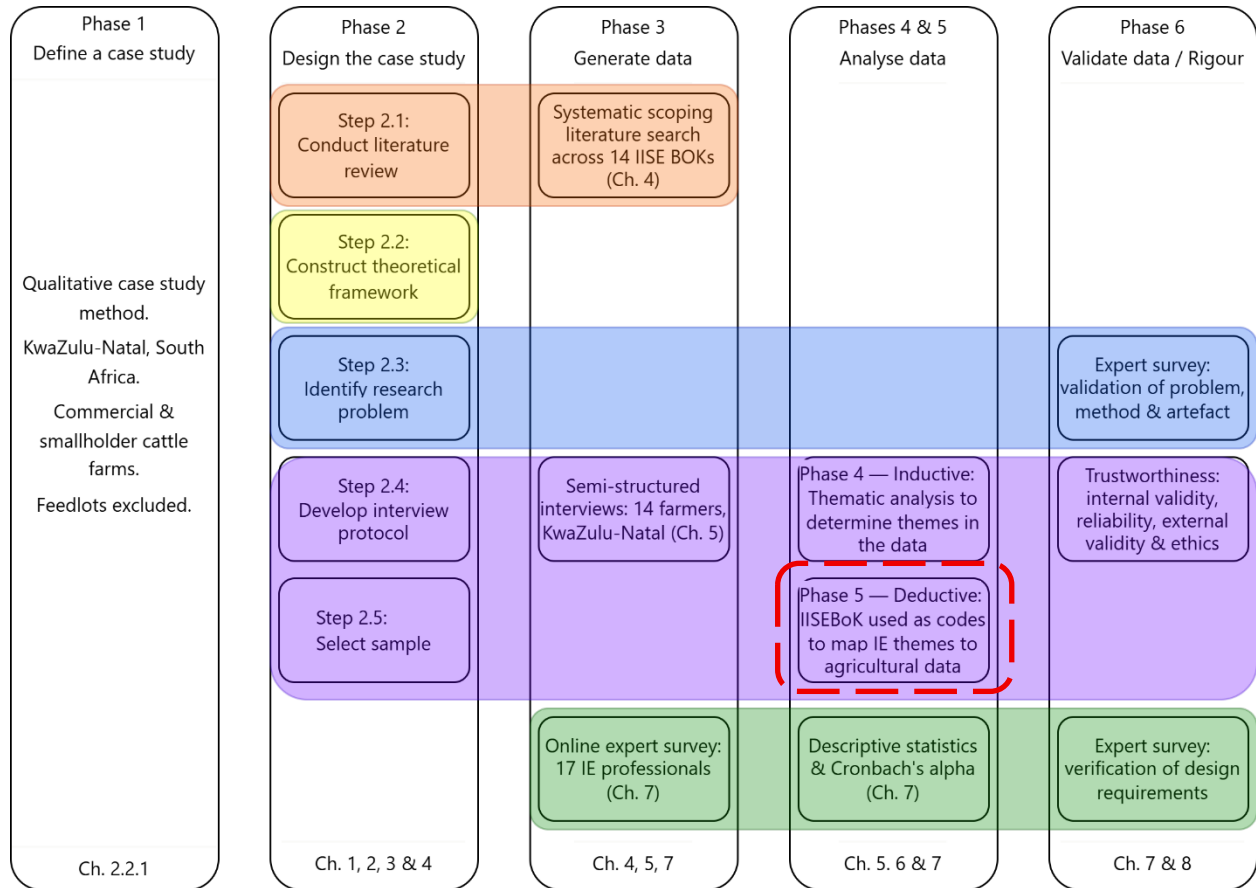


Figure 6-1: Research method

6.1 Introduction

Although Chapter 6 is formatted similarly to a research article, it is not intended for standalone publication and should be read as an integral chapter of this dissertation. This chapter aims to bridge the qualitative findings from Chapter 5 with Industrial Engineering knowledge by creating a contextualisation framework that maps the IISE Bodies of knowledge to farmer-reported challenges (Research Objective 3). Chapter 5 established the system-level challenges faced by cattle farmers in KwaZulu-Natal, and this chapter shows how and where Industrial Engineering methods and concepts align with these challenges, using deductive coding of interview transcripts. The design process is shown in Figure 6-1, with the details discussed in sections 6.2 – 6.5.

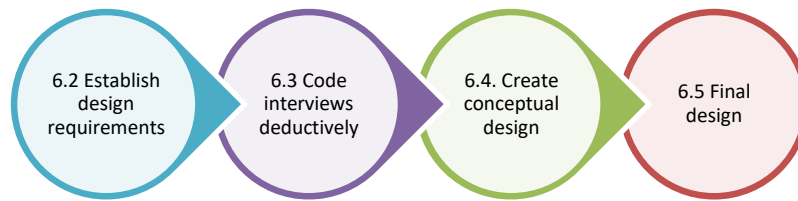


Figure 6-2: Design Process

6.2 Design requirements

The first step in the design process was to establish the design requirements for the matrix. The following design requirements (DR) were adapted from Mangaroo-Pillay (2020) and guide the aesthetics of the matrix:

- DR 1 – Simple in structure
- DR 2 – Visually intuitive
- DR 3 – Legible

The rest of the design requirements were set in accordance with objective 3 of this research: Contextualise the Industrial Engineering body of knowledge (IIE-BOK) within red-meat cattle production systems in KwaZulu-Natal:

- DR 4 – Connects BOK to actual farm practices
- DR 5 – Explains why BOK applies to the context
- DR 6 – Accessible to both IE and the agriculture disciplines

6.3 Coding of Interviews

This section focused on the deductive data analysis. Therefore, the interview transcripts were analysed using the IIE BOK to identify where it has been applied in practice. These instances were then grouped into the themes from Chapter 5. This maps the BOK to farmer-reported challenges, demonstrating which areas of industrial engineering knowledge currently address (or have the potential to address) specific production challenges. It is important to note that the farmers were not consciously applying the IE principles; this analysis identifies where the farmers' practices aligned with established industrial engineering methodologies, thereby contextualising the IIE-BOK within cattle production systems.

Although Industrial Engineering comprises 14 Bodies of Knowledge defined by the Institute of Industrial and Systems Engineers, only 12 were identified in the interview data. The two bodies of knowledge that were not identified were Operations Research and Analysis (BoK 2) and Design and Manufacturing Engineering (BoK 12). A possible reason is that these knowledge areas usually involve specialised analytical modelling or product manufacturing processes that are not directly used in everyday farm management practices. For example, Operations Research and Analysis often involves formal optimisation models, simulation, or advanced quantitative decision-support tools, which are not typically applied in routine farm management decision-making. Similarly, Design and Manufacturing Engineering is mainly focused on the design and production of manufactured products and industrial processes. However, cattle production is a biological system in which products result from animal growth and reproduction rather than engineered manufacturing processes. Consequently, these knowledge areas were not explicitly reflected in the interview responses.

The 12 knowledge areas were compiled into a table-formatted framework for each BOK subheading. The analyses went down to the third sub-level in the IISEBOK (e.g. 3.2.2 First Cost).

6.4 Conceptual design

Each table consists of the same layout, as shown in Table 6-1.

Table 6-1: Conceptual design table layout

Main BOK subheading name			
BOK	Theme(s)	Context	Explanation
2 nd level subheading names			
3 rd level subheading names			

Originally, another column was part of the table (Table 6-1). This column, the 'Quote' column, contained a direct quote from the interview data to support the context and explanation. This column has since been removed as it makes the tables extremely large and difficult to read. Each BOK's table was also given a certain colour that corresponds to the IISE Body of Knowledge diagram shown in Figure 6-1, to assist with readability.

- Column 1: Bodies of Knowledge (BOK) Subheading

This column lists the specific area or concept applied from the Industrial and Systems Engineering Body of Knowledge. These were standard IE terminology and knowledge areas as defined by IISE.

- Column 2: Theme(s)

This column lists the inductive themes (identified in Chapter 5) applicable to this context and explanation.

- Column 3: Agriculture context

This column provides a concise label identifying the specific approach, tool, method, metric, or strategy farmers used in practice. It served as a bridge between the theoretical IE concept (Column 1) and the detailed explanation (Column 4), briefly capturing how the BOK area manifested in actual cattle farming operations. These labels describe what farmers did, even when farmers did not use formal IE terminology.

- Column 4: Explanation

This column describes how the IE concept from Column 1 was observed in actual cattle farming practice. It shows the connection between theoretical knowledge of IE and its practical application in cattle production, even when farmers did not consciously use IE terminology.

The following design requirements were applied:

- **DR 1 – Simple in structure:** Four, clearly labelled columns were used, and a consistent row format was used across tables.
- **DR 2 – Visually intuitive:** consistent ordering lets the readers scan from left to right from theory to practice, and each BOK has its own colour.
- **DR 3 – Legible:** concise labels were given in Column 3 with short explanatory sentences in Column 4. Readable fonts, spacing, and font sizes were used in the final layout. This was presented in a standalone format (PDF).
- **DR 4 – Connects BOK to actual farm practices:** Column 4 explicitly ties each BOK subheading to farmer behaviour/evidence from interviews.
- **DR 5 – Explains why BOK applies to the context:** Column 4 includes explanation sentences (why the BOK area is relevant given the theme/farm action).
- **DR 6 – Accessible to both IE and agriculture disciplines:** Column 1 preserves formal IISE terminology; Column 3 provides plain-language practice labels so non-IE readers can follow.

6.5 Final design

Each of the BOK has been colour-coded according to the IISE Body of Knowledge diagram shown in Figure 6-2. The IISE-BOK Cattle Production Contextualisation Matrix (CPCM) maps Industrial Engineering knowledge areas to farmer-reported challenges in commercial cattle production

systems in KwaZulu-Natal. It should be noted that the CPCM is best understood as a structured contextualisation matrix and interpretive mapping tool — its value lies in bridging formal IISE-BOK terminology with farmer-reported practices, rather than in constituting a fully developed theoretical framework.



Figure 6-3: Knowledge areas of Industrial and Systems Engineering (IISE, 2021)

6.5.1 Work Design & Measurement (BOK 1)

Alignment with BOK 1 was evident, with a focus on performance measurement and data recording practices. Farmers used mortality percentages, calving rates, and stocking density as informal KPIs and kept records on animal health and reproduction. These practices reflect principles of work design and measurement, although they were developed through practical farming experience rather than through formal industrial engineering methods. An example of lean thinking was also identified in breed selection, where farmers attempted to reduce losses and inefficiencies at the source. However, sub-areas such as time study, work sampling, and operations analysis were not evident in the interview data. This likely reflects the variable and biologically driven nature of cattle farming, where highly standardised work measurement approaches are more difficult to apply. The entries were coded specifically as BOK 1, focusing on measurement and monitoring as a management tool, distinct from BOK 7.12, which captured the same metrics in the context of operational performance management.

Table 6-2: BOK 1.3 contextualised according to themes

BOK 1.3 Performance Metrics and Exploratory Tools			
BOK	Theme(s)	Context	Explanation
1.3. Performance Metrics and Exploratory Tools	1A - Tick-borne diseases, 5B - Disease management costs	Mortality percentages.	Farmers used mortality percentages as a performance benchmark/KPI for disease impact assessment. Farmers established target mortality ranges (2-3% good, 5% threshold) as performance standards for herd health management.
	5C - Reproductive challenges	Annual calving standard.	The annual calving standard served as a productivity criterion for evaluating asset performance and making culling decisions.
	5D - Feed production	Stocking density.	Farmers used the stocking density metric (animals/hectare) as a benchmark against industry standards: 0.2-0.5/ha (normal) vs 1.67/ha (intensive).
	3B - Climate & Weather	Rainfall patterns.	Rainfall patterns served as a predictive metric for tick activity, allowing farmers to intervene proactively before disease pressure peaked.
	8B - Cash flow management	Mortality percentages.	A farmer used the mortality metric to measure the financial impact by applying current market prices to production losses.
	2B - Other crimes	Mortality percentages.	A farmer tracked the mortality rates caused by snares, separate from other sources of mortality.

Table 6-3: BOK 1.4 contextualised according to themes

BOK 1.4 Recording and Analysis Tools			
BOK	Theme(s)	Context	Explanation
1.4 Recording and Analysis Tools	1A - Tick-borne diseases	Daily visual inspections.	Farmers conducted daily visual inspections for ticks to generate data for health monitoring, enabling them to respond rapidly to early disease detection.
	5B - Disease management costs	Daily visual inspections.	Farmers used visual inspections as a data collection tool, triggering condition-based interventions rather than calendar-based schedules.
	2A - Direct theft	Daily head counts.	Farmers recorded daily counts to detect theft.
	5C - Reproduction	Historical record systems.	Farmers used formal recording systems that tracked reproductive performance and market data over time.
	1C - Other health issues	Historical data comparison	A farmer could compare historical data to detect abnormalities.

Table 6-4: BOK 1.11 contextualised according to themes

BOK 1.11 Workplace Equipment & Tool Design			
BOK	Theme(s)	Context	Explanation
1.11 Workplace Equipment & Tool Design	7A – Water availability	Trough design modifications.	Farmers made trough modifications (adding walls/partitions) that prevented calf injuries by implementing physical design changes in response to observed hazards.
1.11.1 Lean Manufacturing	5A – Labour challenges, 1A - Tick-borne diseases (indirect)	Genetic breed selection (or Polled trait selection).	A farmer decided on his breed selection based on genetics for the polled trait (naturally hornless cattle) and tick resistance, eliminating the need for dehorning intervention rather than improving dehorning tools—representing the lean principle of waste elimination at the source. Polled animals also avoided infection risks associated with dehorning wounds, particularly maggot infestation in hot climates.

6.5.2 Engineering Economic Analysis (BOK 3)

BOK 3 showed strong, consistent overlap across the interviews, with 10 subheadings identified covering cost behaviour, cash flow, choice, accounting practices, and cost estimation. Because these subheadings are closely related, the coding relied on the main emphasis of each extract

rather than on isolated keywords. Entries were coded as 3.2 (Classification of Cost) when farmers focused on the nature of the cost itself, such as distinguishing between fixed and variable costs or identifying incremental expenditure. Entries were coded as 3.4 (Cash Flow Analysis) when farmers considered money, affordability, liquidity, payment timing, or broader cash-flow pressures. In contrast, 3.5 (Decision Making Among Alternatives) was used where farmers described choosing between options without a cash-flow focus (3.4). References to bookkeeping, cost tracking, invoices or accounting systems were coded to 3.9 (Accounting and Cost Accounting). Lastly, 3.12 (Estimating Economic Elements) captured instances in which farmers used historical data, benchmarks, or practical judgement to estimate future costs. Although participants did not use formal engineering economic terms, many of their management decisions showed how they developed practical economic reasoning through farming experience.

Table 6-5: BOK 3.2 contextualised according to themes

BOK 3.2 Classification of Cost			
BOK	Theme(s)	Context	Explanation
3.2.2 First Cost	5C - Reproduction	Animal replacement.	Replacing animals requires upfront capital investment with a 2-3 year lead time before achieving productivity. When farmers decided to cull a cow due to low production, they accepted the first cost of the replacement animal rather than continue incurring rehabilitation expenses.
	7A - Water Availability	Water infrastructure investment	Water systems that require upfront capital costs (boreholes, solar pumps, piping) constrain infrastructure expansion across camps.
	5D - Feed Production	Feed production costs	Feed production required upfront capital investment in machinery before operational capability was enabled.
	8A - Cashflow Management	Land restitution arrangement.	Farmer avoided the first costs of the land purchase through a 16-year restitution arrangement, preserving capital for productive livestock assets.
3.2.3 Fixed and variable cost	8A - Cashflow Management	Municipal rates	Municipal rates represented a recurring fixed expense.
	2A - Direct Theft, 5A - Labour Challenges	Fence replacement and labour costs.	One farmer responded to fence theft by converting occasional fence repairs (variable cost) into a permanent doubling of the workforce (fixed cost), creating continuous labour expense regardless of theft events. Replacing the stolen fences also creates a high variable cost determined by theft frequency rather than production volume.
	5E - Input Costs	Recurring operational costs	Fixed and variable recurring costs (electricity, forge account) remained regardless of revenue fluctuations.
	4A - Price Challenges, 5B - Disease management costs, 5E - Input costs	Variable cost reduction strategy	When market prices are low, farmers consider reducing variable costs (feed, medical) as a primary cost-control strategy, but they know it will involve trade-offs.
	5D - Feed Production, 5E - Input costs	Bulk purchasing strategy	Multiple variable costs (electricity, fertiliser, licks, fuel) showed escalation patterns. Farmers are considering bulk purchasing to reduce the variable cost per unit through volume discounts.
	5D - Feed Production	Feed system cost comparison.	Farmers compared cost structures for cattle feed: a natural grazing model (low variable cost) versus a feed production system (high variable cost, requiring increased cash).
3.2.4 Incremental Cost	3B - Climate & weather	Drought response costs	Drought created incremental expenses (tractor operation, diesel, bale distribution labour) beyond normal grazing operations.
	5B - Disease management costs	Sick animal treatment costs	Sick animal treatment caused incremental costs (isolation, special feed, medication, additional labour) above the routine herd care baseline.
	5D - Feed Production	Feed production system incremental costs	The feed production strategy created incremental costs compared to the natural grazing system baseline operations.

Table 6-6: BOK 3.3 contextualised according to themes

BOK 3.3 Classification of Cost			
BOK	Theme(s)	Context	Explanation
3.3.2 Equivalence Involving Interest	8A - Financing/ Interest Rates	Loan term comparison	The farmer understood how the repayment period of a loan affected the payment amount: shorter bank loans (10-15 years) resulted in higher payments than historical Landbank terms (25 years) for the same principal amount.
	8A - Financing/ Interest Rates	Asset-loan term matching	The farmer matched the loan repayment periods to asset productive lives and cash generation timelines - cattle assets financed over 5-10 years versus land over 15-20 years.

Table 6-7: BOK 3.4 contextualised according to themes

BOK 3.4 Classification of Cost			
BOK	Theme(s)	Context	Explanation
3.4.1 Present Worth	4A - Price Challenges	Sale timing comparison	One farmer delayed sales to reach target weights, comparing the present value of an immediate, lower-weight sale with that of a future, higher-weight sale.
	4A - Price Challenges	Market timing decision	Another farmer achieved better value by selling heifers early at R30/kg versus waiting for the current depressed market at R23-26/kg.
3.4.5 Benefit-Cost Ratio	4A - Price Challenges, 4B - Market Structure - Distance to Market	Transport benefit-cost analysis	The farmer applied benefit-cost analysis at the market: once cattle arrived, the cost of return transport exceeded any potential benefit from waiting for better prices, forcing acceptance of low offers.
3.4.6 Payback Period	1A - Tick-Borne Diseases, 5C - Reproductive Challenges	Replacement animal payback period.	Mortality created a 2-3 year payback period before replacement animals reached productivity and began generating revenue (recovering the funds initially spent on the initial investment).
	3B - Climate & Weather - Drought	Drought recovery timeline	When drought forces the sale of breeders (cows in production age), it causes a multi-year recovery period before the replacement herd restores to full calf production capacity.
3.4.7 Rate of Returns	8B - Cash Flow Management	Return on capital measurement	Intensive beef enterprises generated a negative 2% return on capital in the last financial year.
3.4 Cash Flow Analysis	5B - Disease Management Costs	Disease response cash requirements	Blocking interventions resulted in large immediate costs (R20,000-30,000), requiring immediate liquidity for the disease response.
	1B - Controlled/ Notifiable Diseases	FMD liquidity impact	FMD quarantine prevents sales while operating costs (feed, concentrates, labour) continue to accrue, creating a liquidity crisis.
	2A - Direct Theft - Cattle	Theft asset loss (or theft cash impact)	Cattle theft (7-10 animals) created immediate asset loss, limiting cash flow with no recovery mechanism.
	2A - Direct Theft - Fence	Recurring fence costs	Weekly fence material purchases (minimum 52 rolls annually) created a recurring cost. Impacting the farmer's cash flow.
	3B - Climate & Weather - Drought	Emergency destocking strategy	Destocking during drought creates immediate cash to buy emergency feed, but simultaneously reduces future revenue through herd reduction. Destocking also ensures that operations stay within the farm's grazing capacity during droughts, allowing them to continue for a while without purchasing feed.
	3B - Climate & Weather - Drought, 4A - Price	Emergency destocking strategy	Drought forced destocking at minimum prices, affecting all farmers and creating an immediate revenue crisis.
	4A - Price Challenges, 4B - Market Structure - Distance to Market	Market closure revenue disruption	Market closures caused by COVID-19 and FMD led to an immediate halt in cash flow, cutting off all auction revenue streams.
	4A - Price Challenges	Market price constraints	Low market prices directly limit cash flow and operational spending capacity.
	5E - Input Costs	Input cost escalation	Escalating input costs, particularly for electricity, fertiliser, and fuel, exceeded gains in beef revenue, compressing profit margins.

BOK 3.4 Classification of Cost			
BOK	Theme(s)	Context	Explanation
	8B - Cash Flow Management	Budget monitoring	The farmers conducted regular monthly cash flow and budget monitoring.
	8B - Cash Flow Management	Annual revenue vs daily expenses	Farmers receive an annual revenue payment (once or twice a year) but incur continuous daily expenses, requiring liquidity management throughout the year.

Table 6-8: BOK 3.5 contextualised according to themes

BOK 3.5 Financial Decision Making Among Alternatives			
BOK	Theme(s)	Context	Explanation
3.5.2 Decision Criteria for Alternatives	5B - Disease Management Costs	Dipping method comparison	The farmer evaluated two alternative dipping methods based on cost and operational efficiency, strategically choosing the treatment that best met their needs.
	2A - Direct Theft - Cattle	Breed colour selection	The farmer specifically chose white Brahman over red/black cattle, evaluating security benefits (theft recovery capability and ease of visual monitoring).
	2A - Direct Theft - Security Methods	Kraaling trade-off decision (or Security-health trade-off)	The farmer accepted kraaling-induced health problems (foot rot) as a necessary cost for theft prevention, choosing security over animal health in a trade-off between competing risks.
	3B - Climate & Weather - Environmental Adaptation	Deforestation vs purchase evaluation	A farmer with a forest-constraining grazing terrain explicitly compared two alternatives (conduct deforestation on the sweet veld property versus buy an alternative property), choosing to address terrain challenges rather than seeking different land.
	5C - Reproductive Challenges	Fertility treatment vs culling evaluation	The farmer evaluated alternatives: treating low-fertility cows to restore productivity, or culling them and purchasing replacements.
	5D - Feed Production	Feed production comparison	The farmer chose hay production over silage based on total cost comparison, including machinery requirements and ongoing operational expenses.
	5E - Breed Selection	Breed genetics trade-off evaluation.	Farmer evaluated the trade-off between indigenous cattle genetics (tick/heat-resistant but lower feedlot performance) and commercial breeds (higher production but more vulnerable), choosing a crossbreeding compromise to balance traits.
	8A - Financing/ Interest Rates	Early sale vs weaning sale comparison	Farmer evaluated two alternatives for heifer sale timing: selling the herd early at 6 weeks vs holding to the traditional weaning age, choosing the immediate sale based on market risk.
3.5.3 Decision Criteria Under Limited Funds	1A - Tick-Borne Diseases, 5B - Disease Management Costs	Cash preservation vs production trade-off	Under price pressure and limited funds, the farmer weighed a financial trade-off: cutting variable costs (feed, medical), recognising this could compromise production but preserve immediate cash flow.
	3B - Climate & Weather - Drought	Emergency destocking strategy	The farmer made realistic trade-offs during drought (selling animals and purchasing emergency feed, destocking to match resources) based on immediate cash availability and survival urgency rather than formal ROI calculations.

Table 6-9: BOK 3.6 contextualised according to themes

BOK 3.6 Replacement Analysis			
BOK	Theme(s)	Context	Explanation
3.6.1 Decision Criteria for Replacement	5C - Reproductive Challenges	Annual calving criterion	The farmer applied a productivity-based replacement criterion: mature cows must produce one calf per year; failure to meet this standard triggers replacement regardless of age.
3.6.2 Determining Economic Life of Asset	1A - Tick-Borne Diseases, 5C - Reproductive Challenges	Cattle economic lifecycle analysis	The farmer described a complete asset economic life cycle: 2-3 years to develop the animal to productive capacity (first calf), followed by a 2-3 year replacement cycle when lost, with sunk development costs requiring recovery before the replacement generates profit.
	8A - Financing/ Interest Rates	Asset-specific financing terms	The farmer matched financing terms to asset-specific economic lives: cattle assets (5-10 year planning horizon) received shorter-

BOK 3.6 Replacement Analysis			
BOK	Theme(s)	Context	Explanation
			term financing, while land purchases (15-20 year value period) justified longer loan structures.

Table 6-10: BOK 3.9 contextualised according to themes

BOK 3.9 Accounting and Cost Accounting			
BOK	Theme(s)	Context	Explanation
3.9.1. General accounting	8B - Cash Flow Management	Formal accounting and budgeting tools	The farmer used a computerised accounting system (Pastel software) and formal bank-designed cash flow budgeting tools for financial record-keeping and planning.
3.9.2 Cost Accounting	5E - Input Costs, 8B - Cash Flow Management	Overhead cost tracking	The farmers track ongoing overhead costs (electricity, forge account) as distinct accounting categories.

Table 6-11: BOK 3.12 contextualised according to themes

BOK 3.12 Estimating Economic Elements			
BOK	Theme(s)	Context	Explanation
3.12.1 Cost Estimating Methods	1A - Tick-Borne Diseases, 5B - Disease Management Costs	Disease intervention cost range	The farmer provided a cost estimate for herd-wide disease intervention as a range.
	4A - Price Challenges, 5E - Input Costs	Historical trend analysis	The farmer used historical cost and price data for trend analysis, comparing current conditions to a 10-year baseline to assess the shrinking margins.
	5E - Input Costs	Input cost tracking	The farmers tracked escalating input costs (fencing equipment, labour, herbicides) for budgeting and replacement cost estimation.
	5E - Input Costs	Feed cost analysis	The farmer noted that buying feed after grazing losses increased costs faster than beef prices rose, reducing profit margins.
	8B - Financial Analysis Methods	Land cost calculation steps	A farmer demonstrated a systematic multi-step cost estimation method: (1) establish cost target per animal (R600/year), (2) determine land requirement (5 ha/cow), (3) calculate maximum acceptable land cost (R600 ÷ 5 ha = R120/ha/year ceiling).
	8B - Cash Flow Management	Ongoing financial monitoring	The farmer maintained systematic, ongoing financial monitoring through self-managed bookkeeping, cash flow, and budgets to support daily operational awareness.

Table 6-12: BOK 3.13 contextualised according to themes

BOK 3.13 Estimates and Decision Making			
BOK	Theme(s)	Context	Explanation
3.13.1 Estimating Economic Benefits	4A - Price Challenges	Target weight revenue comparison	Farmer estimated economic benefits of the target weight strategy using explicit per-kilogram revenue calculations, comparing 230kg @ R36/kg versus 260kg @ R32/kg to demonstrate that heavier animals generate superior total revenue despite lower per-unit pricing.
	5E - Input Costs	Cost-revenue trend comparison	The farmer is explicitly comparing cost increases to revenue increases to understand his net benefit/margin erosion.

Table 6-13: BOK 3.14 contextualised according to themes

BOK 3.14 Decision Making Involving Risk			
BOK	Theme(s)	Context	Explanation
3.14.1 Probabilistic	1A - Tick-Borne Diseases, 5C -	Treatment success probability	The farmer acknowledged probabilistic treatment outcomes, where resource investment (isolation, medication, care) does not guarantee success, recognising the uncertainty of interventions.

BOK 3.14 Decision Making Involving Risk			
BOK	Theme(s)	Context	Explanation
Decision Making	Reproductive Challenges		
	1A - Tick-Borne Diseases	Early detection probability	The farmer identified detection uncertainty as a risk, as missing early red water signs reduces the probabilistic likelihood of treatment success within the 24-hour window.
	1A - Tick-Borne Diseases	Medication buffer strategy	The farmer implemented a risk mitigation strategy by maintaining a medication inventory buffer to reduce the probability of treatment delays and improve intervention success rates.
	3B - Climate & Weather - Drought	Post-fire feed risk	The farmer noted that burnt-grass feeding carries abortion risk, with probabilistic negative outcomes that must be managed after fires.
	3B - Climate & Weather - Drought	Market price collapse risk	The farmer made repeated sell-versus-hold decisions under price uncertainty, recognising the probabilistic risk of price collapse when all farmers destock during drought.
	3B - Climate & Weather - Drought	Price recovery speculation	The farmer chose to hold stock when advised of a probabilistic price recovery, balancing market risk against the ongoing costs of keeping cattle during uncertain conditions.
	3B - Climate & Weather - Drought	Total herd loss probability	The farmer highlighted the existential risk during drought, noting that without alternative feed, the probability of total herd loss could be high.
	4A - Price Challenges	Certain versus uncertain revenue decision	The farmer made an early sale decision under market uncertainty, accepting certain immediate revenue (R30/kg) over uncertain future pricing, with subsequent market deterioration to R23-26/kg validating the risk-averse strategy.

Table 6-14: BOK 3.15 contextualised according to themes

BOK 3.15 Decision Making Under Uncertainty			
BOK	Theme(s)	Context	Explanation
3.15.1 Decision Making Under Uncertainty	3B - Climate & Weather - Drought, 2B - Other Crises - Fires	Emergency feed decision under rainfall uncertainty	The farmer chose between two alternatives under uncertainty: wait for uncertain rain-dependent grass regrowth (there probably would not be any rain until October) versus purchase emergency feed immediately, operating without meaningful data on rainfall timing and quantity.
	3B - Climate & Weather - Drought	Destocking under feed uncertainty	The farmer made a destocking decision under rainfall uncertainty and feed constraints, forcing a practical economic choice between culling versus risking feed exhaustion.
	3B - Climate & Weather - Drought	Feeding under pasture uncertainty	A farmer must make feeding decisions when future grass availability is uncertain and unpredictable.

6.5.3 Facilities Engineering and Energy Management (BOK 4)

The alignment of BOK 4 was limited, with only two subheadings identified, both related to the farm's physical infrastructure. Data were coded to BOK 4 when the focus was on the layout and maintenance of infrastructure such as fencing, water systems, and general facilities. In these cases, the emphasis was on the physical condition and arrangement of assets rather than the operational or financial implications of maintaining them. Where the discussion shifted to day-to-day operations or cost considerations, these were captured under BOK 7 and BOK 3, respectively. In general, the BOK 4 data reflect practical infrastructure management rather than formal facilities engineering practice.

Table 6-15: BOK 4.3 contextualised according to themes

BOK 4.3 Facilities Layout			
BOK	Theme(s)	Context	Explanation
4.3.3 Systematic Layout Planning	2A - Direct Theft - Fence	Fence layout planning	The farmer planned fence placement to minimise material consumption and labour requirements for construction and maintenance.
	3C – Terrain & Vegetation	Revegetation planning	The farmer implemented replanting and restoration planning following de-bushing operations to re-establish productive grass species.

Table 6-16: BOK 4.6 contextualised according to themes

BOK 4.3 Plant and Facilities Engineering			
BOK	Theme(s)	Context	Explanation
4.6.7. Security and loss control systems	2A - Direct Theft - Fence	Fence security monitoring	The farmer identified ongoing fence cutting and unauthorised livestock placement as persistent security threats that require ongoing fence maintenance.
4.6.10 Facilities Maintenance Management	3C – Terrain & Vegetation	Fence maintenance	The farmer noted that bush encroachment and challenging terrain substantially increased the difficulty of accessing the fence and the overall maintenance burden.
	3C – Terrain & Vegetation	Bush maintenance and labour management	The farmer must continually plan and allocate labour for manual debushing to maintain the farm, as the terrain prevents the use of machines.
	7A - Water Availability	Through safety modifications	The farmer made changes to the facilities, such as adding trough partitions and above-ground water systems, after calves drowned in open water areas.
	7A - Water Availability	Drowning prevention infrastructure	The farmer installed fencing around the dams as a facility modification to prevent livestock from drowning in open water bodies.
	7B – Road Conditions	Road infrastructure maintenance	Road maintenance preserves access for operations, recognising road infrastructure as difficult to maintain.
	2B - Other Crimes - Fires	Fire break maintenance	Fire breaks can be used to limit the potential for fires to spread and to maintain the facility's grazing capacity as much as possible.

6.5.4 Quality and Reliability Engineering (BOK 5)

The alignment of BOK 5 was concentrated within the reliability engineering subheading, with farmers applying maintenance and failure management principles to the herd's health. Scheduled vaccination and dipping protocols indicated preventive maintenance; daily visual inspections were compared with condition-based maintenance; and culling decisions based on reproductive failure followed failure replacement strategies. The main difference in the coding process was between the maintenance strategy and the actual maintenance implementation. The entries were coded as BOK 5.5 when the focus was on the maintenance approach itself, and as BOK 7.9 when the emphasis shifted to the organisation, scheduling and resourcing of those activities. For example, vaccination programmes were coded to 5.5.4.2 when discussed as a preventative strategy, but when explained how they were planned and implemented, they were captured under BOK 7.9.

Table 6-17: BOK 5.5 contextualised according to themes

BOK 5.5 Reliability Engineering			
BOK	Theme(s)	Context	Explanation
5.5.1 Fundamentals	1A - Tick-Borne Diseases	Mortality rate KPI targets	The farmer established explicit mortality rate targets as reliability KPIs: 2-3% as good performance, 5% as an acceptable limit, and rates above 5% indicating system reliability failure.
	1A - Tick-Borne Diseases	Disease protection cycles	Blocking interventions creates a 28-day protection window, serving as a reliability parameter (mean time before failure) that must be repeated at each cycle to maintain disease protection.
5.5.3 Failure Analysis	1A - Tick-Borne Diseases	24-hour intervention window	The farmer described a failure mode with a 24-hour intervention window: early detection enables recovery, while late detection results in irreversible loss.
	1A - Tick-Borne Diseases	Cross-boundary disease transmission	The farmer identified a root cause (ticks) and a secondary external root cause: untreated stray cattle from neighbours carried ticks across boundary fences, repeatedly reintroducing disease despite on-farm control. This combination drives failure (reducing animal mortality increases herd availability).
	1A - Tick-Borne Diseases	Unintended treatment failure mode	The system change from pour-on to spray dip resolved tick infestations but unintentionally caused a parasite-related failure.
	1A - Tick-Borne Diseases	Identifying hidden disease threats	The farmer recognised hidden failure modes (parasites, worms) that initially go undetected but escalate into larger production problems without early intervention.
	1B - Controlled/Notifiable Diseases	Identifying treatment resistance	The farmer described an escalating cycle: single-chemical tick treatments lose effectiveness, combination products work briefly, then drive resistance to multiple ingredients, leading to repeated control failures.
	2A - Direct Theft - Cattle	Theft detection	The farmer recognised theft as a recurring failure mode that results in asset loss.
	2B - Other Crimes - Fires	Identifying firebreak inefficiency	The farmer identified the firebreak failure mode: perpetrators deliberately ignited fires inside the defended perimeter, rendering the system ineffective.
	3B - Climate & Weather - Drought	Drought-induced reliability failures	The farmer treated drought-related deaths and low calving rates as reliability failures, managing risk by destocking to reduce exposure.
5.5.4.2 Preventive Maintenance	1A - Tick-Borne Diseases	Scheduled vaccination and dipping protocols	The farmer implemented scheduled preventive maintenance through vaccination protocols (annual) and dipping cycles (2-4 weeks), reducing failure incidence and preserving herd availability.
	1A - Tick-Borne Diseases	Annual liver fluke dosing	The farmer maintained annual liver fluke dosing as a preventive maintenance routine, reducing parasite-induced failures.
	2A - Direct Theft - Fence & cattle	Employing guards to prevent theft	Farmers employed guards as a preventive measure to prevent cattle theft (asset loss) and fence theft.
	1C - Other Diseases	Monthly kraal spraying routine	The farmer implemented monthly kraal spraying as a preventive maintenance routine to keep flies and disease at bay.
5.5.4.3 Failure Replacement	5C - Reproductive Challenges	Productivity-based culling replacement	The farmer implemented a failure-replacement strategy: culling nonproductive breeding cows and purchasing replacements when assets failed to meet the annual calving availability standard.
5.5.4.4 Condition-Based Maintenance	1A - Tick-Borne Diseases	Visual condition-triggered treatment	The farmer relied on daily condition monitoring, triggering treatment only when signs or tick loads appeared.
	2A - Direct Theft - Fence	Corrective fence repair	The farmer repaired destroyed boundary fencing as condition-based maintenance, restoring infrastructure availability and preventing repeat asset losses.

6.5.5 Ergonomic Basics (BOK 6)

BOK 6 showed the least representation among the BOKs included in the CPCM, with only one subheading identified. The overlap focused on physical work capacity, particularly when steep or inaccessible terrain caused strain and fatigue among farm workers. In general, the area of knowledge on ergonomics and human factors was largely absent from the interview data, reflecting the outdoor and highly variable nature of farm work.

Table 6-18: BOK 6.4 contextualised according to themes

BOK 6.4 Work Capacity and Fatigue			
BOK	Theme(s)	Context	Explanation
6.4.1 Physical Capacity	3C – Terrain & Vegetation	Manual work methods	Manual work methods without machinery increased the physical labour strain and muscle fatigue.
6.4.6 Applied Physiology	3C – Terrain & Vegetation	Manual work methods	Manual bush clearing on difficult terrain placed intense physical demands, leading to elevated fatigue and increased injury risk from sustained exertion.

6.5.6 Operations Engineering and Management (BOK 7)

The codes for BOK 7 appeared a lot in the interview data, with subheadings identified in operations planning, scheduling, capacity management, and operational metrics. Farmers regularly used seasonal planning, market timing, labour scheduling, and herd capacity decisions. Maintenance scheduling for dipping and vaccination routines was also discussed consistently in the interviews. Because BOK 7 overlapped with several other BOKs, the coding depended on the main focus of each extract. Planning activities focused on internal farm operations were coded as BOK 7.1 (Operations Planning), while broader supply chain issues were captured under BOK 8. Extracts focused on labour, equipment, or herd numbers were coded to BOK 7.6 (Capacity Management) when the emphasis was on managing available capacity rather than financial implications, which were coded under BOK 3. Operational performance indicators were coded as BOK 7.12 (Operational Metrics) when used to manage daily farm activities. Maintenance activities were coded as BOK 7.9 when they were specifically focused on scheduling and coordinating the work itself, rather than on the maintenance strategy, which was captured in BOK 5.

Table 6-19: BOK 7.1 contextualised according to themes

BOK 7.1 Operations Planning			
BOK	Theme(s)	Context	Explanation
7.1.2 Forecasting	1A - Tick-Borne Diseases	Climate-based tick forecasting	Farmer forecasts seasonal tick surges using temperature and rainfall patterns, increasing control frequency from six-week to three-week intervals during expected high-pressure periods.
	4A - Price Challenges	Price decline prediction	Farmer forecasted declining market conditions and therefore sold early at R30/kg, with later prices of R23–26/kg confirming the prediction.
	6A - Law Enforcement Failure	Long-term security trend analysis	Farmer forecasted a persistent or worsening security threat based on demographic analysis: more youth entering the labour market without employment prospects in a stagnant economy.
7.1.4 Market Analysis	4A - Price Challenges	Seasonal supply pattern analysis	The farmer analysed historical seasonal supply patterns, avoiding peak weaning months (April-June) by targeting March and November sales windows when market prices are stronger.
	4A - Price Challenges	Market demand assessment	The farmer analysed buyer preferences in his market area, identifying that the feedlot rejects females while local buyers have a strong demand.
	4A - Price Challenges	Market competitiveness assessment	The farmer assessed market competitiveness, noting that premium segments like Karan Beef and the A market are highly competitive and unsuitable for smaller operators, and therefore targeted less competitive niche markets.
7.1 Operations Planning	4A - Price Challenges	Seasonal calving alignment	The farmer aligned calving with natural grazing cycles, timing births so young animals grow during the grass season and avoid costly winter feeding.

BOK 7.1 Operations Planning			
BOK	Theme(s)	Context	Explanation
	4A - Price Challenges	Annual revenue distribution planning	The farmer emphasised that cash flow planning determines business survival, requiring careful scheduling of weaner and cull cow sales to maintain a steady income throughout the year.
	1A - Tick-Borne Diseases	Immunisation scheduling	The farmer incorporated blocking costs and the 28-day protection window into new cattle integration, treating immunisation as a required step before operations can continue.
	5D - Feed Production	Integrated grazing-crop rotation	The farmer planned an integrated rotation cycle where cattle grazing restores soil health for vegetable production, creating a regenerative loop.

Table 6-20: BOK 7.3 contextualised according to themes

BOK 7.3 Planning and Control for Manufacturing Systems/Projects			
BOK	Theme(s)	Context	Explanation
7.3.1 Scheduling	1A - Tick-Borne Diseases	Routine dipping and vaccination schedule	All farmers operated a scheduled maintenance program, implementing various dipping intervals and annual vaccination cycles as part of their routine operational calendar.
	1B - Controlled/Notifiable Diseases	Critical vaccination window	The farmer identified the strict 6–8 month vaccination window for Brucellosis as a non-negotiable deadline, noting that missing it permanently prevents compliance with vaccination requirements.
	1A - Tick-Borne Diseases	Movement coordination	The farmer timed new cattle movements around the prescribed three-week blocking period, ensuring animals are exposed to ticks at the right moment to develop immunity before entering new camps.
	1A, 1B - Diseases	Master treatment calendar	The farmer followed a vet-designed master schedule that coordinated all disease interventions—dipping, vaccinations, and injections—each with its own specific timing requirements.
	4A - Price Challenges	Strategic calving timing	The farmer scheduled calving to occur 8 weeks before grass availability, so that weaning aligns with natural feed abundance and avoids costly winter supplementation.
	4A - Price Challenges	Early breeding timeline	The farmer accelerated the reproductive cycle by mating heifers at 14 months, shortening the production timeline to improve cash flow turnover.
	5D - Feed Production	Seasonal crop scheduling	The farmer scheduled seasonal crop rotations, planting summer crops in spring, winter crops in autumn, and maintaining continuous year-round production.
	4A - Price Challenges	Monthly sales schedule	The farmer implemented a regular monthly sales schedule, determining production holding periods and cash flow rhythm.
	3C – Terrain & Vegetation	Grazing rotation scheduling	The farmer planned grazing rotations around Tulip toxicity, avoiding contaminated areas in winter and using them in summer when tall grass prevents consumption.
	7A - Labour Availability	Disrupted task reshuffling	The farmer experienced operational disruptions due to worker absences, which forced unplanned rescheduling and task reshuffling.
	3C – Terrain & Vegetation	Scheduled deforestation cycles	The farmer restored pasture productivity by scheduling regular deforestation of encroached areas to increase carrying capacity and improve herd throughput.
	1A - Tick-Borne Diseases, 3C - Terrain & Vegetation	Weekly cattle gathering time allocation	The farmer experienced a weekly time burden, spending 1-2 days weekly gathering cattle from difficult terrain for dipping operations.

Table 6-21: BOK 7.4 contextualised according to themes

BOK 7.4 Production Scheduling			
BOK	Theme(s)	Context	Explanation
7.4.5 Work schedules/personnel scheduling	2A - Direct Theft - Fence	Combined herding and fence repair duties	The farmer integrated fence repair into the daily cattle supervision routine, where herd boys simultaneously performed livestock monitoring and infrastructure maintenance.
	5D - Feed Production	Seasonal crop rotation schedule	Farmer scheduled seasonal crop production transitions: spring planting, summer crops (sorghum), autumn planting, winter crops

BOK 7.4 Production Scheduling			
BOK	Theme(s)	Context	Explanation
			(rye grass, oats), maintaining a continuous year-round production schedule.
	2A - Direct Theft - Cattle	Daily kraaling routine	Farmer maintained a precise daily kraaling schedule (5 AM release, 4 PM return), conditioning cattle to a location-specific routine, creating theft resistance through predictable animal behavioural patterns.
	3B - Climate & Weather - Drought	Increased feeding schedule	The farmer revised the feeding schedule during drought from single daily feeding to twice-daily bale distribution (morning and afternoon).
	3B - Climate & Weather - Rainfall	Schedule flexibility	The farmer experienced weather-imposed scheduling constraints, as rain prevented fieldwork and cattle counting, requiring operational scheduling adaptation to weather conditions.

Table 6-22: BOK 7.6 contextualised according to themes

BOK 7.6 Capacity Management			
BOK	Theme(s)	Context	Explanation
7.6.1 Labour	2A - Direct Theft - Fence	Labour expansion	Farmer doubled the herd boy workforce from 3 to 6 employees to accommodate continuous fence repair requirements, allocating additional labour capacity to manage theft-driven fence repair.
	2B - Other Crimes - Hunting	Unplanned labour reallocation	The farmer experienced unplanned labour reallocation, losing 5-6 hours per hunting incident for emergency response, disrupting planned work, and reducing productive capacity.
	3C – Terrain & Vegetation	Manual labour tasks	The farmer experienced continuous daily labour requirements due to terrain constraints, manually de-bushing, and retrieving cattle from areas inaccessible to machinery.
	7A - Labour Availability	Skilled labour constraints	Limited availability of skilled labour constrained operations, with costs preventing sufficient hiring.
	7A - Labour Availability	Worker absence impact	The farmer experienced reduced labour capacity due to worker absences (drinking), requiring remaining staff to fill gaps and slowing operational tasks.
	4A - Price Challenges	Labour reduction	The farmer selected polled (naturally hornless) genetics to eliminate the need for dehorning labour, reducing workforce demands and animal handling.
	4A - Price Challenges	Management team expansion	As the farm operation scaled up, management workload exceeded one person's capacity, requiring the farmer's son to join and share management responsibilities.
7.6.2 Equipment	3B - Climate & Weather - Drought	Emergency tractor capacity	Tractors were required to distribute bales during drought, ensuring equipment capacity for emergency feeding.
7.6.3 Materials	5D - Feed Production	Continuous feed capacity planning	Feed supply was a critical recurring constraint, requiring continuous capacity planning to meet herd requirements.
	5D - Feed Production	Seasonal feed production capacity	The farmer implemented a year-round feed production system with seasonal crop rotations (summer sorghum and winter rye/oats), ensuring a continuous feed supply.
	3B - Climate & Weather - Drought	Emergency feed sourcing	Emergency feed materials (hay and bales) were sourced when natural grazing failed, thereby maintaining herd survival during drought.
	3C – Terrain & Vegetation	Winter feed capacity	The farmer ensured adequate feed capacity during winter to prevent cows from consuming toxic plants.
7.6.4 Demand Management	3B - Climate & Weather - Drought	Demand management during drought	The farmer reduced herd size to match available forage during drought, actively managing animal numbers relative to carrying capacity.
7.6.5 Throughput	3C – Terrain & Vegetation	Carrying capacity restoration	The farmer restored pasture productivity through active deforestation, increasing carrying capacity and potential herd throughput.
	5D - Feed Production	Growth rate as a throughput constraint	The farmer recognised that slow-growing animals reduced effective carrying capacity by grazing longer, preventing new animal entry, and reducing system throughput.
	3B - Climate & Weather - Drought	Proactive drought destocking	The farmer implemented destocking during drought as a proactive capacity management strategy, deliberately selling animals to match reduced forage availability.
	5D - Feed Production	High-density stocking	The farmer operated an intensive stocking system far exceeding industry norms through supplementary feed production.
	4A - Price Challenges	Throughput-profitability trade-off selection	Another farmer recognised the throughput-profitability contradiction where intensive systems (higher stocking density) generate lower

BOK 7.6 Capacity Management			
BOK	Theme(s)	Context	Explanation
			profitability than extensive systems, despite higher throughput, selecting the extensive strategy for weaner production.

Table 6-23 presents BOK 7.9 contextualised within the interview data and categorised according to the inductive themes from Chapter 5. This BOK was selected for entries that focused on the organisational and logistical aspects of executing maintenance rather than the maintenance tasks themselves. While BOK 5.5 captured what maintenance was performed, BOK 7.9 captured how maintenance operations were managed and controlled—including resource planning (labour, supplies), readiness systems (standby equipment for fires), scheduling coordination, and managing external constraints.

Table 6-23: BOK 7.9 contextualised according to themes

BOK 7.9 Maintenance Management & Control			
BOK	Theme(s)	Context	Explanation
7.9 Maintenance Management & Control	1A - Tick-Borne Diseases	Daily inspection routine	The farmer scheduled daily animal inspections, requiring resource planning for labour and supplies as part of an ongoing operational routine.
	2B - Other crimes - fire	Fire readiness standby system	The farmer maintained a fire readiness system by keeping standby equipment and supplies (20-litre containers, back sprays), particularly over weekends.
	1C - Other Health Issues	Maintenance operations management	The farmer managed corrective maintenance operations, isolating animals, performing daily wound care, providing special feeding, and exceeding normal maintenance workload.
	6B - State Service Collapse	Maintenance schedule constraints	The farmer experienced timing failures when government-issued medication arrived after the disease season (winter delivery for summer disease), preventing effective seasonal preventive maintenance execution.
	6B - State Service Collapse	Preventive maintenance supply constraints	The farmer faced major constraints in preventive maintenance due to vaccine shortages and unreliable supply from Onderstepoort, forcing purchases at a higher cost and with limited availability.

Table 6-24: BOK 7.12 contextualised according to themes

BOK 7.12 Operational Metrics			
BOK	Theme(s)	Context	Explanation
7.12.1 Cost	1A - Tick-Borne Diseases	Disease control cost tracking	The farmer recognised disease control as a high operating cost, tracking both routine expenses (weekly dipping, biannual inoculations) and major interventions (R30,000 for blocking 140 cattle)
	2A - Direct Theft - Fence	Fence replacement cost tracking	Fence theft was identified as a big recurring expense, with the farmer replacing many rolls of fencing and doubling labour from three to six herd boys to keep up with repairs.
	1C - Other Diseases	Seasonal loss cost calculation	The farmer quantified kraaling-related productivity losses at approximately R24,000 per season (3-4 calves at R6,000 each), plus monthly kraal-spraying costs.
	5A - Labour Availability	Labour cost monitoring	Labour was seen as an expensive operational challenge, with rising minimum wages increasing faster than inflation.
	5B - Input Costs	Input cost-return comparison	Farmer tracked input cost inflation (electricity, fertiliser, fuel), increasing faster than beef price returns.

BOK 7.12 Operational Metrics			
BOK	Theme(s)	Context	Explanation
	4B - Market Structure - Distance	Transport expenses	The farmer identified distance as the primary driver of transportation costs, quantifying operational expenses through fuel consumption and tyre wear.
	8A - Financing	Financing cost assessment	Financing costs were identified as a major expense, prompting farmers to seek alternatives to high-interest bank loans.
7.12.2 Quality	4B - Market Structure - Distance	Stress-impact quality monitoring	Transport stress—bumps, knocks, trauma—was recognised as reducing final meat quality and market value.
7.12.5 Productivity	1C - Other Health Issues	Disease impact monitoring	Ongoing disease issues caused weight loss and reduced reproductive performance, lowering overall animal value.
	1A, 1C - Diseases	Mortality rate benchmarking	Farmers monitored mortality as a key productivity metric, aiming for 2–3% losses, with anything around 5% viewed as poor performance.
	1A - Tick-Borne Diseases	Calving benchmark	The farmer used a 250-day inter-calving interval as a key productivity benchmark, noting that a cow must produce a calf each year to stay profitable.
	2A - Direct Theft - Cattle	Kraaling mortality estimation	The farmer linked kraaling to productivity losses, estimating 3–4 calf deaths per season due to foot rot and diarrhoea caused by confinement.
	2B - Other Crimes - Hunting	Poaching productivity loss measurement	The farmer measured productivity loss due to poaching: 4 adult cows lost to snares over the past year, representing a significant loss of productive animals.
	3B - Climate & Weather - Drought	Drought productivity monitoring (or Calving percentage tracking)	The farmer noted that drought forces herd reductions and sharply lowers calving percentages, cutting overall productivity.
7.12.6 Throughput	3B - Climate & Weather - Fire	Throughput management by supplementary feed	The farmer maintained throughput during grazing losses by purchasing supplementary feed and managing feed cost per kg gain.
	4A - Price Challenges	Monthly sales throughput	The farmer established a monthly sales cadence setting throughput rhythm (animals/month), driving capacity planning and cash flow patterns.
	4B - Market Structure	Batch transport optimisation (or Volume-based transport efficiency)	The farmer improved throughput efficiency by selling animals in larger batches to fill a truck, lowering transport cost per animal.
7.12.7 Plan Effectiveness	5A - Labour Availability	Labour shortage impact assessment	A shortage of one worker slowed daily tasks and disrupted the entire schedule, reducing overall productivity.
	5D - Feed Production	Year-round feed planning	Ensuring enough feed was a constant planning challenge, requiring continuous planning throughout the year.

6.5.7 Supply Chain Management (BOK 8)

The extracts for BOK 8 could clearly be related to supply chain risk management, inventory control, transportation management, and supplier relationships. The extracts were coded as BOK 8 when the focus was on external supply chain activities, such as buying inputs, accessing markets, managing suppliers, or arranging transport. Discussions centred on internal farm operations were instead captured under BOK 7. Disease outbreaks such as FMD often disrupt normal supply channels and highlight the importance of supply chain resilience. These entries were coded as 8.1.1 and 8.6.7 because the main concern was maintaining supply chain continuity and managing supplier-related risks, rather than controlling hazards or ensuring farm safety.

Table 6-25: BOK 8.1 contextualised according to themes

BOK 8.1 Supply Chain Management Fundamentals			
BOK	Theme(s)	Context	Explanation
8.1.1 Supply Chain Processes	1B, 4A - Market Structure	Emergency sales channel	During the FMD outbreak, the normal supply chain collapsed—auction prices crashed, and heifers could not be sold—forcing the farmer to switch from auctions to direct farm sales through agents.
	4A, 4B - Market Structure	Diversified sales channels	The farmer moved from a historical, centralised, stable marketing system to a more flexible mix of direct abattoir sales, local buyers, and niche markets, avoiding the crowded traditional channels.
	4B - Market Structure	Monthly local market sales	When feedlots refused to buy females, the farmer relied on strong local demand, selling to local buyers every month and securing a steady cash flow.
8.1.5 Risk Management	4A - Price Challenges	Strategic sales timing	As a price taker, the farmer managed risk by carefully timing sales, aiming for March and November to avoid the April–June oversupply period that drives prices down.
	4A - Price Challenges	Informed holding strategy	The farmer managed risk by using informal timing strategies, holding back sales when market agents advised that prices were temporarily low and likely to rise again.
	6B - State Service Collapse	Supply stockpiling and neighbour support network	The farmer managed the risk of government vaccine supply failure by relying on other farmers and keeping extra vaccine stock so neighbours could help during shortages.
	1B - Controlled/Notifiable Diseases	Finished cattle channel security	By shifting to finished cattle rather than weaners, the farmer could sell directly to abattoirs—a more reliable route that remained open even when auctions shut down during FMD or COVID, effectively managing cash flow risk.

Table 6-26: BOK 8.4 contextualised according to themes

BOK 8.4 Managing Product Flow			
BOK	Theme(s)	Context	Explanation
8.4.1. Inventory control methodologies	8B - Cash Flow Management	Monthly sales cycle	The farmer used a fixed monthly selling cycle, releasing cattle to the market once a month as a simple, time-based inventory control system.
	5C - Reproductive Challenges	Non-productive cow replacement	The farmer applied a performance rule for herd inventory, culling cows that failed to produce a calf each year and replacing them to keep the breeding herd productive.
8.4.4 Transportation Management	4B - Market Structure - Distance	Transport sunk cost constraint	The farmer faced a transport commitment constraint: once a hired truck delivered cattle to market, the cost of return transport was too high, forcing immediate sales regardless of market prices to avoid wasting the transport expense.
	4B - Market Structure - Distance	Vehicle and road maintenance	The farmer managed transport costs by maintaining vehicles, repairing roads, improving fuel efficiency, and keeping routes workable.
	4B - Market Structure - Distance	Own transport strategy	The farmer preferred owning transport, reducing dependence on hired trucks, and gaining more control over scheduling and costs.
	4B - Market Structure - Distance	Batch transport	The farmer used load consolidation, loading up to 40 animals per truck to benefit from lower unit costs than sending multiple smaller loads.

Table 6-27: BOK 8.6 contextualised according to themes

BOK 8.6 Managing Supplier Relationships			
BOK	Theme(s)	Context	Explanation
8.6.2 Strategic Purchasing	5E - Input Costs	Collective bulk purchasing	Farmers used collective purchasing with neighbours to pool demand, improve price negotiation power, and lower unit input costs.
8.6.4.1 Supplier Selection	5D - Feed Production	Product supplier selection	Farmer sourced specialised suppliers for specific alternative tick-control products tailored to their operational conditions (Molatek Trophy Block designed for game).
	6B - State Service Collapse	Private supplier selection	Due to repeated failures at Onderstepoort, farmers shifted to private vaccine manufacturers, prioritising access to a reliable supply despite higher prices.

BOK 8.6 Managing Supplier Relationships			
BOK	Theme(s)	Context	Explanation
8.6.7 Supplier Risk Management	6B - State Service Collapse	State supply failure risk mitigation	Farmers faced severe supply failures—including critical vaccine shortages, epidemic-period delays, off-season medication delivery, and non-functional state facilities—forcing reliance on costly private options.
	1A - Tick-Borne Diseases	Chemical resistance management	The breakdown of research at Onderstepoort halted the development of new tick-control products, increased the risk of tick resistance, and required careful management of the limited remaining chemicals.
	1A - Tick-Borne Diseases	Commercial treatment risk assessment	Farmers noted that commercial combination treatments worsened long-term tick resistance by enabling multi-family resistance to develop simultaneously.

6.5.8 Engineering Management (BOK 9)

Alignment with BOK 9 was identified across customer focus, knowledge systems, strategic planning, and human resource management. The entries were coded as BOK 9 when they addressed the management and organisational aspects of farm operations. This included strategic decisions, knowledge sharing, and people management, rather than day-to-day implementation, which was covered by BOK 7. For example, the decision to move from selling weaners to finished cattle was coded as 9.1.2 (Market Product Strategy), as it represented an intentional choice in positioning the product. Meanwhile, the operational scheduling involved in that change was captured in BOK 7.

Table 6-28: BOK 9.1 contextualised according to themes

BOK 9.1 Customer Focus			
BOK	Theme(s)	Context	Explanation
9.1.1 Needs Identification	4B - Market Structure	Customer colour preference identification	The farmer noted that buyers across all markets prefer red cattle and tend to avoid black animals. Because of this, colour preference becomes part of how they plan their breeding.
	4B - Market Structure	Alternative market need identification.	The farmer identified strong local market demand for females (heifers, cows) that the closest commercial feedlots rejected. This developed alternative customer relationships, providing a steady monthly market for cows and heifers.
9.1.2 Market Product Strategy	4A, 4B - Price Challenges, Market Structure	Finished cattle product strategy	The farmer shifted from selling weaners to selling finished, slaughter-ready cattle. This lets them deal directly with abattoirs and choose when and where to sell, especially useful during market disruptions.
	4B - Market Structure	Low-competition market strategy	Instead of competing with big commercial producers in high-pressure markets, the farmer targets smaller niche markets that better suit their herd size and reduce competition.
	8B - Cash Flow Management	Year-round sales	The farmer spreads sales across the year by selling both weaners and cull cows at different times. This keeps cash flow steady rather than relying on one big seasonal sale.

Table 6-29: BOK 9.3 contextualised according to themes

BOK 9.3 Shared Knowledge Systems			
BOK	Theme(s)	Context	Explanation
9.3.1 Systems Planning	1A - Tick-Borne Diseases	Cross-referencing expert advice	The farmer cross-checks the vet's advice with other farmers in similar conditions to make sure the treatment is practical before using it.

BOK 9.3 Shared Knowledge Systems			
BOK	Theme(s)	Context	Explanation
	4B - Market Structure	Farm study group membership	The farmer joined a paid study group that provides access to anonymous financial records from other farms, creating a structured knowledge system for benchmarking performance analysis.
9.3.3 Infrastructure	2B - Other Crimes - Fire	Community fire response network	The farmer relies on a community fire-response system where neighbours coordinate standby equipment, water stockpiles, and labour to tackle fires together.
	1A - Tick-Borne Diseases	Neighbour vaccine backup network	The farmer and neighbours keep extra vaccines so they can help each other during shortages, ensuring someone always has backup stock.
	2A - Direct Theft - Cattle	Real-time alert system	The farmer depends on quick (real-time) phone alerts from herd boys, allowing them to respond immediately to hunting or security incidents.
	4B - Market Structure	Auction social networking	The farmer identified the collapse of traditional knowledge infrastructure, in which auctions served as social gathering spaces that enabled knowledge exchange among farmers.
	2A, 4B - Security, Marketing	Mutual neighbour support network	The farmer is part of a mutual-help system where neighbours watch out for each other and offer support when they can, strengthening local security and cooperation.

Table 6-30: BOK 9.6 contextualised according to themes

BOK 9.6 Strategic Management			
BOK	Theme(s)	Context	Explanation
9.6.2 Environmental scanning	1B - Controlled/Notifiable Diseases	FMD spread monitoring	The farmer engaged in environmental scanning by tracking the southward spread of FMD, observing widespread non-compliance with compulsory vaccinations, and monitoring regional disease patterns.
	2A - Direct Theft, 6A - Law Enforcement Failure	Institutional failure tracking	Farmers witnessed the complete institutional failure of law enforcement, which led to increased theft, making private security efforts essential.
	6B - State Service Collapse	Institutional failure tracking	The farmer used environmental scanning to identify the collapse of state veterinary and vaccine systems, prompting a shift toward costly private alternatives.
	6C - Political Threats	Political risk monitoring	Farmers monitored political uncertainty, including Ingonyama Trust land pressures, expropriation threats, and corruption risks from local officials, recognising these as strategic risk factors that require ongoing situational awareness despite their inability to control outcomes.
9.6.6 Strategic planning	4A - Price Challenges, 5E - Input Costs	Cost reduction strategy	Farmers implemented cost-cutting as a strategic response to sustained low beef prices and rising input costs, reducing feed and medical treatments, despite recognising this compromises production quality and creates a deteriorating cycle in which underfed cattle produce less.
	4A - Price Challenges, 8B - Cash Flow Management	Diversified sales strategy	Farmers strategically diversified sales timing and product mix (weaners, cull cows, heifers) across the year and developed alternative marketing channels (local sales, direct farm sales) to transform traditional twice-yearly revenue into monthly cash flow, mitigating price volatility and seasonal income gaps.
	4B - Market Structure	Finished product market strategy	The farmer strategically shifted from weaner sales to finishing cattle for abattoirs, planning around the fact that slaughter markets remain stable during crises while weaner markets collapse.
	4B - Market Structure	Proactive market timing	The farmer applied proactive strategic planning by closely monitoring disease outbreaks and market price trends, allowing them to anticipate the coming price collapse.
	1A - Tick-Borne Diseases	Visual dipping and breeding strategy	The farmer strategically moved from routine dipping to dipping only when ticks are visible and is breeding more tick-resistant, heat-tolerant cattle because chemicals no longer work well.
	4B - Market Structure, General	Market-driven breeding strategy	The farmer strategically breeds for market-preferred red, polled, hardy cattle and uses Boran cows crossed with terminal sires to balance adaptation and performance.
	2A - Direct Theft	Security-based cattle management	The farmer strategically keeps white Brahmans because they are easier to spot from the air during theft, and trains cattle to return home when stolen.

Table 6-31: BOK 9.7 contextualised according to themes

BOK 9.7 Human Resource Management			
BOK	Theme(s)	Context	Explanation
9.7.1 Human capital management	5A - Labour Challenges	Skilled labour constraints	Farmers identified labour as a major operational cost, with skilled labour unobtainable and expensive, limiting workforce size and constraining maintenance capacity.
	5A - Labour Challenges	Disciplinary intervention	Farmers applied disciplinary interventions (unpaid suspension for drinking) and had a high staff tenure (30 years).
9.7.3 Learning, education, training	5A - Labour Challenges	Practical skills development	Farmers provided on-farm training, teaching staff proper fencing techniques and animal handling procedures to address skilled labour shortages.
	1A - Tick-Borne Diseases	Cross-disciplinary learning	Farmers engaged in cross-disciplinary learning from wildlife management (observing eland aloe consumption), consulted multiple information channels (vets, peer farmers in similar geographic conditions), and applied iterative learning from treatment failures to shift strategies.
	General	Innovation beyond traditional knowledge	Farmers recognised survival requires learning beyond traditional multi-generational knowledge transmission, identifying knowledge deficits among emerging farmers as the root cause of poor disease control.

6.5.9 Safety (BOK 10)

The alignment with BOK 10 focused on hazard recognition and safety management, especially around biological hazards and emergency planning. A clear distinction was made between BOK 10.3 and BOK 10.4. Extracts were assigned to 10.3 (Hazard Recognition, Evaluation, and Control) when farmers identified specific hazards and described direct control measures. This included recognising tick-borne diseases and responding with dipping or vaccination. In contrast, the entries were coded 10.4 (Safety and Health Management) when the emphasis was on broader safety systems. This included how farmers prepared for emergencies, assessed risk likelihood and seasonality, and planned protective strategies. This distinction reflects the difference between spotting hazards and managing overall safety systems. Although only two subheadings were used, BOK 10 was linked to seven distinct interview themes, indicating that safety and risk considerations play a role across many aspects of farm operations.

Table 6-32: BOK 10.3 contextualised according to themes

BOK 10.3 Hazard Recognition, Evaluation, and Control			
BOK	Theme(s)	Context	Explanation
10.3 Hazard Recognition, Evaluation, and Control	1A - Tick-Borne Diseases	Biological hazard identification and disease control	Farmers identified tick-borne diseases (heartwater, red water, gall sickness) as major biological hazards, noting that different diseases occur in different areas and that ticks cannot be controlled in the veld but only on animals through dipping, blocking, and vaccination within critical time windows.
	1A - Tick-Borne Diseases	Natural immunity-based tick control	Farmers identified which ticks cause disease in different areas (heartwater tick in thorn country, frost kills ticks), using preventive dipping and blocking, but preferring to build natural immunity through controlled exposure.
	1B - Controlled/Notifiable Diseases	Infectious disease identification and treatment	Farmers identified serious infectious diseases (CA/Brucellosis, abscesses, foot rot) with environmental triggers, treating them while recognising treatment limitations and that diseased animals cannot be used for human consumption and must be disposed of.

BOK 10.3 Hazard Recognition, Evaluation, and Control			
BOK	Theme(s)	Context	Explanation
	1C - Other Health Issues	Treatment window identification	Farmers identified hidden health problems (parasites, worms, liver fluke, lung disease) that require antibiotic treatment and dosing, recognising that treatment must occur within specific time windows and that animals cannot be saved once abscesses become too large.
	1C - Other Health Issues	Environmental and nutritional hazard management	Farmers recognised environmental and nutritional hazards, including burnt grass causing abortions, 'geilsiekte' from excessive lush growth, and toxic hazards (poisonous plants, snakes) requiring plant removal or controlled grazing.
	3A - Predators	Seasonal predator control	Farmers identified jackals as a seasonal threat to calves during calving season (August-December), controlling them by shooting and culling.
	3A - Predators	Livestock guarding	Farmers used dogs and guards to protect both sheep and cattle from predators and theft.
	2B - Other Crimes - Fire	Fire hazard response	Farmers recognised wildfire as a human-caused hazard caused by illegal hunting and arson, requiring emergency preparedness and response infrastructure for fire suppression.
	7A - Water Availability	Water infrastructure safety modifications	Farmers identified drowning hazards in water infrastructure (clay dams, stone troughs), implemented partition walls in troughs to prevent larger animals from pushing calves into the water, fenced off muddy dam areas, and installed above-ground drinking systems.

Table 6-33 presents BOK 10.4 contextualised within the interview data and categorised according to the inductive themes of Chapter 5. Where BOK 10.3 focused on identifying and controlling specific hazards, BOK 10.4 focused on the broader safety management infrastructure—how farmers prepare for emergencies and assess risks to plan protective strategies.

Table 6-33: BOK 10.4 contextualised according to themes

BOK 10.4 Safety and Health Management			
BOK	Theme(s)	Context	Explanation
10.4.2 Emergency planning	2B - Other Crimes - Fire	Community fire response	Farmers prepared for fire emergencies by keeping seasonal stockpiles (20L water containers, back sprays), gathering neighbours, and calling workers for community fire response.
	1C - Other Health Issues	Emergency health response protocols	Farmers developed various emergency response protocols, for instance: for poisoning incidents, keeping buffer stocks of medicines and quarantine plans, using activated charcoal for poisoning, vaccinating whole herds during outbreaks, and relying on neighbour backup when supplies ran low.
	2A - Direct Theft	Theft recovery system	Where police failed, farmers used local security groups to investigate and secure compensation, organised community repairs, and deployed urgent theft-recovery measures (helicopters, armed response, herd-boy alerts), relying on community pressure to recover losses and get paid.
	1A - Tick-Borne Diseases	Mortality threshold intervention	If mortality exceeded ~5%, the operation escalated from individual treatment to emergency protocol, specifically whole-herd blocking—an explicit trigger for rapid intervention.
10.4.5 Risk assessment/hazard analysis	1A - Tick-Borne Diseases	Controllable vs uncontrollable risk assessment	Farmers separated what they could control (dipping, vaccination, fencing) from field-level risks (tick prevalence, stray animals), using intervention windows to determine when treatment remained effective.
	1B - Controlled/Notifiable Diseases	External disease threat monitoring	Farmers watched for stray animals and tracked their neighbours' vaccination practices, understanding that disease spreads regionally when neighbours do not vaccinate, even if they control it well on their own farms.
	2A - Direct Theft	Theft risk assessment	Farmers assessed theft vulnerability by farm location (near roads), armed offenders (to avoid confrontation), and night thefts (leaving no evidence), shaping realistic security responses.

6.5.10 Information Engineering (BOK 11)

BOK 11 alignment was found mainly in the data analysis subheading. Farmers described using historical production and market data to support operational decisions. Coding focused on 11.17

(Data Analytics) rather than BOK 1.4 (Recording and Analysis Tools), because the emphasis was on interpreting the data, such as identifying patterns, trends, and seasonal effects, rather than collecting or recording them.

Table 6-34: BOK 11.17 contextualised according to themes

BOK 11.17 Data Analytics			
BOK	Theme(s)	Context	Explanation
11.17.1 Data preparation	4B - Market Structure, 5C - Reproductive Challenges	Production performance tracking	Farmers systematically recorded historical data, including conception rates, weaner weights, and prices from previous years, maintaining organised datasets for operational analysis and decision-making.
11.17.4 Descriptive analytics	4B - Market Structure	Historical price trend analysis	Farmers analysed historical price trend data to identify seasonal market patterns (an April-June weaner influx causing price drops) and used descriptive analytics to optimise sale timing for March and November, when prices are higher.

6.5.11 Product Design and Development (BOK 13)

BOK 13 had limited alignment with cattle production, with only one subheading identified (13.1 Design process). The entries were coded as BOK 13 when the focus was on the product's characteristics or suitability rather than broader management or market decisions, which were captured under BOK 9.

Table 6-35: BOK 13.1 contextualised according to themes

BOK 13.1 Design Process			
BOK	Theme(s)	Context	Explanation
13.1.2 Identify need	1A - Tick-Borne Diseases, 3C - Terrain & Vegetation	Environment-based breed selection	Farmers identified the need for breeds adapted to local tick-borne diseases and terrain, noting that African and Indian breeds (Boran, Nguni, Brahman) cope better than European types. They emphasised selecting hardy cattle capable of long-distance grazing, making English breeds like Angus unsuitable for their conditions.
13.1.6 Product life cycle	5C - Reproductive Challenges, 4B - Market Structure	Product stage definition	Farmers defined their main product stage—whether weaners, finished cattle, or stud animals—with some shifting from selling weaners to producing slaughter-ready cattle. This shift aimed to improve income stability and retain more control over market timing.

6.5.12 Systems Design and Engineering (BOK 14)

BOK 14 was related to only one subheading, namely risk analysis, but this subheading appeared in nine different interview themes. This was one of the highest levels of theme coverage in the CPCM. The entries were coded as BOK 14.10.4 when farmers discussed how risks affected the larger agricultural system, particularly in terms of time, production or financial impact. Farmers often described the long recovery period after drought-related destocking, as well as the effects that animal losses had on production and cash flow. BOK 14.10.4 was applied only when farmers linked a risk to its longer-term or wider system effects. Although only one subheading was identified, the findings show that risk is connected to many parts of cattle farming operations.

Table 6-36: BOK 14 contextualised according to themes

BOK 14.10 Completing the Systems Engineering Process			
BOK	Theme(s)	Context	Explanation
14.10.4 Risk analysis	1A - Tick-Borne Diseases	Weekend treatment delay risk	Farmers recognised that animals frequently get sick on weekends when medication suppliers are closed, creating a predictable risk where treatment delays can turn manageable diseases into fatal ones.
	1A - Tick-Borne Diseases	Geographic disease risk assessment	Farmers assessed how geographic and climatic factors shape disease risk, noting that thorn veld conditions and mild winters create persistent heartwater and tick pressure. They noted that red water has a 24-hour treatment window, where delayed detection increases mortality.
	1A - Tick-Borne Diseases	Long-term chemical availability risk	Farmers assessed Onderstepoort's research collapse as an escalating future risk: with no new tick chemicals under development, they face increasing tick resistance and fewer treatment options.
	2A - Direct Theft	Continuous security threat assessment	Farmers recognised theft as a continuous threat, with thieves stopping on roads at night to shoot cattle and load them into trucks. They saw theft as driven by unemployment.
	6C - Political Threats	Political risk assessment	Farmers identified land expropriation as an existential threat that outweighs operational risks such as disease or theft. They viewed land insecurity as a risk that could end their operations.
	3B - Climate & Weather - Drought	Climate risk assessment	Farmers analysed how drought forces immediate destocking, reduces carrying capacity, and lowers calving percentages, creating predictable production losses. They also recognised that excessive rainfall increases the risk of foot rot outbreaks. They concluded that drought and rain cannot be prevented at the farm scale, rendering them hazards that can only be managed reactively.
	2B - Other Crimes - Fire	Fire risk assessment	Farmers identified fire as a human-caused hazard, often started by illegal hunters. Because ignitions usually occur inside property boundaries, the fires bypass perimeter firebreaks, creating a persistent risk. They concluded that prevention alone is insufficient and that farms require robust emergency response capacity and standby resources.
	7A - Water Availability	Water infrastructure risk	Farmers analysed compound risks, such as borehole-solar dependency during extended cloudy periods, the high cost of distributing water to multiple camps, and storms that fall short of the intensity needed to fill dams.
	4B - Market Structure	Market disruption analysis	Farmers assessed how deregulated markets removed price protections and how epidemics (FMD, COVID) repeatedly disrupt weaner auctions. Through this analysis, they determined that finished cattle marketed to abattoirs exhibit a more resilient risk profile: abattoirs remain open during crises to meet food security requirements. Shifting to finished cattle, therefore, provides greater income stability and strategic control.
	1A - Tick-Borne Diseases, 1C - Other Health Issues	Treatment delivery delay analysis	Farmers noticed how schedule delays trigger cascading failures: late vaccine delivery turns a timing slip into treatment failure and animal losses.
	2B - Other Crimes - Fire	Fire recovery trade-off analysis	Farmers modelled fire damage as a cost-schedule trade-off: wait for natural grass regrowth (low cost, long delay) versus buy emergency feed (high cost, immediate schedule), both carrying abortion and performance risks if nutritional needs are not met.
	4A - Price Challenges	Demand risk assessment	The farmer noted that tough economic conditions posed a systemic risk, as they pushed consumers toward cheaper proteins like chicken and maize meal, reducing red meat demand and lowering beef prices across the supply chain.
	4B - Market Structure	Market price manipulation assessment	Buyer concentration was a major risk: with one company holding around 60% of the market, farmers saw clear price manipulation and depressed weaner prices.
	3B - Climate & Weather - Drought	Drought market price assessment	Drought created a compound supply chain risk; everyone had to sell at the same time, flooding the market and forcing prices down to the bare minimum.

6.6 Synthesis of Findings

The contextualisation of the IISE Body of Knowledge within cattle production systems identified several patterns across the findings. Figure 6-3 summarises the coverage of the CPCM across all 14 BOKs, showing the number of IISE BOK subheadings identified in the interview data relative

to the total available subheadings per BOK, along with the number of unique interview themes covered in each BOK. It is clear from the graph that the BOK subheadings identified from the interview data (purple bar) are much fewer than the actual number of BOK subheadings that exist for all BOK except BOK 3.

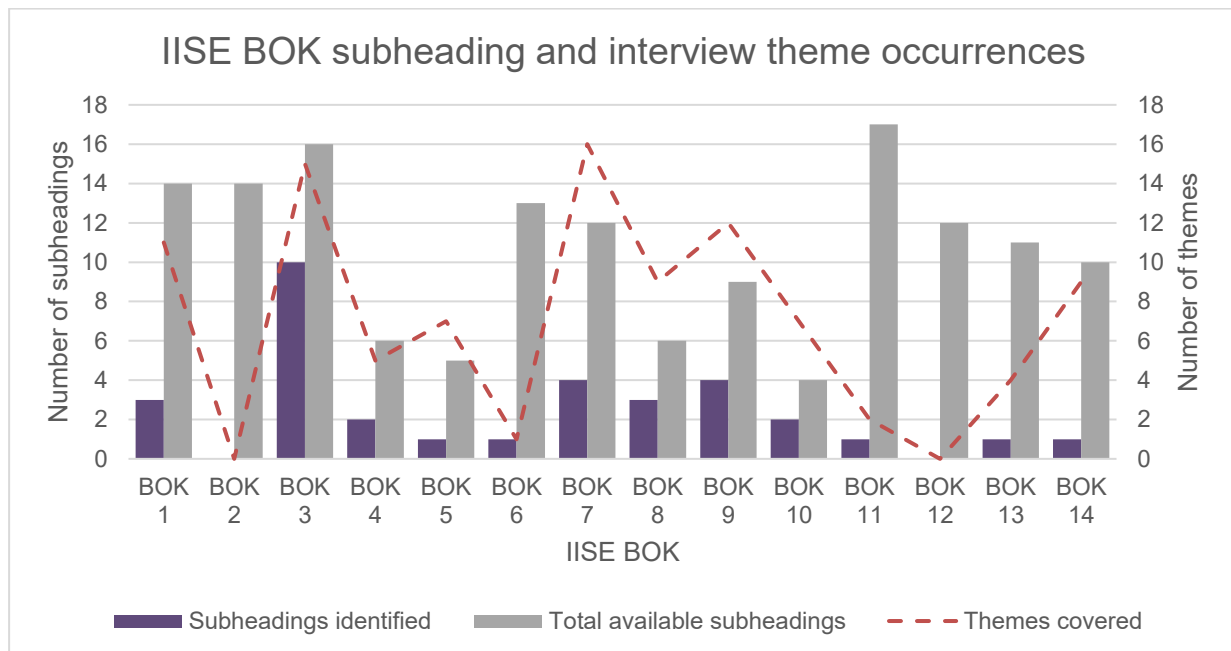


Figure 6-4: IISE BOK subheading coverage and interview theme breadth per BOK in the CPCM

1. Pattern 1 — Strongest BOK alignments:

A notable first pattern was that certain BOK areas showed stronger alignment with the challenges and practices described by the participants. In particular, Engineering Economic Analysis (BOK 3), Operations Engineering and Management (BOK 7), Supply Chain Management (BOK 8), Safety (BOK 10), and Systems Design and Engineering (BOK 14) appeared repeatedly across multiple themes and subthemes. These BOK areas were supported by detailed farmer-reported examples specifically relating to production planning, financial pressures, logistics, disease management, labour coordination, operational decision-making, and the interconnected nature of farm systems. The recurring presence of these BOKs suggests that many of the practical challenges in cattle production are strongly systems-oriented and operational, aligning closely with core industrial engineering principles.

2. Pattern 2 — Weakest BOK alignments:

In contrast, several BOK areas showed weaker or more limited alignment within the data. Work Design and Measurement (BOK 1), Ergonomics and Human Factors (BOK 6), Information Engineering (BOK 11), and Product Design and Development (BOK 13) were represented by

fewer subheadings and narrower thematic coverage. This does not necessarily indicate that these areas are irrelevant to cattle production systems, but rather that they are currently less visible in existing farming practices and farmer-reported experiences. Therefore, these findings may point to opportunities for future industrial engineering intervention and research, particularly in areas such as structured data systems, human-factor optimisation, formal work measurement, and innovation-focused product development within agricultural systems.

3. Pattern 3 — Recurring themes across BOKs:

Another important finding was that certain inductive themes appeared repeatedly in multiple BOK areas. Several of the challenges identified in Chapter 5 emerged throughout the contextualisation framework, particularly Theme 1A (tick-borne diseases), Theme 3B (climate and drought), and Theme 4A (price challenges). These themes were related to economic, operational, supply chain, safety, and system-related BOK categories, suggesting that they are not isolated production issues but broader challenges affecting multiple parts of the cattle production system simultaneously. Their repeated appearance across the matrix indicates that these are among the most interconnected and difficult challenges in cattle farming and, therefore, may offer strong opportunities for integrated industrial engineering approaches.

4. Pattern 4 — Implicit vs explicit application:

A final pattern that emerged from the findings is that the link to industrial engineering was mostly indirect. None of the participants described their practices using terms from industrial engineering or formal IE methods. Instead, farmers seemed to develop these types of practices through experience, adjustment, and trial and error in the course of daily farm management. This suggests that a link exists between the findings and industrial engineering, but it is not formally recognised.

6.7 Chapter Summary

This chapter examined how farmers' reported production challenges align with the Industrial Engineering Bodies of Knowledge. It maps each challenge to the relevant BoK areas, showing which domains already intersect with farmers' day-to-day practices and where additional IE methods could be applied. Although farmers were not intentionally using IE frameworks, their practical decision-making often reflected established IE principles. This analysis, therefore, positions the IISE-BoK within the realities of cattle production systems.

CHAPTER 7 ARTEFACT EVALUATION

Figure 7-1 shows the current position within the research method.

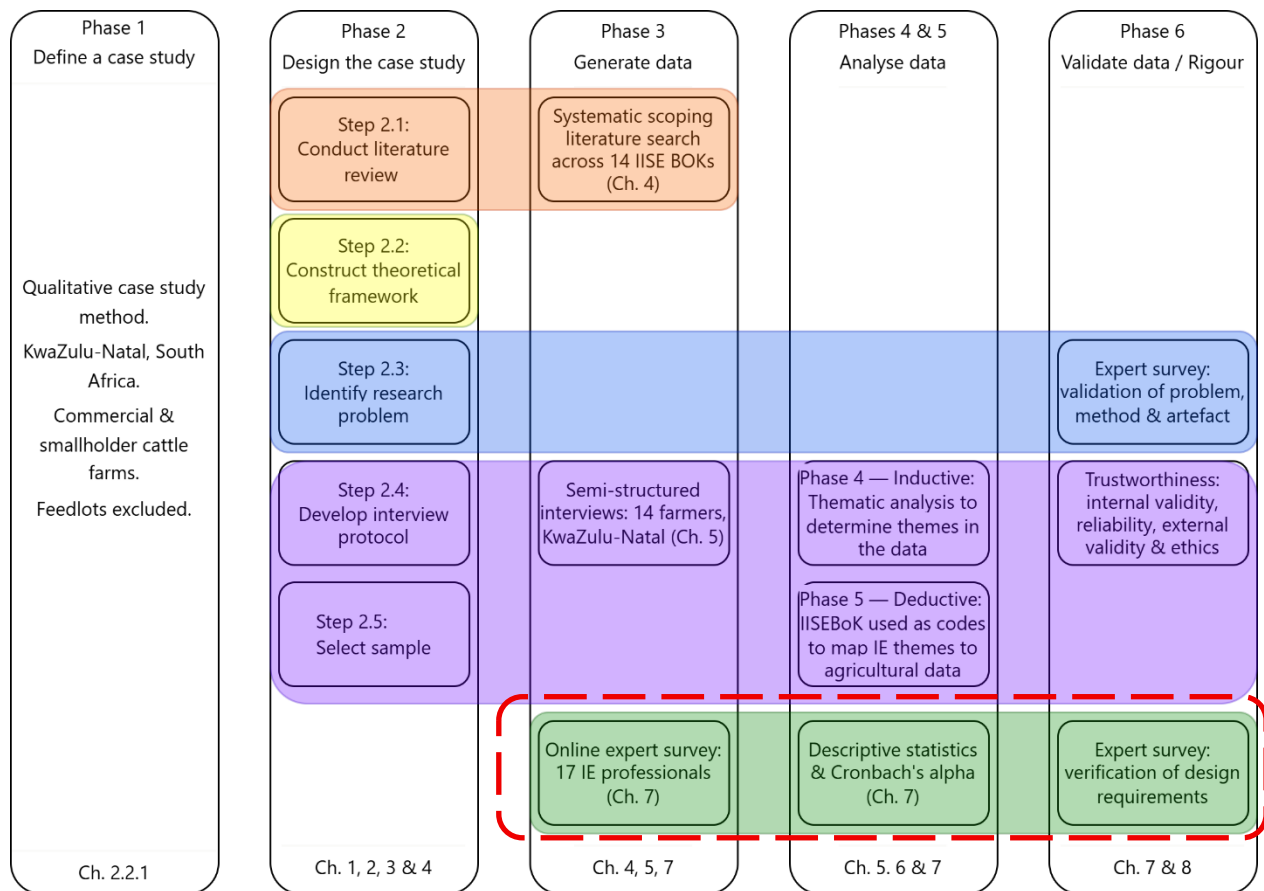


Figure 7-1: Research method

7.1 Introduction

The IISE-BOK Cattle Production Contextualisation Matrix (CPCM), developed in Chapter 6, was evaluated through expert surveys. The purpose of the surveys was to evaluate the contextualisation tables within cattle production systems. This chapter describes the survey design, its administration, and the results obtained from the responses. Based on the feedback received, the artefact was refined to incorporate the suggested improvements.

7.2 Selection of survey participants

The survey participants were selected through purposive sampling, targeting industrial engineers who were familiar enough with cattle production systems to judge whether industrial engineering concepts were applicable in that context.

The survey invitation was shared through professional networks, including LinkedIn posts and the researcher's professional contacts. The invitation was also shared through messaging platforms such as WhatsApp to increase exposure among potential participants with relevant expertise.

The survey participants included industrial engineering professionals from both industry and academia. Purposive sampling was supplemented with snowball sampling, in which initial participants recommended colleagues who met the inclusion criteria for dual exposure to industrial engineering and cattle production. The evaluation was an expert survey that provided a single round of structured feedback on the CPCM.

In total, 18 responses were received, of which one was used for the pilot test of the survey instrument. The remaining 17 responses formed the final data set used for artefact evaluation.

In accordance with qualitative research guidelines, the sample size remained flexible. In addition, the following inclusion criteria were established:

1. Inclination and ability to partake in the study
2. Adequate time to partake

Figure 7-1 provided a summary profile of the 17 survey participants and their years of experience in Industrial Engineering. All participants held formal qualifications in Industrial Engineering and had 1 to 10+ years of experience. The majority had 2-4 years of formal IE experience. Figure 7-2 and Figure 7-3 provided a summary profile of the 17 survey participants and their exposure to cattle production. Most participants had exposure to agriculture through a family farming background. Eight participants grew up on a cattle farm, four currently live or work on one, and two had academic or research exposure to cattle production systems. Participants could select multiple exposure types, reflecting the overlapping nature of lived experience in agricultural contexts. This dual exposure to both IE and cattle production was the primary inclusion criterion, ensuring that participants were sufficiently qualified to evaluate the applicability of IE knowledge within the cattle production context.

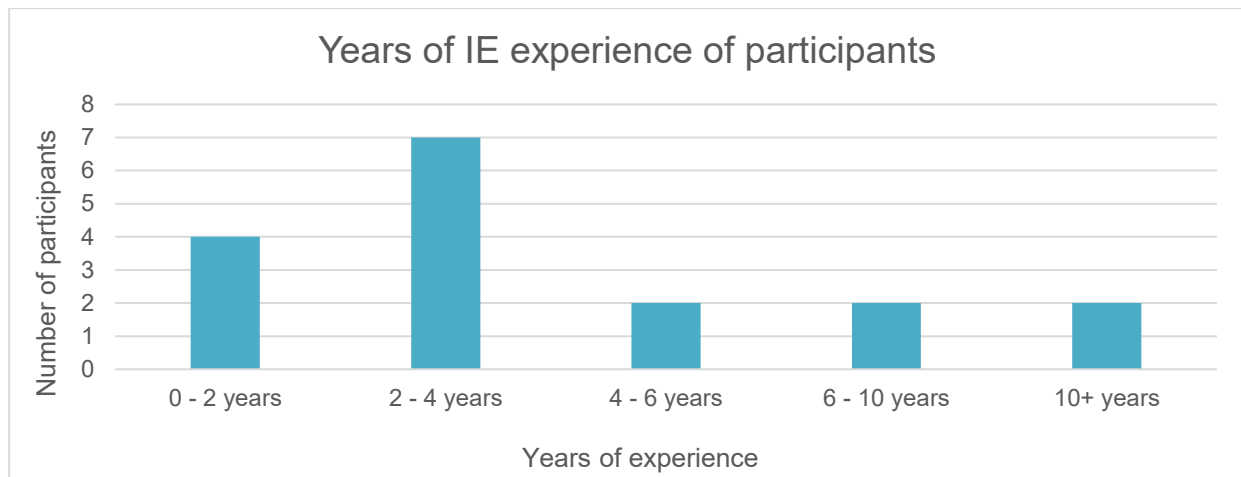


Figure 7-2: Survey participant profile (IE experience)

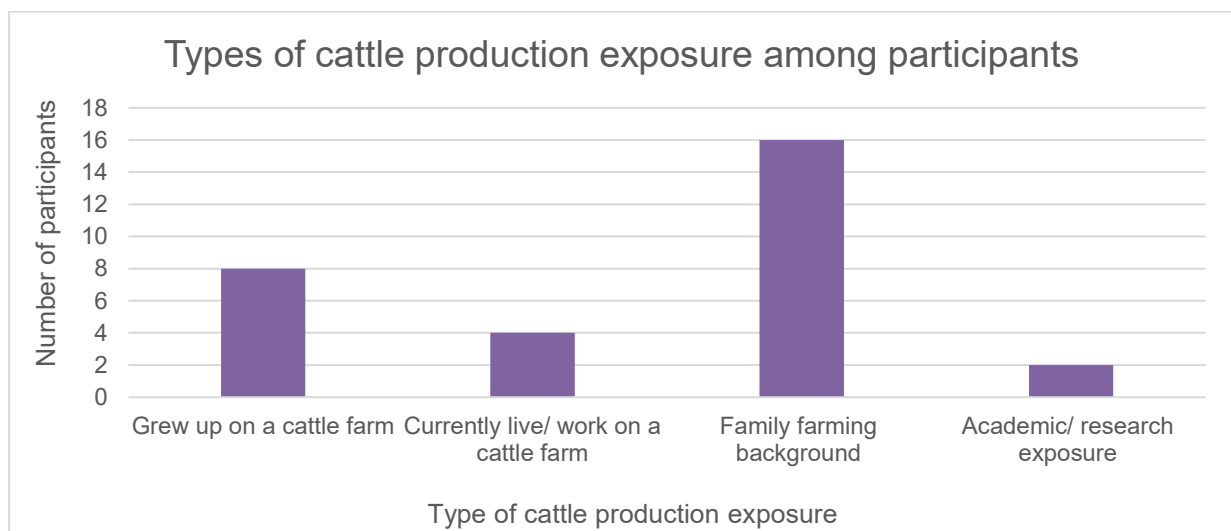


Figure 7-3: Survey participant profile (Cattle production exposure)

7.3 Administration procedure

An online survey was administered using a Google Form, with a downloadable PDF holding the contextualisation framework and an informed consent overview. A link to the survey was emailed to potential participants.

7.4 Survey design

To assess the contextualisation framework, a self-administered survey was used, allowing participants to complete it in their own time without the researcher present (Sinkowitz-Cochran, 2013). The survey consisted mainly of closed-ended, five-point Likert-scale statements in which respondents indicated their level of agreement (Sinkowitz-Cochran, 2013). An open-ended

comment section was included to capture any additional insights, concerns, or suggestions participants wished to share beyond the structured rating items.

7.4.1 Survey design requirements

Drawing on the guidelines outlined in Section 2.3, a checklist was used to inform and structure the survey design. All identified design requirements were applied during the development of the survey, as demonstrated in the checklist presented in Table 7-1

Table 7-1: Survey design requirements checklist

No.	Survey design requirement	Achieved (Y / N)
1.	Format should be uncluttered and well-spaced.	Y
2.	Instructions should be included.	Y
3.	The survey should have a thank-you message at the end.	Y
4.	Use a pre-existing scale for responses.	Y
5.	Statements should be comprehensible and not vague/ambiguous.	Y
6.	Statements should avoid bias and not be leading/persuasive.	Y
7.	Statements should avoid jargon and unexplained acronyms.	Y
8.	Avoid unnecessary statements.	Y
9.	Statements should be short.	Y
10.	Avoid double-barrelled statements.	Y
11.	Compartmentalise statements by grouping them.	Y
12.	Use simple/basic English at the correct reading level.	Y

7.4.2 Scale of choice

Fanning (2005) and Sinkowitz-Cochran (2013) note that Likert-type response scales are well-suited for measuring the strength of participants' agreement or disagreement with survey statements. Based on these recommendations, this study used a five-point Likert scale, as shown in Table 7-2.

Table 7-2: Likert scale for survey

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree

7.4.3 Defining consensus

A statement was considered to have reached consensus when its average rating exceeded 75%—equivalent to a score of 3.75 or higher on the 5-point Likert scale (Nordin, et al., 2012).

When this threshold was met, the statement was considered to have received sufficient expert agreement to be considered supported.

7.4.4 Survey statements design

The survey was designed to evaluate the IISE-BOK contextualisation framework developed for cattle production systems. To systematically assess the matrix's validity and contribution, Table 7-3 maps survey statements to the following evaluation criteria (De Vos, et al., 2011):

1. Verify design requirements – Confirm the matrix meets specified usability, comprehensiveness, or accessibility criteria.
2. Validate the problem statement – Confirm that industrial engineering knowledge application in cattle production currently lacks systematic integration.
3. Verify the artefact addresses the problem – Assess whether the contextualisation framework successfully bridges industrial engineering and cattle production.
4. Verify novelty and contribution – Establish that the transdisciplinary mapping represents a unique contribution to both IE and agricultural domains.

Table 7-3 details how each survey statement aligns with these evaluation objectives, ensuring a comprehensive assessment of the validity, applicability, and contribution of the matrix to the transdisciplinary IE-agriculture collaboration.

Table 7-3: Development of survey statements

Objective	Elements	Survey statements
Verify design requirements (as discussed in section 7.4.1).	DR 1 – Simple in structure DR 2 – Visually intuitive DR 3 – Legible DR 4 – Connects BOK to actual farm practices DR 5 – Explains why BOK applies to the context DR – 6 Accessible to both IE and the agriculture disciplines	1 - The matrix is simple in design. 2 – The matrix is visually intuitive. 3 – The matrix is legible. 4 - The matrix shows how the Industrial Engineering BoK can link to real cattle-farm practices. 5 - The matrix explains why each BoK area is relevant to cattle production. 6 - The matrix is understandable to both industrial engineering and agriculture professionals.

Objective	Elements	Survey statements
Validate the problem statement (PS)	PS – The problem is that Industrial Engineering research has not been aligned with the beef cattle industry, limiting the development of pragmatic solutions to food security challenges.	7 - Industrial engineering knowledge is not as widely applied in cattle production, and structured methods for applying IE to cattle production are limited.
Verify the artefact addresses the problem.	PS – The problem is that Industrial Engineering research has not been aligned with the beef cattle industry, limiting the development of pragmatic solutions to food security challenges.	8 - Challenges in cattle production could benefit from industrial engineering solutions. 9 - The matrix provides a valid approach for transferring industrial engineering knowledge into cattle production.
Verify novelty and contribution of the artefact.	To test the originality and novelty of the proposed framework	10 - To the best of your knowledge, would you say the construction and integration of the contextualisation matrix is an original design (as opposed to just a duplication of other previous work)?

7.4.5 Format (Layout) of the survey

The final survey format (available in Annexure E) was composed of the following sections:

- Introduction and informed consent
- Participant data
- The downloadable PDF
- Confirmation of the design requirements
- Confirmation that the contextualisation framework addresses the research problem
- Closure

7.5 Survey Analysis Method

To analyse the survey results, the following steps were completed:

- (i) The results were exported to an Excel sheet and formatted into a table.
- (ii) To analyse the quantitative and qualitative results separately, they were split.
- (iii) The Cronbach's alpha statistic was calculated to assess the survey's reliability.
- (iv) For the quantitative results, the average for each statement was calculated.
- (v) If the average of the quantitative results was above 75% (3.75), a consensus was reached, and the statement was therefore verified or validated. The findings were discussed in section 7.6.
- (vi) If a consensus were not achieved for a statement, the qualitative results for that statement would have been analysed. This would have been done to understand why consensus was not achieved and to address any shortcomings identified in the qualitative feedback.

7.6 Survey Results

After the survey was conducted, all the results and feedback from 17 respondents were tabulated (as shown in annexure F). The average and percentage for each survey statement were calculated and are shown in Table 7-4.

Table 7-4: Survey results

Survey statement	Average (1-5)	Percentage (%)
1 - The matrix is simple in design.	4.35	87.06
2 - The matrix is visually intuitive.	4.18	83.53
3 - The matrix is legible.	4.53	90.59
4 - The matrix shows how the Industrial Engineering Bodies of Knowledge can link to real cattle-farm practices.	4.18	83.53
5 - The matrix explains why each specific Body of Knowledge area is relevant to cattle production.	4.53	90.59
6 - The matrix is understandable to both industrial engineering and agriculture professionals.	4.65	92.94
7 - Industrial engineering knowledge is not as widely applied in cattle production, and structured methods for applying IE to cattle production are limited.	4.53	90.59
8 - Challenges in cattle production could benefit from industrial engineering solutions.	4.29	85.88
9 - The matrix provides a valid approach for transferring industrial engineering knowledge into cattle production.	4.53	90.59
10 - To the best of your knowledge, would you say the construction and integration of the contextualisation matrix is an original design (as opposed to just a duplication of other previous work)?	4.29	85.88

Cronbach's alpha was calculated to assess the survey's reliability. This measured the internal consistency and reliability of the survey design. The calculation overview is showcased as follows, but the detailed calculation can be found in Annexure G:

$$\alpha = \left(\frac{k}{k-1} \right) \left(\frac{s_y^2 - \sum s_i^2}{s_y^2} \right) = \left(\frac{17}{17-1} \right) \left(\frac{23.404 - 4.919}{23.404} \right) = 0.839$$

Therefore, an α value of 0.839 was calculated. According to the Cronbach's alpha values (in Section 2.4), this falls within the good range of internal consistency, the survey was well-designed, and participants answered with understanding. The results from Table 7-4 are further discussed in sections 7.6.1 – 7.6.4 using both quantitative (averages) and qualitative (comments and feedback) data. The artefact was given to participants in a PDF format. The PDF included a table of contents for easy navigation between sections. As the analysis identified only 12 of the 14 BOKs from the interview data, each BOK was a section; therefore, there were 12 sections. The artefact included a diagram showing the 14 IISEBoK in various colours in the document's introduction. After the introduction, each section included its associated contextualisation tables. The artefact is in Annexure H.

7.6.1 Verify the matrix's design requirements.

The design requirements for the matrix were evaluated using survey statements 1 – 6. From the results in Table 7-4, it is evident that all the statements received consensus from participants. Although for statements 1, 2, and 3, which are more about the visual design of the matrix, one participant added that the colour coding of the different sections made it more user-friendly. Another participant commented that the colours of each section should have matched those in the IISEBoK diagram in the introduction section, but still gave statement 1 a rating of 5, statement 2 a rating of 4, and statement 3 a rating of 4. Although a consensus was also reached for statements 1, 2, and 3, with average percentages of 87.06%, 83.53%, 90.59%, the colours in the tables have been adjusted to match those from the IISEBoK diagram.

7.6.2 Validate problem statement

Survey statement 7 was focused on validating the problem statement. The results in Table 7-4 indicate that this statement achieved consensus amongst participants, suggesting that experts in the field perceive the research problem as relevant and recognisable in industry. The statement achieved an average percentage of 90.59%. This supports the conclusion that Industrial Engineering research has not been widely transferred to the beef cattle industry, thereby limiting the availability of pragmatic solutions to the industry's challenges. This gap presents an

opportunity for Industrial Engineering to contribute knowledge, tools, and methodologies that support more effective decision-making and problem-solving in cattle production systems.

7.6.3 Assess the artefact's relevance and applicability.

To gather expert feedback on whether the artefact is perceived as relevant and useful in addressing the research problem, survey statements 8 and 9 were evaluated. For statement 8, there was consensus that challenges in cattle production could benefit from industrial engineering solutions, with an average percentage of 85.88%. Statement 9 also reached an agreement, indicating that participants perceived the artefact as a useful approach for transferring industrial engineering knowledge into cattle production, with an average percentage of 90.59%. Thus, no changes were made to the artefact.

7.6.4 Verify the novelty of the artefact.

Statement 10 was added for exploratory purposes, but it still reached consensus, with an average percentage of 85.88%. This means that the construction and integration of the contextualisation framework was approved as an original design. However, originality is more appropriately assessed through academic peer review than through a practitioner survey, since practitioners do not typically conduct formal reviews of the research literature. The results for Statement 10 should therefore be interpreted carefully. The consensus reflects participants' professional experience and awareness of similar tools, rather than a comprehensive evaluation of existing academic work. One participant added a comment for this section:

"It is the first time I have seen each aspect accurately identified and linked to its specific BOK. It is very intuitive and makes one realise just how much opportunity there is for IE knowledge and methods to be applied in cattle production."

7.7 Chapter summary

This chapter explored the approach, design, and results from the survey. The qualitative and quantitative feedback was examined for statements, providing supportive expert feedback on the perceived relevance, usability, and applicability of the CPCM.

CHAPTER 8 Verification and Validation

Figure 8-1 shows the current position within the research method.

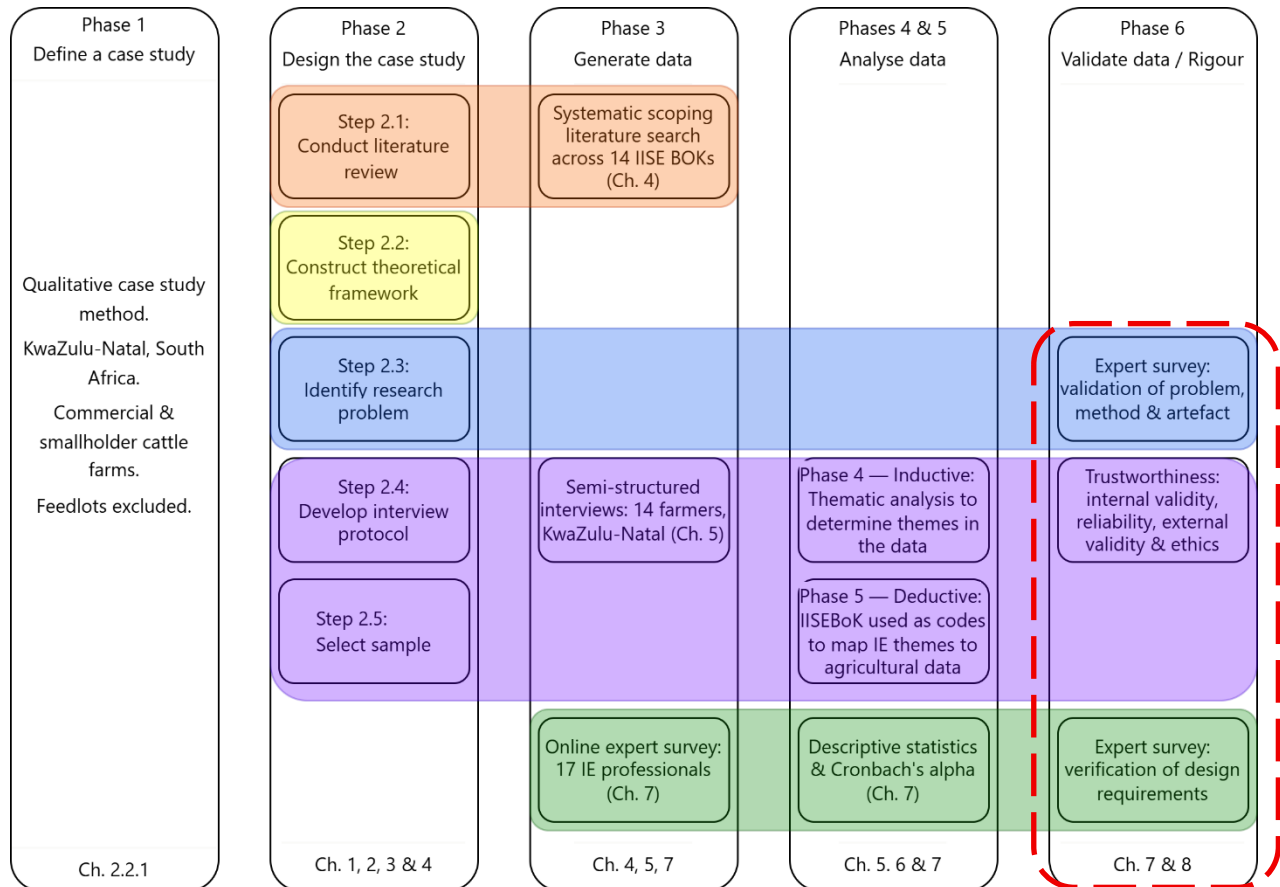


Figure 8-1: Research method

8.1 Introduction

The research presented in this study was evaluated using two approaches: the rigour of the research process and the verification and validation of the designed artefact. The different strategies used to ensure both the credibility of the research process and the artefact developed in this study are summarised in this chapter.

The research process followed a qualitative case study approach and therefore addressed rigour through credibility, dependability, and transferability as discussed by Merriam (2009). These principles relate to the extent to which the research findings accurately reflect reality, the consistency of the research procedures, and the applicability of the findings to similar contexts. Techniques such as triangulation, peer review, audit trails, and rich descriptions were used to strengthen the study's trustworthiness.

The verification and validation for this study were conducted in accordance with engineering design principles. Therefore, verification and validation are defined as follows:

- Verification is the process of determining whether the artefact meets the intended specifications (Le Dain, et al., 2013).
- In this study, validation is interpreted across three dimensions: (1) whether the research problem was valid and relevant to industry; (2) whether the research methodology was appropriate and rigorously applied; and (3) whether the resulting artefact is valid, that is, whether the designed framework addresses the research problem (Le Dain, et al., 2013).

Therefore, this chapter first discusses the strategies used to ensure rigour in the research process. The verification and validation of the artefact (the IISE-BOK Cattle Production Contextualisation Matrix) are also presented.

8.2 Artefact Verification

- **Confirm that the artefact adheres to the design requirements** – Surveys were used to verify that the CPCM met the design requirements.

8.2.1 Verification of adherence to the design requirements for the final artefact

The adherence to the design requirements of the contextualisation tables was verified by Engineers with agricultural experience with a survey (as discussed in Chapter 7). The survey used 6 questions to confirm that the matrix met the design requirements, as shown in Table 8-1. As discussed in section 7.6, all the questions reached consensus.

Table 8-1: Verification of artefact design requirements

Survey statement	Average	Percentage
1 - The matrix is simple in design.	4.35	87.06
2 - The matrix is visually intuitive.	4.18	83.53
3 - The matrix is legible.	4.53	90.59
4 - The matrix shows how the Industrial Engineering Bodies of Knowledge can link to real cattle-farm practices.	4.18	83.53
5 - The matrix explains why each specific Body of Knowledge area is relevant to cattle production.	4.53	90.59
6 - The matrix is understandable to both industrial engineering and agriculture professionals.	4.65	92.94

8.2.2 Summary of artefact verification

The step discussed in the previous section ensured that the artefact met its design requirements, and therefore supported the verification of the matrix.

8.3 Validation

The validation for this research had three outcomes:

- **Support the existence of a valid research problem** – An initial investigation was conducted to determine the extent to which Industrial Engineering has been contextualised within cattle production (Chapter 1), along with an in-depth investigation via a scoping review (Chapter 4). The expert survey further supports the relevance of the research problem, as engineers with agricultural experience indicated agreement with its significance (Chapter 7).
- **Demonstrate that a rigorous research method was followed** – The study used the trustworthiness framework proposed by Lincoln & Guba (1985) to ensure the quality and integrity of the research method.
- **Support the validity of the artefact** – The expert survey supports the relevance of the problem statement and indicates that the contextualisation tables offer a useful way to address it.

8.3.1 Validation of the research problem

As stated in Chapter 1, the research problem is that Industrial Engineering research has not been aligned with the beef cattle industry, limiting the development of pragmatic solutions to food security challenges. The research problem was explored in the scoping review (Chapter 4) and further supported by an expert survey (Chapter 7). The scoping review showed that practical farm-focused applications of IISE BOK methods in beef production appear limited, suggesting a literature gap between academic applications and farm practice. The expert survey provides additional support for this finding as survey statement 7 (“Industrial engineering knowledge is not as widely applied in cattle production and structured methods for applying IE to cattle production are limited”) produced an average agreement of 4.53 (90.59%), exceeding the consensus threshold of 75%. The combination of the scoping review and survey results provides convincing evidence that the research problem is real and relevant within the intended context.

8.3.2 Validation of the research method

Rigour in qualitative research is typically evaluated using the criteria of credibility, dependability, transferability, and confirmability. As discussed in Section 3.6, this study adopted the trustworthiness framework proposed by Lincoln & Guba (1985) to ensure the quality and integrity of the research process. The strategies used to achieve these criteria were implemented throughout the data collection and analysis stages of the study. This section summarises how

credibility, dependability, confirmability, and transferability were addressed during the research process.

8.3.2.1 Credibility (Internal Validity)

Credibility was discussed in Section 3.6.1. In summary, credibility was achieved through prolonged engagement with the data, triangulation of multiple data sources (audio recordings, interview transcripts, and field notes), and regular peer review by the supervisory team. Member checks and iterative theme refinement were also used. These steps ensured that the findings reflect participants' perspectives and, in turn, support the study's credibility.

8.3.2.2 Dependability (Reliability)

Dependability was discussed in Section 3.6.2. In summary, dependability was strengthened by maintaining an audit trail (researcher journal, coding memos, and document versions) and by triangulating coding decisions and emerging interpretations. Coding decisions and emerging interpretations were regularly discussed with and reviewed by the supervisory team, providing an ongoing peer review function. The procedures and changes made during the analysis are therefore traceable. Therefore, transparent documentation and supervisor review ensured that the research process was consistent and auditable, supporting dependability.

8.3.2.3 Transferability (External Validity)

Transferability was discussed in Section 3.6.3 and achieved by providing rich, thick descriptions of the study setting, participant characteristics, and data-collection procedures. The study also used purposive sampling that captured the maximum variation within the cattle-production sector. Readers can therefore judge the applicability of the findings to similar contexts.

8.3.2.4 Confirmability (Objectivity)

Confirmability was discussed in Section 3.6.4 and supported through an audit trail, triangulation, the use of verbatim excerpts in the analysis, and clear coding decisions documented in memos that were discussed with supervisors. Therefore, the combination of documented analytic steps and reflexive practice demonstrates that the findings are grounded in the data, thereby supporting their confirmability.

8.3.2.5 Summary of rigour and trustworthiness

Together, the measures implemented address the four parallel trustworthiness criteria. Each criterion is supported by the specific procedures described in Section 3.6. Therefore, the research process demonstrates acceptable rigour for a qualitative case-study design.

8.3.2.6 Validation of the artefact development process

As explained, the artefact was developed by following a structured qualitative case study design. Following recognised case study phases ensured that the artefact was constructed through a systematic and transparent research process. The case study phases and their roles in developing the artefact are summarised in Table 8-2.

Table 8-2: Case study design

Case study methodology phase/step			Validation	Research objectives	Chapter
1. Define a case study			An established case study definition informed the formulation and overall design of this study.		2.2.1
2. Design the case study	a.	Conduct a Literature review.	A scoping review was conducted in accordance with the PRISMA guidelines. Scoping review procedures were carried out clearly and methodically across all phases (Arksey & O'Malley, 2005). Enough information on the procedure was provided in the report so that other researchers could repeat the study (Arksey & O'Malley, 2005). This distinct methodology addresses any criticism that the study lacks scientific rigour and improves the dependability of the results (Arksey & O'Malley, 2005).	1 - Investigate available literature on the application of IE knowledge in the beef cattle production systems via a scoping review.	4
	b.	Construct a theoretical framework.	A theoretically grounded framework derived from the IISE Body of Knowledge (BoK) informed the study design and analysis.		2.3
	c.	Identify a research problem.	The scoping review and survey findings confirmed the existence of the research problem.		1.2
	d.	Develop research questions	The interview protocol was developed using the structured guidelines proposed by John W. Creswell and J. David Creswell (2017).		1.8 & 5
	e.	Select the sample	Purposive sampling, followed by snowball sampling, was implemented until data saturation was achieved.		3.2.2 & 5
3. Generate data (Gather data)			Data were generated through semi-structured interviews, allowing for consistency across participants while maintaining flexibility to explore emerging themes in depth.	2 - Explore the challenges and their root causes experienced in cattle production lines via interviews	5
4. Analyse data inductively.			An inductive thematic analysis was conducted using a structured, stepwise approach to systematically identify patterns and emergent themes within the data.	2 - Explore the challenges and their root causes experienced in cattle production lines via interviews.	5

Case study methodology phase/step	Validation	Research objectives	Chapter
5. Analyse data deductively.	Data were further analysed using the IISE BoK as a coding framework to map Industrial Engineering themes to the agricultural context.	3 - Explore and compare the similarities between cattle production challenges and industrial engineering bodies of knowledge by creating a contextualisation framework	6
6. Validate data / Rigour	Rigour was ensured through internal validity, reliability (consistency), external validity, and adherence to ethical standards. (explained more in section 3.6).	4 - Verify that the contextualisation framework complies with the design requirements through expert review.	7 & 8

8.3.3 Validation of research output

The primary source of feedback on the artefact was an expert survey of engineers with agricultural experience (Chapter 7). The respondents indicated that the matrix is easy to read and use and that it illustrates how knowledge of industrial engineering can be applied to common farm practices (Table 8-3). In particular, the survey statement 9 (“The matrix provides a valid approach to transfer industrial engineering knowledge into cattle production”) received an average of 4.53 (90.59%). The respondents also confirmed the artefact’s novelty (average 85.88%) and that the matrix met its design requirements (Section 8.2). The results suggest that the matrix is perceived as relevant to the research problem and potentially useful within the cattle-production context, providing supportive expert feedback on the CPCM as an initial contextualisation artefact.

Table 8-3: Verification of artefact

Survey statement	Average	Percentage
9 - The matrix provides a valid approach for transferring industrial engineering knowledge into cattle production.	4.53	90.59

The novelty of the artefact (the contextualisation tables) was verified by Engineers with agricultural experience via a survey (as discussed in Chapter 7). The survey used a statement to confirm that the construction of the contextualisation tables was an original design (rather than a duplication of previous work), as shown in Table 8-3. The statement reached consensus with an average of 85.88%.

Table 8-4: Verification artefact novelty

Survey statement	Average	Percentage
10 - To the best of your knowledge, would you say the construction and integration of the contextualisation framework is an original design (as opposed to just a duplication of other previous work)?	4.29	85.88

8.3.4 Summary of validation

These validation outcomes directly address the study's objectives related to artefact applicability and problem relevance. In particular, Objective 4 (verify that the matrix complies with the design requirements through expert review) and Objective 5 (confirm that a valid problem, method, and artefact were developed through expert review) are supported by the consensus results discussed in the previous sections. Therefore, the scoping review and the expert survey collectively show that the CPCPM responds to a meaningful industry gap and is perceived as a useful initial means of contextualising IISE knowledge for cattle production systems.

8.4 Chapter summary

This chapter has presented the rigorous strategies applied throughout the study and the outcomes of the expert evaluation of the CPCPM. The evidence gathered suggests that the problem statement is relevant, the research design is valid, and the CPCPM represents a useful initial contextualisation artefact.

CHAPTER 9 CONCLUSIONS

9.1 Introduction

This chapter provides an overview of the research conducted and sets the way forward for future research by outlining the limitations and recommendations.

9.2 Research overview

Although industrial engineering uses many tools and methods, there has been little deliberate transfer of that knowledge to commercial red-meat cattle production. The problem this study addresses is that Industrial Engineering research has not been aligned with the beef cattle industry, thereby limiting the development of pragmatic solutions to food security challenges. This limits the sector's ability to improve productivity, sustainability, and operational flexibility.

A scoping literature review was conducted to investigate the intersection of Industrial Engineering knowledge and cattle farming. The review found that while Industrial Engineering body-of-knowledge methods appear in the literature, their applications have mostly been academic and conceptual, with few practical, farm-level implementations aimed at solving everyday farm challenges.

To explore this gap, the study focused on cattle production in KwaZulu-Natal (commercial and smallholder farms in the Midlands and Highveld) and used an exploratory case-study design. Data collection combined purposive and snowball sampling until saturation was reached (14 interviews). The analysis was conducted in two ways: (1) inductive thematic analysis to explore farm challenges and their root causes, and (2) deductive mapping using the IISE Body of Knowledge (IISE-BoK) as a coding framework. The deductive work produced the main artefact, namely the IISE-BOK Cattle Production Contextualisation Matrix. Afterwards, expert reviews were used, via online surveys, to verify the artefact and support the relevance of the problem, method, and outputs.

9.3 Contribution

This study makes three linked contributions: a literature contribution, a practical contribution, and a methodological contribution.

1. Contribution to the literature. This research shows that numerous on-farm challenges closely align with Industrial Engineering concepts, indicating that engineering knowledge is relevant and

potentially applicable to the red-meat cattle sector. The study reframes the IISE Body of Knowledge (IISE-BoK) to be meaningful for commercial cattle production problems rather than only traditional engineering contexts.

2. Practical contribution. The main artefact is a set of contextualisation tables that link specific cattle-production challenges to relevant Industrial Engineering knowledge areas and tools. These tables act as an initial reference tool for practitioners, including researchers and engineers, to identify potential approaches for on-farm testing. They offer a way to translate abstract Industrial Engineering methods into practical farm-level solutions that could improve productivity, sustainability, and operational flexibility. The CPCM, while a structured and detailed artefact, is more precisely an interpretive mapping tool than a deeply developed theoretical framework. Its contribution lies in making IE knowledge accessible and contextualised within a new domain, providing a structured starting point for future transdisciplinary research and practice

3. Methodological contribution. The study presents a structured approach for linking inductive thematic analysis with deductive mapping against an established body of knowledge, supported by expert review. Inductive analysis was used to identify challenges in the agricultural context, which were then mapped to relevant engineering knowledge areas for interpretation. While inductive–deductive combinations are well established in qualitative research, the value of this approach lies in its application to a body-of-knowledge contextualisation process within a non-traditional domain. This provides a worked example of how engineering knowledge can be explored and interpreted in an agricultural setting, which may be useful for future studies working across disciplinary boundaries.

Together, these contributions make collaboration between industrial engineers and cattle producers more available. Engineers are provided with a clearer starting point for applying their knowledge in agriculture, while producers are shown a structured way to consider engineering-based improvements that can be tested and refined on the farm.

9.4 Limitations and recommendations for future research

This study focused exclusively on red-meat cattle production in the Midlands and Highveld areas of KwaZulu-Natal, included only 14 participants, and excluded feedlots. This limits the transferability of the findings to other regions of South Africa with different climate conditions, land tenure systems, and farming practices. The challenges identified may not be representative of cattle production across the full diversity of South African farming contexts. Future studies should expand research into feedlots and other areas in South Africa.

Another limitation is that the contextualisation framework primarily shows conceptual alignment between on-farm practices and the Institute of Industrial and Systems Engineers' Body of Knowledge in Industrial Engineering.

A further limitation concerns the deductive coding process used in developing the CPCM. Some of the challenges described by farmers could reasonably fit within more than one area of industrial engineering knowledge, resulting in themes that appear under multiple BOKs. In addition, assigning themes to specific BOK subheadings involved researcher interpretation and judgement, meaning that alternative classifications were also possible. This is a recognised limitation of qualitative deductive coding and should be kept in mind when interpreting the matrix. Two of the 14 IISE BOK (BOK 2: Operations Research Analysis, BOK 12: Design and Manufacturing Engineering) did not match the interview data. Although this could be due to too many differences between IE knowledge and farm-level practice for these BOKs, it is also possible that the interview protocol did not sufficiently probe for activities that might correspond to these knowledge areas.

The expert survey used to verify the CPCM has several limitations. First, the sample of 17 respondents, while meeting the consensus threshold, is small and may not capture the full diversity of expert opinion. It is suggested that a larger sample be utilised in the future to provide more detailed and diverse feedback. Survey statement 10 asked participants to assess the originality of the CPCM. This places a difficult expectation on practitioners, as they do not usually engage with academic literature. The agreement on this statement should therefore not be read as proof of academic originality, but rather as an indication that participants had not previously encountered a similar tool in their professional experience.

The study shows that several approaches already used by farmers align with established concepts of industrial engineering (e.g., the use of mortality percentages as performance indicators for herd health management). However, the study focused on identifying and structuring these connections rather than implementing specific Industrial Engineering applications on farms. Future research can therefore build on this framework by testing engineering applications derived from the contextualisation. These studies should measure practical outcomes, including productivity, cost implications, and operational improvements. Such studies could include:

1. **Performance management systems:** Develop structured KPI dashboards for herd health, mortality rates, and productivity to support data-driven farm management decisions.

2. **Process optimisation studies:** Analyse cattle production workflows (e.g. vaccination scheduling, feeding routines, or herd movement) using Industrial Engineering process-improvement methods to identify bottlenecks and reduce operational losses.
3. **Supply chain coordination research:** Investigate how industrial engineering supply chain tools could improve logistics, aggregation, and market coordination for cattle producers.
4. **Risk modelling:** Apply systems modelling and risk analysis tools to evaluate how cattle production systems can better respond to disruptions such as disease outbreaks, drought, or market volatility.
5. **Decision-support tools:** Develop simple digital tools or planning frameworks that help farmers apply Industrial Engineering concepts in daily management decisions.

9.5 Concluding remarks

This study addressed the limited transfer of Industrial Engineering knowledge to the beef cattle industry by contextualising the Industrial Engineering Body of Knowledge within cattle production systems in KwaZulu-Natal. Through a scoping review, farmer interviews, and deductive mapping against the IISE Body of Knowledge, the study identified that many challenges experienced in cattle production correspond with established Industrial Engineering concepts. The resulting contextualisation matrix provides a structured way of linking cattle-production challenges with relevant Industrial Engineering knowledge areas and tools.

Importantly, the findings show that several practices already used by farmers correspond with Industrial Engineering principles, even though they are not explicitly recognised as such within the agricultural context. By making these connections visible, the matrix creates a starting point for collaboration between industrial engineers and cattle producers.

Although the matrix does not yet provide specific interventions, it provides an initial conceptual basis for future research to design and test practical engineering solutions in agricultural systems. In this way, the study initiates a transdisciplinary approach for applying Industrial Engineering methods to improve productivity, sustainability, and operational resilience in cattle production.

Many cattle-production challenges correspond to established concepts in industrial engineering, but these connections have not been previously structured or made explicit. By contextualising the Body of Knowledge on Industrial Engineering within cattle production, this research bridges

engineering knowledge and agricultural practice, offering a starting point for future collaboration and practical innovation in the red-meat production sector.

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ANNEXURE A: PREFERRED REPORTING ITEMS FOR SYSTEMATIC REVIEWS AND META-ANALYSES EXTENSION FOR SCOPING REVIEWS (PRISMA- SCR) CHECKLIST (ADAPTED FROM (TRICCO, ET AL., 2018)

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	
Limitations	20	Discuss the limitations of the scoping review process.	
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	

JBİ = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBİ guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

ANNEXURE B: IISEBOK CATEGORISATION RESULTS FOR THE SCOPING REVIEW

No.	BOK categorisations	Reference
1	1.6 Evaluates the labour impact of different grazing strategies. 2.13 Uses simulation models to assess economic outcomes of grazing strategies. 3.4 Calculates profitability differences between traditional and conservative grazing strategies. 5.3.1 Compares grazing strategies using statistical analysis. 7.12 Assesses the cost, productivity, and profitability of grazing strategies. 11.3 Studies information needs for economic decision-making in cattle ranching. 11.6 Organises data related to forage production and economic outcomes. 14.2.8 analyses economic risks in grazing strategies.	(Quiroga, et al., 2009)
2	2.1.1 Uses mathematical models to compare the economic feasibility of cattle vs. game ranching. 2.7.1 Applies linear programming to optimise game species composition. 3.4 Evaluates the financial feasibility of switching to game ranching. 3.5.2 Assesses profitability differences between cattle farming and game ranching. 7.12 analyses the cost and revenue impact of switching from cattle farming to game ranching. 8.2.10 Evaluates the impact on game auctions and hunting supply chains. 11.3 Uses data models to support financial decision-making in game ranching. 11.17.7 Uses predictive models to estimate long-term profitability. 14.2.8 Conducts a sensitivity analysis on the economic risks of conversion to game ranching. 14.10.2 Assesses long-term viability of conversion.	(Cloete, et al., 2007)
3	2.10 Examines how farmers assess and select information for decision-making. 5.1.2 Uses statistical methods to analyse data flow. 11.3 Identifies key information categories used in farm management. 11.6 Organises farm data. 11.7 Structures informational resources for farm decision-making. 14.9.1 Compares the conceptual model with real-world farming data.	(Magne, et al., 2010)
4	2.13 Uses simulation modelling to evaluate the economic feasibility of FMD control strategies. 3.2 Cost Analysis - Estimates the cost implications of vaccination programs. 3.4 Assesses the financial viability of disease prevention measures. 3.5.2 Evaluates trade-offs between vaccination and treatment costs. 7.12 Measures the economic efficiency of vaccination adoption. 10.4.5 Evaluates risks of disease spread. 11.3 Defines key data needs for disease management decisions. 11.17.7 Forecasts long-term benefits and risks of vaccination programs. 14.2.8 Assesses the economic risks of different vaccination scenarios. 14.10.2 Evaluates the long-term economic sustainability of FMD control.	(Sieng, et al., 2022)
5	2.1.1 Uses UML-based modelling for participatory decision-making. 2.13 Simulates stakeholder interactions in participatory models. 11.3 Identifies data needs for participatory modelling. 11.6 Structure data in UML models. 11.10 Develops UML-based decision support models. 11.11 Develops UML-based decision support models. 14.9.1 Compares model outputs with real-world scenarios.	(Bommel, et al., 2014)
6	11.17 Uses deep learning for cattle face identification. 12.12.1 Develops embedded AI systems for cattle recognition. 13.2.7 analyses design trade-offs for model efficiency. 14.9.1 Compares AI model performance with real-world results.	(Li, et al., 2022)

No.	BOK categorisations	Reference
7	2.13 Uses NSGA-III algorithm to optimise grazing allocation. 2.10.1 Balances weight gain and animal welfare objectives. 5.3.1. Analysis of variance (ANOVA) 7.12 Measures impact of optimised grazing strategy on productivity. 11.17 Uses predictive analytics to model livestock performance. 14.2.8 Assesses the impact of different grazing strategies on animal welfare. 14.9.1 Compares optimisation model outputs with real-world data.	(Jiménez, et al., 2024)
8	2.1.1 Uses deep learning-based object detection to recognise multiple cattle faces. 11.17 Implements AI-based object detection for cattle face recognition. 11.10 analyses system requirements for real-time detection. 11.11 Develops optimised detection models for livestock monitoring. 12.12.1 Automation and Systems Integration - Deploys deep learning-based detection in precision agriculture. 13.2.7 Assesses model performance in real-world detection scenarios. 14.9.1 Compares detection model results with actual farm conditions. 14.3.1 Defines the structure of AI-based cattle monitoring systems.	(Lei, et al., 2024)
9	2.1.1 Uses system dynamics to simulate value chain scenarios. 2.13 Models the trade liberalisation and disease control impacts. 3.4 Evaluates the financial performance of market liberalisation policies. 3.5.2 Assesses the profitability impacts of policy options on value chain actors. 7.1.4 Examines trade and disease control policies in beef export competitiveness. 7.12 Measures trade liberalisation effects on supply chain efficiency. 8.2.10 Evaluates market shifts due to policy changes. 10.4.5 Evaluates risks of foot-and-mouth disease outbreaks. 11.3 Identifies data needs for market decision-making. 11.6 Structure value chain data for policy evaluation. 11.17.7 Forecasts long-term effects of trade policies. 14.2.8 Assesses economic risks of trade and disease policy changes. 14.9.1 Compares system dynamics model predictions with real-world data.	(Dizyee, et al., 2017)
10	2.10.1 Uses statistical regression and mathematical programming for efficiency analysis. 2.13 Applies data-driven modelling to livestock production. 3.2 Assesses the economic efficiency of cattle production. 3.4 Evaluates profitability trends using population data. 5.1.2 Uses regression analysis for livestock efficiency studies. 7.12 Measures the efficiency and cost-effectiveness of cattle production systems. 11.3 Identifies data collection challenges in population studies. 11.17 Applies statistical models to predict economic and production trends. 14.2.8 Evaluates the impact of external factors on cattle production models.	(Jones & Langemeier, 2010)
11	2.13 Uses Monte Carlo simulations to assess risk in cattle finishing strategies. 2.10.1 Evaluates trade-offs between profitability and risk. 2.10.3 Apply decision tree-based methods to analyse financial outcomes. 3.4 Estimate the financial feasibility of backgrounding and finishing systems. 3.5.2 Compares risk-adjusted returns for different feeding approaches. 3.14 Uses probabilistic methods and decision trees to assess market fluctuations. 5.3.1 Analyse the effects of different feeding regimes on profitability. 5.1.2 Uses probability and distribution models for risk analysis. 7.12 Measures the economic and productivity performance of backgrounding and finishing operations. 11.17.7 Forecasts economic outcomes based on risk-adjusted models. 14.2.8 Assesses financial risk under different feeding and market conditions.	(Perillat, et al., 2004)
12	2.1.1 Uses discrete-event simulation to model farm operations. 2.13 Develops a simulation framework for evaluating farm management strategies. 3.2 Assesses the cost implications of different farm configurations. 3.4 Evaluates the financial viability of alternative farm	(Martin, et al., 2011)

No.	BOK categorisations	Reference
	designs. 5.3.1 Uses simulation experiments to test farm performance. 7.12 Evaluates the efficiency of different farm management strategies. 11.3 Structure data for farm simulation. 11.10 Analyse system-wide impacts of different management strategies. 11.17 Uses statistical modelling to evaluate farm performance. 14.2.8 Assesses the impact of environmental and economic changes on farm systems.	
13	5.1.2 Injury count, Basic statistics, Distribution of injuries 10.4.5 Evaluates agricultural work-related injuries among children. 11.3 Identifies data gaps in farm injury reporting. 11.17 Uses injury surveillance data to assess trends in farm-related accidents.	(Browning, et al., 2003)
14	11.17 Uses AI models to predict estrus in livestock. 11.17.3 Assesses the performance of the YOLO-based recognition system. 11.2.12 Integrates cloud-based service models for estrus prediction. 14.3.1 Design a system architecture for AI-based livestock monitoring.	(Cho & Kim, 2023)
15	2.13 Uses an agent-based model to evaluate reproductive strategies. 2.10.1 Assesses trade-offs between reproductive efficiency and costs. 3.4 Evaluates the profitability of different reproductive strategies. 3.14 Uses stochastic methods to assess financial risk. 5.3.1 Simulates economic outcomes of reproductive strategies. 7.12 Measures the productivity impacts of different breeding programs. 11.17 Uses economic and reproductive data to optimise herd management. 11.10 Evaluates interactions within the cow-calf operation. 14.2.8 Assesses the impact of reproductive strategies on economic stability.	(Ojeda-Rojas, et al., 2022)
16	2.13 Uses a Monte Carlo economic simulation model to evaluate forage-based beef production. 2.10.1 Assesses trade-offs between different forage options and their economic impact. 2.10.3 Examines financial outcomes under different price and weight gain scenarios. 2.14.3 incorporates feedback loop analysis in economic modelling. 3.4 Evaluates farm profitability using economic modelling of revenue, costs, and payback periods. 3.5 Analyse profitability under different farm management strategies using NPV and IRR. 3.14 Applies risk-based financial modelling to compare scenarios. 7.1.4 Evaluates market demand and pricing for cattle. 7.12 Measures financial viability based on farm income and cash flow. 8.2.10 Study logistical and economic feasibility of integrating forage-based cattle production. 11.3 Identifies critical farm-level data for decision-making. 11.6 Structure data to model farm profitability. 11.17.7 Uses economic modelling to predict financial outcomes under various conditions.	(MacLeod, et al., 2007)
17	1.4.2 Uses flowcharts to visualise pasture growth, cattle liveweight interactions, and weather impact. 2.13 Uses Monte Carlo simulations to analyse uncertainty in cattle weight gain and pasture growth under varying weather conditions. 2.10.3 Incorporates long-term weather forecast uncertainty in stocking rate decisions. 2.11.1 incorporates stochastic processes for climate-based production modelling. 3.4 Cash Flow Analysis, 3.5 Evaluates the economic risks of different stocking rates under variable climate conditions. 3.15 Uses payoff matrices to compare economic outcomes. 5.3.2.4 Uses least squares regression to predict cattle weight gain based on pasture conditions. 5.3.2.6 Evaluates model accuracy using MSE, MAE, and R ² . 7.1.4 Examines long-term beef supply implications based on the climate impact on cattle weight. 7.12 Measures effects of stocking rates on pasture depletion and beef production sustainability. 8.2.10 Analyses beef production planning based on predictive modelling of pasture and cattle growth. 11.3 Identifies key data	(Masoud, et al., 2023)

No.	BOK categorisations	Reference
	sources needed for predictive modelling. 11.6 Structure climate, pasture, and cattle data for modelling. 11.17.7 Uses statistical modelling to estimate livestock production under different weather scenarios.	
18	2.10.3 Uses the Logit model to analyse the probability of cow breeding decisions under economic uncertainty. 2.10.2.1 Uses ISM (Interpretative Structural Model) to create a hierarchical structure of decision-making factors. 2.11 Uses Logit regression and ISM modelling to assess decision-making behaviour under economic uncertainty. 3.5 Evaluates the impact of loans, policy subsidies, and market expectations on breeding decisions. 3.14 Uses risk assessment methods. 5.3.2.4 Uses OLS regression as a control before Logit analysis to ensure robust results. 7.1.4 Examines how policy advocacy, subsidies, and economic expectations affect farmers' decision-making. 11.3 Identifies key economic and policy variables needed for decision-making analysis.	(Li, et al., 2022)
19	2.1.1 Structured system modelling approaches. 2.11 Uses system dynamics models to analyse market interventions and policy failures. 2.14.2 Balancing Loops - Identifies stabilising mechanisms in the beef supply chain. 2.14.3 Uses causal loop diagrams to analyse reinforcing and balancing loops affecting beef production. 3.12 Estimating Economic Elements 3.15 Uses system dynamics modelling to estimate economic influences on the beef value chain and evaluates uncertain policy interventions. 7.1.4 Examines policy interventions in beef imports, price fluctuations, and their impact on domestic beef production. 7.6 Identifies bottlenecks and constraints in the beef supply chain, which ties into capacity management for labour, equipment, and materials. 8.2.10 Analyse dependencies within the beef supply chain, particularly how feed supply constraints impact production. 8.1.6 Analyses supply chain inefficiencies and policy impacts on the beef industry. 11.3 Identifies critical data needs for understanding stakeholder interactions and market policies. 14.5 Uses system archetypes (e.g., fixes that fail, shifting the burden, limit to growth) to explain long-term impacts of policy interventions on the beef industry.	(Alizadeh, et al., 2020)
20	2.10.1 Evaluates trade-offs between iCL, continuous cropping, and continuous livestock in terms of profitability, risk, and sustainability. 2.13 Scenario-based simulations. 2.2.12 Goal programming to optimise resource allocation. 3.4 Uses NPV, IRR, and ROI to assess long-term profitability of integrated crop-livestock systems. 3.5 Compares investment costs, payback periods, and risk factors in different production systems. 3.7 Evaluate break-even points for crop-livestock integration under different market conditions. 7.1.4 Examines commodity price trends and their impact on the profitability of iCL, continuous cropping, and continuous livestock systems. 7.6 analyses capacity constraints in livestock-crop integration. 7.12 evaluates system productivity. 8.2.10 Analyses the role of iCL in feed and beef production sustainability. 8.2.1 evaluates profitability improvements through supply chain integration. 11.3 Identifies data needs for economic modelling, including production costs, revenue, and investment scenarios.	(dos Reis, et al., 2020)
21	2.10.1 Evaluates trade-offs between adopting big data analytics and traditional farm management approaches. 2.10.3 Uses binary probit modelling to analyse technology adoption probability under economic uncertainty. 5.3.2.4 Uses probit regression analysis	(Piña, et al., 2023)

No.	BOK categorisations	Reference
	to estimate the impact of farm size, producer age, and prior technology adoption on big data adoption. 7.1.4 Examines how farm characteristics, producer behaviour, and market conditions influence big data adoption in beef farming. 7.12 Assesses how big data impacts operational efficiency and operational performance metrics like productivity and throughput. 11.3 Identifies critical data needs for implementing big data analytics in beef production, including sensor data and predictive modelling.	
22	2.1.1 Uses system-wide modelling approaches. 2.10.1 Evaluates trade-offs between livestock management strategies to optimise economic and biological outcomes. 2.11 Uses system dynamics modelling to simulate livestock production under climatic and economic uncertainty. 2.13 Develops a bioeconomic simulation model using differential and integral equations. 2.14.3 Uses system dynamics methodology to model feedback effects in livestock production systems. 3.4 Uses cash flow efficiency (CFE) as a key metric for financial decision-making. 3.5 Analyse trade-offs in land use and herd size. 3.12 Estimating Economic Elements 3.14 Estimate economic outcomes for farm systems, and apply probabilistic risk assessment. 7.1.4 Examines market dynamics and economic influences on livestock profitability. 7.12 Uses a decision support system to analyse efficiency and profitability. 8.2.10 Supply Chain Network Design. 8.2.1 Uses decision-support models to improve supply chain performance and resource allocation. 11.3 Identifies data requirements for integrating biological and economic models in farm management.	(Tanure, et al., 2015)
23	2.10.1 Evaluates trade-offs between cost, feasibility, and effectiveness of biosecurity measures. 2.11 Assesses disease risk and farmer decision-making under uncertain economic conditions. 2.10.5 Robust Decision Making - Uses robust decision-making methods for managing uncertain disease control policies. 3.5 Examines economic constraints on biosecurity investments in cattle farms. 3.12 Estimating Economic Elements 3.15 applies uncertainty-based decision frameworks for policy interventions. 7.1.4 Uses SWOT analysis to assess market barriers, policy gaps, and economic incentives for biosecurity adoption. 7.12 Evaluates the effectiveness of biosecurity measures, relevant to cost, quality, and productivity assessments. 8.1.5 Biosecurity directly affects supply chain risk. 10.1 Identifies biosecurity risks, threats, and mitigation strategies through SWOT analysis. 11.3 Highlights gaps in biosecurity knowledge and the need for structured guidance.	(Renault, et al., 2021)
24	2.2 Uses LP models to optimise breeding traits 2.10.1 Compares different breeding strategies by assessing biological and economic trade-offs. 2.13 Uses bio-economic profit models to simulate different production scenarios. 2.10.5 Robust Decision Making - uses robust decision-making techniques for trait selection under uncertainty. 3.5 Evaluates economic returns from different breeding and management strategies. 3.12 Estimating Economic Elements 3.14 Uses profit models, cash flow projections, and risk-based economic evaluations of breeding strategies. 7.1.4 Market Analysis 7.12 Assesses the economic and genetic efficiency of cattle breeding, including operational aspects like throughput and productivity. 8.2.10 Breeding strategies impact supply chain design. 11.3 Identifies critical data needs for economic and biological modelling. 13.2.3 Formulates breeding objectives based on economic and genetic considerations. 13.2.7.3.2 Uses trait selection weighting to maximise genetic and economic efficiency.	(Rewe, et al., 2006)

No.	BOK categorisations	Reference
25	2.10.3 Uses logistic regression models to evaluate injury risk factors, applying statistical decision-making under uncertainty. 2.11.1 Injury rates are modelled using probabilistic methods, making use of stochastic analysis techniques. 3.12 Analyse the cost implications of injuries, including lost work time and medical costs. 5.1.2.4 Uses descriptive statistics to analyse farm injury data. 5.1.2.7 Applies logistic regression modelling to assess injury risk factors. 5.3.2.4 Uses multivariate regression techniques for injury prediction. 6.3.2 The study examines manual cattle handling tasks and their association with injuries, strain, and fatigue. 6.7.2 Identifies farm tasks (e.g., herding, medical treatment) that increase injury risk, contributing to prevention strategies. 6.13.6 Analyse workplace accidents on cattle farms, linking injuries to farm management practices and equipment use. 7.6 Examines how farm labour hours and herd size affect operational risks, a core aspect of capacity management. 7.12 Uses injury rates and work-hour statistics to measure farm operational efficiency and risk factors. 10.1 analyses cattle-related injury risks and how farm management practices impact worker safety.	(Browning, et al., 2013)
26	2.10.1 Uses participatory ranking methods (pairwise ranking, matrix scoring) to assess cattle production challenges. 2.10.3 Evaluates economic risks (losses from disease, rustling, market conditions) under uncertainty. 2.11.1 Applies probability-based models (Kruskal-Wallis ANOVA, concordance coefficients) to estimate disease incidence and impact. 3.12 Estimate economic losses due to cattle diseases, rustling, and production constraints. 3.14 Assesses economic risks in cattle farming, including disease outbreaks, theft, and resource shortages. 5.1.2.4 Uses Kruskal-Wallis ANOVA and Kendall's coefficient for statistical ranking of challenges. 5.3.1.2 Uses ANOVA to analyse statistical differences in cattle disease impacts and production constraints. 7.6 Assesses how land conversion, water scarcity, and rustling impact cattle productivity. 7.12 Uses disease incidence rates and production constraint rankings to measure operational performance. 10.1 Identifies disease-related safety risks affecting pastoralists.	(Suleiman, et al., 2015)
27	2.10.1 Uses categorical PCA and Two-Step Cluster Analysis to classify cattle farming systems. 2.10.3 Analyse economic and environmental risks driving transhumance decisions. 2.11.1 Applies probability-based models to assess cattle herd mobility patterns. 3.12 Estimate economic factors influencing herd mobility and crop-livestock integration. 3.14 Evaluates economic risks related to resource scarcity, land disputes, and herd migration. 5.1.2.7 Uses multinomial regression analysis to model cattle farming systems. 5.3.2.4 Applies multinomial logistic regression for classification models. 5.3.2.7 Uses stepwise methods to refine regression models. 7.1.4 Examines how environmental and policy factors influence cattle markets and herd mobility. 7.6 Assesses land availability, forage resources, and water access for cattle. 7.12 Uses herd size, mobility distance, and breed composition as operational performance indicators. 8.2.10 Analyse cattle mobility patterns as part of supply chain logistics for grazing and market access. 11.17.5 Uses Cluster Analysis to classify cattle farming systems. 14.10.4 Addresses systemic risks in cattle production, including land conflicts and policy uncertainty.	(Houessou, et al., 2019)
28	2.10.1 Uses Multinomial Logistic Regression and Cluster Analysis to classify sustainable production strategies. 2.10.3 Evaluates economic and environmental risks in dairy-beef production models. 3.12 Estimates the profitability, cost structures, and economic efficiency	(Hessle, et al., 2017)

No.	BOK categorisations	Reference
	of different production strategies. 3.14 Analyse financial risks associated with integrating dairy and beef production. 5.1.2.7 Uses Multinomial Logistic Regression to assess sustainability factors. 5.3.2.4 Applies regression models to predict economic and environmental trade-offs. 5.3.2.7 Uses stepwise regression for model refinement. 7.1.4 Examines how supply and demand factors influence sustainable beef production models. 7.6 Evaluates land use efficiency and resource allocation in dairy-beef systems. 7.12 Uses GHG emissions, profitability, and land efficiency as key performance indicators. 8.2.10 Analyses supply chain strategies for integrating dairy and beef production. 8.1.5 Evaluates risk factors affecting sustainable meat supply chains. 11.17.5 Uses Cluster Analysis to classify production systems based on economic and environmental performance. 14.10.4 Identifies systemic risks in integrating dairy and beef production.	
29	2.10.3 Uses cost–benefit analysis and sensitivity analysis to assess disease control programme viability. 3.8.3 Benefit-Cost Analysis, 3.12 Evaluates economic impacts of disease control on small-scale farmers. 3.14 Uses sensitivity analysis to determine the economic feasibility of tick control. 3.4 Conducts a cost–benefit analysis comparing investment in tick control vs. potential losses. 5.1.2.4 Uses descriptive statistics to assess mortality rates, productivity loss, and economic impact. 7.1.4 Examines how government-funded tick control impacts cattle market viability. 7.12 Uses mortality rates, productivity, and dipping efficiency as performance indicators. 8.1.5 Assesses risks of disease outbreaks and their effects on supply chain efficiency. 14.10.4 Identifies systemic risks associated with the government withdrawal of disease control funding.	(Randela, 2005)
30	2.1.1 Applies scenario-based economic modelling to compare vaccination strategies. 2.10.3 Considers outbreak probability and financial impact over a 10-year horizon. 3.2.3 Distinguishes fixed vs. variable costs for control, vaccination, and surveillance. 3.3.1 Applies discounting over a 10-year horizon. 3.4.5 Assesses the economic performance of three vaccination strategies. 3.4.6.1 Calculates time to recover costs. 3.5.4.2.1 Evaluates investment viability. 3.8.3 Examines public investment in disease control as a national economic decision. 5.1.2.1 Uses expert-elicited probabilities to simulate incidence and impact. 5.1.2.4 Applies central ranges, means, medians in cost analysis. 5.4.1.7 Data-driven Relies on empirical surveillance and modelling data to guide national strategy choice. 8.2.10 Evaluates vaccine distribution requirements and regional livestock targeting. 8.2.8 Assesses logistics for vaccine delivery, storage, and regional prioritisation. 11.3.3 Identifies data needs for outbreak prevention policy evaluation. 11.6.2 Uses structured model inputs for outbreak simulation (e.g. incidence, control cost, vaccine reach). 11.17.7 Forecasts outcomes of vaccination strategies using stochastic modelling. 13.2.7.2 Assesses trade-offs between frequency of vaccination and economic outcomes. 13.4.1 Applies a 10-year outlook on costs and benefits for national-level disease control. 14.2.9 Compares the economic outcomes of different vaccination schedules. 14.10.2.1 Integrates long-term economic evaluation of disease control strategies into the national planning context. 14.10.4.1 Assesses the uncertainty of FMD outbreaks and return on control investment.	(Jemberu, et al., 2016)

No.	BOK categorisations	Reference
31	2.1.1 Applies heatmap regression and CNNs to model pose estimation. 2.13.3 Uses training-validation pipelines that simulate cattle poses across varying body conditions and angles. 2.11.1 Deals with probabilistic joint detection under uncertainty. 5.1.2.4 Evaluates model performance using PCKh and MSE. 5.3.2.4 Used in training network heatmap outputs. 5.4.1.7 Data-driven compares architectures based on empirical performance metrics. 6.1.2 Removes the need for manual cattle monitoring. 6.3.7 Applies joint detection via body proportion modelling. 6.11.1 Supports human decision making from model output. 6.13.4 Design aids user interaction with AI visual tools. 7.1.2 Predicts joint locations across frames based on learned image features. 7.12.2 Measures model's estimation accuracy for real-world reliability in livestock management. 9.4.3 Applies experimentation and model testing. 9.6.6 Pursues innovation in animal monitoring. 9.5.1 Allocates data/computing efficiently. 9.2.3 Collaborates on labelling and system design. 9.8.2 Plans AI development stages. 10.3.1 Avoids the need for manual cattle handling. 10.4.4 Aligns with safer livestock operations. 10.4.5 Accounts for model weaknesses in rare or hazardous postures. 11.6.2 Annotated key point data structured and processed. 11.17.7 CNNs predict joint positions from images. 12.12.1 Integrates AI into cattle monitoring. 12.11.6 Uses PCKh and MSE to ensure model robustness. 13.2.4 Builds dataset via annotated video frames. 13.6 Identifies edge cases. 14.2.9 Compares CNN architectures. 14.6.3 Standardised testing on the same dataset. 14.9.3 Heatmap visualisation confirms design success.	(Li, et al., 2019)
32	1.4.2 Design a logical workflow of cattle through the weighing chute. 1.6 Reduces labour and improves weighing cycle time to 6–8s per head. 2.13.3 Simulates cattle flow and gate logic for system testing. 2.1.1 Integrates system components using control logic models for real-time performance. 4.5.5 Design movement areas for data capture during animal flow. 4.6.9 Integrates automated hardware like PLCs and sensors in facility layout. 5.3.1.2 Compares system accuracy against traditional weighing using SPSS statistical tests. 5.4.1.7 Data-driven Uses statistically validated results to support the adoption of automated weighing. 5.2.1.1.1 Monitors system output for consistency in recorded weights during trials. 6.3.7 Design chute and weighing platform based on cattle body proportions. 6.8.2 Accounts for technician interface ergonomics via touch screens. 6.13.5 Touch screen design ensures quick and intuitive operation. 7.1.4 Responds to labour shortages in cattle weighing by offering an automated solution. 7.12.2 Ensures weighing system accuracy and reliability with $\pm 2\%$ relative error. 8.2.8 Enhances data reliability for time-sensitive logistics like shipment readiness. 9.4.3 Prototypes and tests rapid weighing solution. 9.6.6 Aligns with national goals for agricultural tech advancement. 9.2.3 Interdisciplinary collaboration across hardware and software teams. 10.3.1 Avoids animal stress and injury by minimising manual handling. 10.4.5 Reduces the risk of inaccurate dosing, feeding or sorting due to outdated weight data. 11.6.2 Weight and ID data are structured and stored via a touch screen interface. 11.17.4 Weight trend reports used for feeding decisions. 11.3.3 Supports real-time herd management decisions with integrated software. 12.12.1 Integrates PLC, sensors, and cloud connectivity for seamless data flow. 12.11.6 Validates hardware setup with experimental trials and real-time testing. 13.2.5 Compares system against foreign solutions. 13.6 Identifies performance advantages of IoT-based vs. static weighing. 13.9 Weighing unit built with local parts for ease of scaling. 14.2.4 Defines functional needs	(Li, et al., 2023)

No.	BOK categorisations	Reference
	(speed, accuracy, data transmission). 14.6.3 Experimental verification of precision and repeatability. 14.10.2.2 Designs system to optimise weighing speed vs. cost and labour savings.	
33	2.1.1 Constructs an agent-based model (ABM) to simulate complex interdependencies between cattle production and transportation networks. 2.13.3 Uses AnyLogic and simulation algorithms to generate and analyse livestock movements and system disruptions. 5.3.1.2 Statistical comparisons and output analysis using plotted data and variation across scenarios. 7.1.2 Simulates weekly cattle movement trends under stable market assumptions. 7.4.1 Models producer-premises operations like cattle flow between ranch, stocker, and feedlot. 7.8 Accounts for procurement decisions by different premises. 7.12 Evaluates demand fulfilment under various disruption scenarios. 8.1.1 Discusses how cattle are transported across a network of ranches, stockers, feedlots, and packers, capturing the full lifecycle. 8.2.10 Evaluates system vulnerability and resilience by simulating the shutdown of critical supply chain nodes (e.g., packers, entry points). 9.4.1 Models interconnected business processes across the cattle production value chain. 9.4.3 Uses simulation to improve systemic understanding and future disaster preparedness. 11.3.3 Supports disaster planning and preparedness using model-driven decision frameworks. 11.4.4 Uses ABM to replicate complex cattle-transport interactions. 11.17.4 Analyse simulation output (e.g., distance travelled, fulfilment percentages) under different scenarios. 14.2.4 Identifies cattle and transport network dependencies under disaster constraints. 14.9.1 Evaluates modelled system behaviour against real-world dynamics. 14.10.4 Investigates system robustness against disruptions like disease outbreaks or transportation failures.	(Yang, et al., 2019)
34	2.13 Data augmentation via SSIM-based filtering and rotations/flips to simulate varied cattle postures. 2.10.3 Trade-off analysis between model complexity and detection accuracy 5.5.1 Precision, recall and mAP metrics to evaluate recognition reliability. Focuses on increasing model robustness and output reliability by using validation metrics. 6.11.2 Deep-learning modules for pattern recognition in behaviour sequences 8.2.1 Behaviour analytics informs resource and feed allocation decisions 11.17.6 Supervised behaviour classification using DSConv and BiFormer architectures. 11.4.3 Real-time output for farm monitoring dashboards 14.3.1 Integrated DSConv, BiFormer & YOLOv8n network design. 14.5.2 End-to-end real-time detection system deployment.	(Li, et al., 2024)
35	3.2 Distinguishes operating cost (OC), total operational cost (TOC) and linear depreciation (LD) as fixed/variable components. 3.3 Apply time-value formulas to compute the present/future worth of investments. 3.4 Analyses operating cost (OC), total operational cost (TOC), gross revenue (GR), operating profit (OP), and financial net income (FNI) in each scenario. 3.4.6 Computes simple payback period in investment cycles. 3.4.7 Derives IRR as $100/SPP$. 3.4.5 Calculates $B: C = (GR-OC)/OC$. 3.5.4.2.1 Calculates IRR as $100/SPP$. 3.10 Applies linear depreciation formula to assets. 3.14 Uses probabilistic measures to compare supplementation strategies; 3.15 Employs benefit-cost and payback metrics under varying weather/price conditions. 11.17.5 Applies Ward's hierarchical clustering on standardised economic metrics using Euclidean distance for scenario grouping.	(Romanzini, et al., 2020)

No.	BOK categorisations	Reference
36	3.2 Distinguishes cultivation TEV (direct + residue value) vs. cattle TEV (direct + manure value) as cost and benefit components. 3.3.2 Uses Net Present Value (NPV = cattle TEV – cultivation TEV) to assess feasibility. 3.4 Calculates TEV for cultivation and cattle farming per hectare. 3.4.6 Implicit in the NPV method for one-cycle assessment. 3.4.5 Computes Benefit-Cost = 11 661.83 M / 44.97 M = 25 833 to confirm profitability.	(Sunu W, 2023)
37	2.10.3 Uses profit-function derivatives to derive economic weights (partial derivatives) for traits under stochastic production and market conditions. 2.10.1 Balances trade-offs among fertility, weight, growth, and carcass traits in a unified selection index. 3.3 Applies discount rate (5 %) and time-value formulas to discount future breeding-trait payoffs. 3.4 Construct profit functions for calves, heifers, cows, fattened calves, and bulls based on incomes/expenses per animal group. 3.4.5 Calculates B/C for each group within the profit functions. 3.4.6 Implicit via profit vs. generation interval for genetic traits. 3.14 Derives economic values (partial derivatives) of fertility, weights, and performance traits. 3.15 Uses genetic discounting to adjust trait values over varied lifespans.	(Fernández-Perea & Alenda Jiménez, 2004)
38	1.3 Uses average daily gain (ADG) and total weight gain to assess treatment effects on steer growth. 3.4 Computes marginal income per steer on implant cost. 5.1.2.4 Reports means $\pm$ SEM (Standard Error of the Mean) for ADG and weight gain. 5.1.2.6 Uses ANCOVA to compare implant vs. control groups. 5.1.2.7 Uses SEM to quantify variability in weight gain 7.12. Uses average daily gain (ADG) as a productivity metric for steer performance 11.4. Presents line charts of live weight and weather trends. 11.3.5 Defines data collection protocol (weights, pasture metrics).	(Arias, et al., 2019)
39	1.3 Measured body weight, ADG, FCR, DMI, and conformation traits 3.4 Calculated feed cost per day and per kg weight gain 5.1.2.4 Reported various means (Feed Conversion Ratio, Body Length, Body weight, Dry Matter Intake, Daily Body Weight Gain). 5.1.2.6 Two-way ANOVA. 11.4.8 Line charts of fortnightly weight and ADG 11.17.4 Correlation analysis between body weight and Body length, Chest (heart) girth, Height at wither.	(Sorang, et al., 2023)
40	1.3 Herd size, income from weaner sales, disease prevalence, protein nutrition, and feed-density index measured as system outputs. 2.13 System dynamics simulation of stocks & flows. 2.14.1 Models long-term system behaviour and feedback. 2.14.2 Captures rangeland degradation dynamics. 2.14.3 Defines causal structures impacting herd and health. 11.10.1 Follows Sterman's problem articulation and structure phase. 11.11.2 Builds an integrated model from six subdomains. 11.12.3 Validates model via sensitivity, structure, and behaviour testing. 14.2.4 Defines system boundaries for One Health domains. 14.2.8 Varying parameters like vet access and rainfall. 14.4.2 Coordinates six model sectors (cattle, climate, health, etc.). 14.6.2 Runs extreme condition tests on feedback loops. 14.10. Analysing how parameter changes (e.g. farm infrastructure, training levels) impact system performance and expose vulnerabilities under extreme conditions.	(Van Heerden, et al., 2024)
41	1.3 Uses Emergy Transformity and Output/Input Emergy Ratios as performance indicators for cattle systems; the environmental impact per unit of meat is calculated. 2.10. Trade-offs across ecological, energy, and economic outcomes highlighted for decision makers. 2.14. Captures flows of environmental energy (sun, rain, pasture) into production outputs. 3.4 Emergy Investment Ratio (EIR), Emergy Yield Ratio (EYR), Environmental Loading Ratio	(Rótolo, et al., 2007)

No.	BOK categorisations	Reference
	(ELR), Emergy Sustainability Index (ESI). 3.5.4.2.3 Benefit–cost ratio interpretation for economic–environmental trade-offs 3.4.5 Assesses cattle production viability through emergy inputs vs. meat output value. 7.12.1 Analysis of emergy costs of production vs returns. 7.12.5 output/input comparisons across subsystems. 7.1.4 Compares domestic consumption vs. export potential concerning ecological integrity and emergy returns. 8.1.6 Comparing emergy indices across systems. 8.2.1 Ecological-economic interaction trade-offs. 8.3 Full grazing production system design evaluated for environmental sustainability and efficiency. 9.6.2 Environmental scanning - The entire emergy analysis is a systematic scan of environmental inputs (rain, soil, solar, etc.) and their interactions with the economic system. 9.6.4 Discussion of “future strategies,” regulatory incentives and incentives for ecosystem-service payments all tie into structured planning. 9.6.6 Concludes with policy recommendations (e.g. incentive structures, pasture-management regulations) that flow from the emergy findings. 9.6.8 The proposed use of emergy indices as ongoing performance metrics is a form of built-in monitoring. 11.4.8 Emergy diagrams and flow charts. 11.17.4 Emergy ratios and subsystem benchmarking 11.3 Requires detailed local climate, soil, pasture and productivity data for emergy accounting. 13.4.1 Cattle system emergy cycle from birth to output and resource renewal. 14.10.2.1 Integration of environmental and economic performance. 14.9.3 Model analysis for system decisions.	
42	1.3 Evaluates gross margin, MJ/t LW, and CO ₂ eq/t LW as system-level indicators. 2.2.1 Linear programming maximises gross margin under CAP constraints; 2.10.1 Assesses economic and environmental performance concurrently. 2.13.3 PLANETE model simulates NRE use and GHG emissions for farm systems. 3.4 Compares income across farming systems (2012 projections). 3.5.4.2.3 Evaluates profitability vs. emissions intensity. 4.2.2 Seasonal calving/finishing strategies compared as production processes. Each farm system involves different resource schedules (e.g., age of slaughter, feeding stages, calving intervals). These can be seen as process flows with scheduled steps in a manufacturing context. 4.6.10 Model machinery and building use over time with energy needs per hectare/hour. 7.1.2 2012 policy and price scenario projections. 7.1.4 Assesses farm system response to changing energy prices and CAP reforms. 7.7.1 Calving–finishing pipeline treated as phased production process. The farm systems represent strategic planning schedules (e.g., baby beef vs. on-farm finishing), each with defined input/output timing over multiple production phases. This aligns with planning the flow of production batches (e.g., cow–calf–finishing pipeline). 7.12 Measures labour productivity and farm restructuring impact over time. 11.10.1 Models developed in Excel and integrated. 11.17.4 Summarises energy/emissions metrics across test cases. 13.4 Emissions and energy footprint of production systems follow the ISO 14040/14041 LCA framework. 13.6 Assesses the effects of input cost shocks on viability. 14.10.2 Captures energy and GHG impact per unit product through integrated models. 14.10.4 Evaluates economic impact under rising energy scenarios. 14.9 Combining models for economic/environmental forecasting.	(Veyssset, et al., 2010)
43	1.3 Evaluates protein output, yield and liveweight to assess productivity; uses multi-year average performance across crop-livestock (CL) systems. 2.13.1 SimaPro used to run 1000 Monte Carlo iterations for LCIA; discernibility analysis identifies statistically robust	(Vogel, et al., 2021)

No.	BOK categorisations	Reference
	impact differences. 2.10.1 Evaluates trade-offs between productivity, profitability, and environmental impact. 3.5.4.2.3 Economic analysis compares gross margins across systems to identify trade-offs with environmental metrics, profitability per crop/livestock component, and the full system analysed. 3.8.3. The systems are evaluated regarding broader environmental and public impacts (e.g., emissions, land use, eutrophication). 4.2.2 Analyses production cycles (rice-ryegrass-soy rotations); seasonal labour/machinery inputs evaluated. 7.12 Tracks land use, water use, labour efficiency, and GHG per ton of protein. 7.7.1 Defined production phases per system. 11.17.4 System performance data compared via tables and figures. 13.4 Emissions and land/water impacts evaluated per ISO LCA standards. 14.10.2 Assesses system-level costs per protein output. 14.10.4.1 Considers yield/market risks in high-input systems.	
44	1.3 Measures energy use, emissions, and eutrophication potential as key system outputs; productivity tracked via rice yield and beef live weight. 2.10.1 Evaluates environmental trade-offs (e.g., reduced GHGs vs increased acidification). 2.14.3 Analyses circular nutrient and energy feedback via manure→digestate→field→feed→cattle. 3.5.4.2.3 Assesses emissions and energy reduction vs productivity; compares specialised vs integrated systems on eco-efficiency. 4.2.2 Evaluates seasonal integration between rice, beef, and biogas operations; 4.6.10 Reviews biogas system configuration and digestate storage impacts on emissions. 7.12 Tracks operational indicators like GHGs, MJ, NH ₃ , and PO ₄ e for integrated vs. specialised systems. 11.3 LCA model built on inventory data from multiple farms. 11.17.4 Summarises subsystem-specific impacts for decision support. 13.4 ISO 14040/14044 LCA used to assess total environmental impact across subsystems. 14.10.2.1 Optimises environmental and productivity trade-offs through biogas/compost return and emissions reduction. 14.9 LCA used as an integrative tool for circular systems evaluation.	(Ogino, et al., 2021)
45	2.1.1 Ordered probit modelling for discrete trait valuation. 3.1.1 Interprets model coefficients as marginal utility of traits. 5.3.2 Ordered probit regression linking traits to value. 11.6 Structure cattle trait data for econometric analysis. 11.17.7 Forecasts trait valuations from model outputs.	(Sy, et al., 1997)
46	2.13.1 Uses Risk to simulate stochastic feed availability and market price scenarios for risk assessment [10,000 iterations combining forage yield variance and price fluctuations]. 2.13.3 Sequential integration of forage-growth, herd dynamics, and economic models [captures intake-to-weight and revenue streams]. 3.6 Compares supplemental feed cost vs. grazing opportunity cost [calculates break-even feed price via cash flow analysis]. 5.3.1.2 ANOVA on biomass yield and net margin across feed treatments [identifies significant profitability differences]. 7.1.2 NDVI (Normalised Difference Vegetation Index)-based seasonal pasture biomass forecasting [projects forage supply under ENSO and flooding regimes]. 11.17.1 Processes satellite NDVI (Normalised Difference Vegetation Index) and climate data into monthly feed supply inputs [handles missing values via interpolation]. 14.9.1 Constructs dynamic whole-farm simulation linking schedules, animal growth, and economics.	(Bilotto, et al., 2021)

No.	BOK categorisations	Reference
47	1.3 Record herd size, land area, feed & medication costs as KPIs for profitability. 3.2 Feed and medications were identified as major variable costs. 3.4 Computes gross margin per head. 3.9 GM (Gross Margin) is used to assess enterprise viability. 5.1.2.4 Descriptive stats on farmer age, experience, and credit access. 5.3.2.4 OLS model to identify drivers of GM. 7.1.4 evaluates channels (open market vs middlemen) and contract sales impact. 7.12 GM per cattle as key performance. 11.3.5 Structured questionnaire design and administration to collect data from smallholder beef cattle farmers. 11.14 Data-collection protocols.	(Jobirov, et al., 2022)
48	2.10.3 Evaluates two innovation-adoption scenarios to assess project outcomes under uncertainty. 3.2 Breaks down total project costs into core (traps, sterile flies, aerial release), other field, studies and administration. 3.4 Computes PP, NPV & IRR for both scenarios 5.1.2.6 Uses ANOVA and t-tests to compare herd size, sales and productivity across farming systems. 7.1.2 applies innovation-diffusion S-curve logic to forecast breed-replacement rates. 7.12 Uses per-head cattle sales as a key performance indicator. 11.3.5 Eliciting Requirements & 11.14 Designs closed-closed-question survey to elicit quantitative farm and production data. 14.5.2 combines insecticide-impregnated targets and sterile insect technique in an AW-IPM framework to design a sustainable elimination system	(Bouyer, et al., 2014)
49	5.1.2 Uses frequencies, means, and SD for age, herd size, and experience. 5.3.2.4 OLS model to identify determinants of cattle sales. 7.1.4 Examines how price, herd size, distance, off-farm income, credit and vet access influence the volume of cattle sold. 11.3.5 Questionnaire development. 11.14 Structured interview protocol for data collection. 14.9 Conceptual framework links determinants (inputs/process) to market participation (output).	(Kibona & Yuejie, 2021)
50	1.4.1 Uses CTS (Cattle Tracing System) logs of daily movements, births and deaths to calculate herd-level metrics and trace infection pathways. 2.13 Implements stochastic SIR (Susceptible-Infected-Recovered) Monte Carlo simulations to model fade-out and estimate Critical Community Size. 3.9.1 Aggregate costs of feed, movement restrictions and breakdown responses across farms. 3.9.2 Allocates direct (veterinary, testing) and indirect (downtime, culling losses) costs to herd-level profit models, incorporating P(HBD) (Probability of Herd Breakdown) when assessing economic impact. 5.1.2 Reports mean, median, variance of herd sizes; bootstrap clearance probabilities for confidence intervals. 7.1.2 Analyses temporal trends in mean herd size and active premises (2002–07). 7.12 Uses herd-size distributions and active-farm counts as KPIs. 11.6 Cleans, integrates CTS & VetNet data. 11.17.4 Computes and visualises time-series of herd-level test-clearance rates, persistence durations, and breakdown intervals to identify hotspots and temporal clusters. 14.9 Combines SIR and financial models to guide optimal farm-size decisions.	(Brooks-Pollock & Keeling, 2009)
51	1.2.2 Methods Engineering – Analyses labour organisation (e.g. calving workload) to identify efficient practices in low-input, high-welfare systems. 2.10.1 Balances trade-offs among economic, environmental, and animal welfare goals via cluster analysis of farm strategies. 3.4.5 Compares the cost per unit gain in welfare or environmental performance. 4.2.2 Defines farming system flows (e.g., feed cycles, calving intervals) as process timelines affecting performance metrics. 5.1.2.6 Uses analysis of variance to test the significance of management strategy clusters across performance dimensions. 7.12 Measures productivity, economic margin, environmental impact, and animal welfare at the	(Mysko, et al., 2024)

No.	BOK categorisations	Reference
	farm level. 8.2.1 Evaluates feed purchasing versus on-farm forage production in low-input systems. 9.6. Sets trade-off-aware performance benchmarks for complex farming goals. 11.17.4 A cluster analysis / structural-equation-based grouping was completed, and then a comparison of the farms' scores on economics, environment, and welfare was done. 14.10.2 Considers long-term economic viability of systems optimised for environmental and welfare goals.	
52	2.13 Agent-based, stochastic SEIR model of cattle & truck movements to mimic FMD spread. 2.1.1 Uses ABM to capture temporal contact sequences. 5.1.2.3 Parameterise latent and infectious periods with PERT, Normal and triangular distributions for disease-state transitions. 5.1.2.4 Reports medians, IQRs, means and SDs for numbers of infected farms and cattle removed across scenarios. 5.1.2.5 Uses Wilcoxon rank-sum tests to compare outbreak sizes under different control and information-sharing strategies. 7.12 Uses the packer operating time & total cattle count as performance metrics. 8.2.10 Builds a dynamic network of farms & transporters to assess outbreak pathways. 8.4.4.3 Simulates truck routes and contamination probabilities between premises. 9.3.1. Implements trace-data infrastructure across producers/packers for outbreak notification. 10.4.5 Assesses indirect-contact hazard via contaminated trucks. 11.3.5 Defines data needs (time-stamped trade records). 11.6.2 Stores and queries movement logs for trace-back/-forward. 11.17.7 Uses simulation outputs to forecast epidemic scenarios. 14.2.8 Varies trace-back window, contamination period & transmission probabilities to probe model robustness. 14.9.1 Employs a digital twin of the beef supply chain to inform control strategies.	(Yang, et al., 2020)
53	1.13.1 Uses SAS (Statistical Analysis System) survey procedures to stratify and weight CAIS (Childhood Agricultural Injury Survey) data. 3.2 Partitions total burden into medical, productivity, and QALY (Quality-Adjusted Life Year) costs and values lost "calf" outputs vs. injury costs. 3.3.1 Applies a 3 % discount rate; 3.4.1 Converts future costs into 2005 USD and translates lifetime productivity losses to present USD. 5.1.2.2 uses CAIS sample to estimate national incidence and uses farm sampling to estimate system failure (injury) rate; 5.1.2.3 Reports rates with 95 % Confidence intervals and models defect frequency. 5.1.2.4 Summarises incidence & costs and measures throughput loss. 7.1.2 Analyse injury-rate trends 1998–2006 and track system throughput changes (injury rates) over time. 9.6.4 Calls for coordinated safety guidelines & farm-level action plans and integrates safety as preventive maintenance in farm operations. 10.3.1 quantifies tractor-related injuries. 10.3.2 Ranks unstable surfaces/structures as leading sources. 10.4.3. Accident investigation and reporting. 11.17.1 Maps & cleans CAIS + cost data. 11.17.4 Tabulates incidence & cost by age, farm type, and activity. 14.10.4 Uses combined cost/QALY metrics to quantify system-level youth injury burden on farms and impact "product" yield and quality.	(Zaloshnja, et al., 2011)
54	1.13.1 Participatory discussions and structured questionnaires coded and analysed to map herd-level incidence. 2.1.1 Multistage cluster sampling to estimate representative rabies incidence. 3.2 Partitions direct losses into mortality vs. salvage (Values lost "calves" vs. meat salvage). 3.4.1 Computes average annual herd-level (output) loss in USD. 5.1.2.2 Uses 532 household survey sample and samples herds as production units. 5.1.2.3 Reports incidence $\pm$ confidence intervals; 5.1.2.4 Compares losses between systems.	(Jibat, et al., 2016)

No.	BOK categorisations	Reference
	10.4.5 Evaluates dog-to-cattle bite risk and herd-level transmission pathways. 11.17.1 Cleans & codes participatory + questionnaire data; 11.17.4 Tabulates herd- & cattle-level incidence and economic loss, and monitors KPI (rabies rate, USD loss) as system performance indicator. 14.10.4 Assesses the system-level economic burden of rabies and evaluates the cost-effectiveness of dog vaccination	
55	1.4.1 The schematic integrates the tsetse, cost, and herd modules into a single bio-economic workflow. 2.13.1 Runs 1,000-iterations of the herd–disease simulation to capture variability in mortality and productivity. 2.13.3 Samples from probability distributions for infection, mortality and reproduction rates. 2.11 Models herd survival and infection as random processes over time. 3.4 Computes annual and 10-year discounted cash flows to derive NPV and BCR for each control scenario. 3.4.5 Reports BCR to compare intervention scenarios. 3.8.3 Conducts CBA to inform public health resource allocation. 5.1.2.3 Assumes and fits distributions for herd mortality and production outcomes. 5.1.2.4 Reports mean, medians and confidence intervals of NPV and BCR. 5.1.2.8 Presents distribution plots of simulated economic outcomes. 7.1.4 Assesses revenue from milk, meat and draught outputs across scenarios. 11.3 Identifies the need for entomology, production and cost data to parameterise models. 14.9 Uses integrated models to guide system-level resource allocation decisions. 14.10.2.2 Balances control cost versus herd-productivity gains. 14.10.4 Sensitivity testing of cost and efficacy parameters to assess decision robustness.	(Meyer, et al., 2018)
56	2.14 Uses energy system language diagrams to map renewable/non-renewable inputs, purchased inputs and outputs, highlighting feedback loops between crop, livestock and integrated systems. 3.4 Calculates gross revenue, net revenue, production cost and net profit per ha for continuous crop, livestock and integrated systems. 5.1.2.4 Report percentages of renewable resource use and emergy index values to compare system performance. 7.12 Evaluates sustainability via emergy footprint, carbon-emergy output intensity, transformity and net profit metrics. 11.3 Integrates survey data (IMEA - Instituto Mato-Grossense de Economia Agropecuária) and case-study inputs to parameterise emergy synthesis and economic analysis models. 14.9 Employs emergy synthesis model outputs to inform sustainable land-use and policy decisions.	(dos Reis, et al., 2021)
57	2.13.2 Implements a daily-step herd–pasture ME model over 10 years to capture seasonal and long-term dynamics. 2.13.3 Incorporates stochastic parameter sampling for growth, intake and reproduction rates. 2.13.3.1 Varies intake, growth and reproduction parameters stochastically. 2.14 Uses inventories, converters and feedback loops to capture interactions among pasture growth, herd ME (metabolizable energy) demand and herd structure. 5.1.2.2 Uses herd and pasture trial data to parameterise the model. 5.1.2.4 Reports mean increases in productivity, efficiency and carrying capacity across scenarios. 7.12 Calculates carrying capacity (throughput), productivity and biological efficiency metrics. 14.9 Constructs conceptual model diagrams to inform system-level intensification decisions. 14.9.1 Abstracts herd–pasture interactions into stock-and-flow diagrams. 14.9.2 Aligns model outputs with on-farm production goals. 14.9.3 Uses scenario outputs to guide intensification strategy.	(López-González, et al., 2020)

No.	BOK categorisations	Reference
58	1.9.2 Simulates stocking levels (animals/ha) and rotation rates akin to production balancing across paddocks; aligns input (grass) and processing unit (cow) to output (meat). 1.11.1 Maximises production efficiency via reduced waste in forage use and paddock design. 2.13. Uses factorial simulations integrating SPUR cattle growth and PASTURE herbage models to test grazing strategies and their interactions with fertilisation and rotation variables. 2.10.1 Evaluates performance based on variables like stocking rate, paddock number, and animal gain. 2.14.1 Explores feedback loops in herbage-animal interactions and environmental variability effects. 3.5.2 Simulates trade-offs in paddock number and fertiliser levels for optimal production. 3.14.1 Incorporates weather variability in productivity outcomes. 5.1.2.4 Reports mean, variances and confidence intervals for G, ADG and stocking metrics across simulated seasons. 5.3.2.4 GLM analysis to rank main effects and two-way interactions on G and ADG. 7.1.1.3 Maps the “machine” (cow) growth phases daily over the 165-day grazing season, coordinating feed intake (forage) and output (weight gain). 7.12 Uses Gmax (peak seasonal production), ADG (average daily gain) and E (production efficiency) as key performance indicators. 11.17.4 Extracts and analyses relationships between herbage allowance, stocking rate, and production efficiency (E), presenting regression outputs and performance curves. 11.4.8 Graphs ADG vs HA (herbage allowance), E vs HA, and stocking curves to interpret model outputs. 14.9.3 Uses the simulation outputs to evaluate how input parameter changes (paddock number, rotation, fertilisation) affect system KPIs and emergent interactions.	(Senft & Tharel, 1989)
59	1.4. Uses IoT sensors to capture real-time environmental and livestock data streams for KPI monitoring. 2.10.3 Evaluates trade-offs between blanket vs precision treatments and automation investments to minimise waste. 7.1.2 Predicts hotspots of resource stress (water, fertiliser) and demand variability to optimise intervention timing. 7.12 Tracks waste reduction, energy use, and spoilage rates. 8.1.5 Leverages real-time shelf-life and transit data to mitigate spoilage risk. 8.4.4 Uses IoT routing to reduce refrigeration time and GHG emissions. 9.3 Designs IoT and sensor network architectures integrated with ERP (Enterprise Resource Planning)/GIS (Geographic Information System) platforms for farm-to-fork visibility. 11.2 Defines IoT architectures (RFID tags, sensor networks, gateways). 11.3 Specifies data types (temperature, location, health) and reporting frequency. 11.4.8 Dashboards for live monitoring of field conditions and cold-chain status. 11.5.4 Handles high-volume sensor streams for anomaly detection. 11.17.4 Computes spoilage rates, resource-use efficiencies, and correlates sensor patterns with environmental outcomes. 14.3 Integrates heterogeneous IoT devices into a cohesive farm-to-fork monitoring system. 14.5.2 Blends hardware (sensors, RFID readers) and software (cloud, edge analytics). 14.6.2 Validates sensor accuracy and end-to-end data fidelity. 14.15 Outlines ongoing calibration and network upkeep to ensure sustained performance. 14.10.2.2. Evaluates trade-offs between blanket vs precision treatments and automation investments to minimise waste.	(Piramuthu, 2022)
60	1.4 Used calibrated scales and standardised weighing procedures at birth and 6 months. 5.1.2 Reports mean birth and 6-month weights, SD and confidence intervals. 5.1.2.5 One-way ANOVA with Tukey post-hoc test to compare severity groups. 7.12 Uses liveweight gain (birth to 6 mo) and average daily gain as KPIs of production impact. 11.4.8 Graphs	(Shaw, et al., 2020)

No.	BOK categorisations	Reference
	weight trajectories by severity group over time. 11.17.4 Analyses weight-gain distributions and identifies significant group differences.	
61	1.13.1 Implements the RAPBEEF tool in Excel to stratify and analyse 20+ indicators across farms & slaughterhouses. 2.13.1 Runs Monte Carlo to test the stability of MDS-based sustainability indices. 3.2 Breaks down total economic burden into investment, water, energy, transport, and labour cost indicators. 5.1.2.3 Reports indicator scores with six-point Likert distributions; 5.1.2.4 Uses MDS ordination goodness-of-fit. 7.12 Computes and compares “added value per labour” and “employee ratios” in slaughterhouses. 8.1.1 Maps cattle flows from smallholders to traders to slaughterhouses to retailers. 8.2.10 Assesses regional self-sufficiency and excess flows. 9.7.3 Includes “% farmers > High School-educated” as a key social indicator. 9.6.4 Uses Delphi rounds to build consensus on policy interventions for top leverage indicators. 10.4.5 Leverage analysis to identify the most sensitive sustainability “hazards” (e.g. feed cost, water use). 11.3 Defines data needs for MDS (primary survey + secondary stats). 11.17.1 Cleans, normalizes & encodes 20+ indicators. 11.17.4 Performs MDS ordination to generate 0–100 sustainability indices. 14.10.4 Quantifies system-level sustainability risk and uses Monte Carlo error bands to support policy design.	(Susanty, et al., 2021)
62	7.1.4 Examines zero-deforestation policy impacts on export competitiveness. 7.12 tracks deforestation reduction as a supply-chain KPI 8.2.10 builds traceable, “deforestation-free” cattle flows via the CAR (Rural Environmental Registry) registry. 9.6.2 Maps deforestation hotspots to guide public–private action. 11.3 Defines data needs for CAR and TAC (Term of Adjustment of Conduct) monitoring. 14.2.4 Derives legal/market criteria for traceability tools. 14.9 Uses standard-setting framework as a system-design model. 14.10.4 assesses legal/reputational risks of non-compliance.	(Guéneau, 2018)
63	1.3 Measures self-reported symptom prevalence via dichotomous survey metrics. 2.1 Applies multivariate log-binomial regression to estimate prevalence ratios and adjust for confounders. 5.1.3 Uses the binomial distribution to model the probability of neurologic symptoms among exposed vs. unexposed farmers. 5.1.5 Conducts Wald tests and chi-square analyses to assess the significance of symptom differences between groups. 7.12 Reports prevalence ratios as key performance indicators of occupational risk. 10.3 Identifies Campylobacter jejuni exposure in cattle farming as a potential neurologic hazard. 10.4.5 Uses cross-sectional prevalence ratio estimates to quantify the magnitude of neurologic risk. 11.3 Defines necessary exposure and symptom variables; 11.14 Designs and implements the take-home questionnaire.	(Vegosen, et al., 2012)
64	1.4 Uses spreadsheets for cost & productivity. 1.11 Details mix-trailer and trench-silo specifications for feed preparation and delivery. 3.2 Breaks down feed, transport, veterinary and labour costs. 3.4 Computes income/expenditure and investment turnover ratios to evaluate economic efficiency. 3.7 Compares 2011 vs 2012 efficiency ratios. 4.2 Specifies box count, animal capacity and silo volumes to meet production scale. 4.3 Arranges four rows of pens with cribs and feed passages for optimised feeding flow. 4.4 Uses 6 m³ mix-trailer and 250 m³ silos to streamline feed transport and distribution. 7.1.1.3 Two fattening phases defined. 7.3.1.1 Feeding twice daily schedule. 7.5.1 Plans feed volumes against	(Živković, et al., 2015)

No.	BOK categorisations	Reference
	cattle numbers. 7.12 Reports daily gain, productivity indices and liquidity/solvency ratios as KPIs of farm performance 8.4.2 Deploys mix trailers and silos for feed movement. 8.2.10 Balances on-farm vs purchased silage and concentrates. 9.2.2 Describes family farm roles and communication. 9.4.2 Integrates economic, tech and organisational segments. 11.3 Defines data fields from farm reports (animal weights, costs, revenues). 11.14 Applies spreadsheets and balance methods for data collection and comparative analysis. 14.9.1 Apply the calculative model to map inputs (feed, cattle).	
65	2.10.3 Builds drought-scenario sensitivity analyses to compare cost outcomes of patch-burning vs. traditional burning under uncertain drought impacts. 3.4.1 Calculates NPV of future savings per cow using 2021 interest rate over a 6-year horizon. 3.4.3 Estimate the cumulative value of cost savings after two burn rotations. 3.4.5 Compares total burn + feed costs vs. benefits of forage savings between practices. 3.5.4.2 Quantifies per-cow/year savings by directly comparing alternatives 7.12 Reports cost per ha/year and per-cow/year savings as key performance indicators for rangeland management choices 11.17.7 Uses forage productivity and cost data to forecast long-term savings and drought-mitigation outcomes per cow 14.9.1 Employs integrated economic-forage models mapping inputs through process to outputs (savings, risk mitigation).	(Baker, et al., 2025)
66	2.1.1 Uses linear & quadratic regression to model ADG and gain/ha response surfaces across stocking rates. 5.1.2 Applies ANOVA on forage samples to compare BMR vs PS before grazing. 5.3.2.1 Fits ADG and gain/ha against stocking rate and hybrid type, checking model adequacy via residuals. 5.3.2.5 Evaluates the significance of forage hybrid × stocking-rate interaction on performance. 7.12 Defines ADG and gain per hectare as KPIs for grazing systems. 14.9 Employs regression-based system models to predict cattle performance under varying stocking rates.	(McCuiston, et al., 2011)
67	1.4 Deploys IoT collars and halter-mounted sensors to capture real-time movement and temperature for estrus detection. 5.3.2.1 Fits baseline estrus indicator vs. sensor features (motion, temp). 5.3.2.4 Builds multivariable estrus prediction models. 5.3.2.5 Tests the significance of predictor coefficients for model refinement. 6.3.3 Evaluated three tag-position prototypes (neck, leg, halter) on comfort vs. data quality; selected halter fit. 7.12 Computes sensitivity, specificity & accuracy from sensor vs. vet labels to assess ML (Machine Learning) model performance. 11.6 Implements MySQL schema and queuing to ingest ~10 M sensor records. 11.17.7 Trains & deploys NN on-tag to infer estrus. 12.1.3 Custom 3D-printed tag housings designed for animal physiology and sensor mounting 13.3.3 Prototypes integrated hardware/software animal tag for edge ML inference under £50 cost constraint. 14.2.4 Defines tag specs (continuous monitoring, low cost, comfort, 48 h autonomy) for on-edge estrus detection system.	(Aloo, et al., 2024)
68	2.2 Uses LP to reconstruct baseline farm production plans and simulate effects of monthly input/output price shocks. 2.7.1 Employs mixed-integer programming to enforce integral herd-size and activity constraints in the farm model. 2.8 Calibrates the Positive Mathematical Programming (PMP) module with nonlinear nutrient-balance and cost functions. 2.8.2.2 Incorporates quadratic penalty terms in PMP calibration to reflect convex cost curves. 2.8.2.3 Integrates probabilistic input/output price shocks as chance constraints	(Brečko, et al., 2024)

No.	BOK categorisations	Reference
	in the production plan. 3.2.3 distinguishes variable vs fixed cost in gross-margin calculation. 3.4.2 Expresses GM (Gross Margin) per FTE-hour (Full-Time Equivalent) to compare farm viability across TAHs (Typical Agricultural Holding). 7.12 Defines GM/h and kg CO ₂ eq. per kg daily gain as KPIs. 8.2.1 Analyse transmission of input/output price volatility from global markets to farm-level GM swings. 9.6.6 Informs CAP (Common Agricultural Policy) policy measures to support scale-up and resilience in pre-Alpine cattle systems. 11.3 Identifies needed price series, herd, and emissions data for the microsimulation model.	
69	2.10.1 Applies AHP (Analytical Hierarchy Process) pairwise comparisons across economic, environmental, and social criteria. 5.1.2.2 Gathers judgments from five expert respondents. 5.1.2.4 Computes weights for each indicator, consistency indices (CI, CR) (Consistency Index, Consistency Ratio). 5.1.2.5 Tests the consistency of judgments. 8.1.1 Defines and structures beef-chain sustainability indicators for measurement. 11.6 Organises the individual/aggregate indicators into composite metrics. 11.17.4 Ranks and visualises global priority weights. 14.2.2 Structure criteria & indicators into AHP hierarchy. 14.2.4 Analyses criterion/indicator importance via priority weights.	(Susanty, et al., 2019)
70	2.13.2 Uses ILCA (International Livestock Centre for Africa) bio-economic herd model to simulate annual herd dynamics (reproduction, mortality, growth) over 10 years. 3.4.1 Discounts 10-yr costs & revenues to calculate NPV per animal. 3.4.5 Compares discounted social vs private profits. 3.4.7 Reports IRR for each site. 5.1.2.2 Parameterise herd model & cost surveys using monthly productivity & budget data. 5.1.2.4 Reports mean of calving rates, mortality, yields and IRRs. 11.3 Defines data needed: herd structure, prices, veterinary, herding and output metrics.	(Itty, 1996)
71	1.4 Uses structured quantitative/qualitative survey forms and R-based data processing to capture credits use, herd counts, zootechnical and economic data. 5.1.2.5 Bartlett, Shapiro-Wilk and paired t-tests to compare herd growth, female proportions, slaughter age and knowledge levels. 5.3.2.4 Fits linear models relating total project value to investments in pasture, subdivisions, equipment and genetics. 7.12 Defines KPIs (Δ herd size, Δ females, Δ slaughter age, capital gain, annual gross revenue) as performance outputs. 11.3.5 Eliciting & Gathering Requirements – designs and administers farm-level forms to collect baseline and post-program data. 11.5.1 Employs R software for variance tests, t-tests, and regressions.	(da Costa Jr, et al., 2019)
72	5.1.2.5 Bartlett's test checks whether different groups (e.g., farms with small vs. large herds) have the same variance in a variable (like land area). Paired t-tests compare the average of one measurement before vs. after (or between two related groups), such as mean fodder use in cluster A farms vs. cluster B farms, to see if there's a statistically significant difference. 5.3.2.1 Models the relationship between log (cattle ownership) (to even out extreme values) and one predictor at a time (e.g., total land). 5.3.2.4 Extends simple regression by including several predictors at once (e.g., land, feeding level, labour) to see each factor's independent effect on herd size, holding the others constant. 5.3.2.5 ANOVA/LR χ^2 on coefficients for model validation. compares the full model against a reduced one (e.g., without the feeding term) to see if removing that predictor worsens the	(Robinson, et al., 2021)

No.	BOK categorisations	Reference
	fit. 11.17.1 Logs and z-score standardise skewed land, livestock and fodder variables in PCA pre-processing. 11.17.5 PCA (Principal Component Analysis) for dimension reduction and K-means cluster analysis to define six production strategies.	
73	1.4 Uses survey forms to log family labour in man-equivalent hours and itemise costs/outputs per enterprise. 3.2.3 Separates medicines, feeding, dipping (variable) vs. family labour & implements depreciation (fixed). 3.3 Applies 12 % opportunity-cost rate to herd capital. 3.4.7 Computes return on capital. 7.12 Defines profit per animal and return on capital as KPIs. 11.3.5 Designs and administers farm-level survey to collect herd, input, and output data. 11.5 Uses spreadsheets to aggregate costs, revenues, and calculate margins.	(Panin & Monkhei, 1999)
74	1.4 Deploys PIR (Passive Infrared) motion sensors and ESP32CAM to capture real-time cattle movement/images. 3.12.1 Compares TTL-based (Transistor-Transistor Logic) system cost vs. RFID, Zigbee, LoRaWAN (Long Range Wide Area Network), ESP32CAM. 5.1.2.5 Applies confusion matrix and Kappa index to assess classification agreement of movement/image detection vs. ground truth. 7.12 Defines accuracy, Kappa index, and power consumption as KPIs for system performance. 11.2 Design IoT architecture with Physical Entity (PED), the cattle and their environment (pens, pastures, water troughs, etc.), Sensing & Controlling (SCD) (PIR sensors, ESP32CAM, microcontroller boards), and user domains (UD) for real-time monitoring. 11.14.2 Develops Arduino IDE (Integrated Development Environment) code for ESP32 + TTL to capture and transmit data. 12.12.1 Integrates PIR sensors, ESP32CAM, GSM (Global System for Mobile Communications) module, SD storage, and cloud dashboard for continuous monitoring. 13.3.3 Prototype low-cost IoT hardware and validate in a 150-head corral. 14.3.1 Architecture descriptions – defines a multi-domain IoT system for cattle monitoring. 14.5.2 Integrates hardware (sensors, microcontroller) + software into a real-time monitoring system.	(Armando, et al., 2023)
75	1.4 Logs every user action in a cloud-hosted database, producing an immutable audit trail. 8.1.5 Supply Chain leverages blockchain's immutability to secure cattle ownership transference, mitigating fraud and traceability breakdowns. 11.2 Defines a three-layer IoT + blockchain architecture to enable real-time, secure monitoring. 11.6 Employs a decentralised, cloud-based database for cattle records, using blockchain as the ledger for data provenance and verification. 11.14 Forms, Programs, & Procedures – implements smart-contract-style transaction validation and firmware routines to capture, hash, and propagate updates to the blockchain network. 14.2 Elicits needs for a secure, decentralised cattle-management platform. 14.3 Design a multi-component architecture integrating RFID, cloud storage, and private blockchain nodes, with clear data flows. 14.5.2 Integrates RFID readers, cloud servers, blockchain nodes, and user dashboards into a cohesive, real-time monitoring system	(Leme, et al., 2020)
76	1.1.2 Contrasts system objectives (increase stocking, preserve stand) with quantitative measurement of outputs (G -Seasonal cattle production per area (e.g., kilograms of beef per hectare), ADG - Average Daily Gain, HE - Harvest Efficiency. 1.4.1 Uses simulation-generated log of paddock defoliation, daily forage mass, and animal movements as recording tools. 2.13.1 Monte Carlo integrates PASTURE (forage growth) and SPUR (cattle	(Senft, 1988)

No.	BOK categorisations	Reference
	growth) submodels to generate multi-year outputs under factorial SDG (Short-Duration Grazing) designs and precipitation regimes. 2.10.1 Evaluates trade-offs among stocking rate, paddock number, rotation length, and precipitation to identify Gmax (The peak seasonal cattle production achieved under a given grazing system), ADGmax (The peak average daily gain achieved by the animals under a given system), and optimal CSR (Critical Stocking Rate). 2.10.3 Incorporates climatic variability (dry/average/wet years) and forage fluctuations into system outcome predictions, guiding robust stocking strategies. 2.14.1 Models feedback loops between forage supply and cattle intake, illustrating how defoliation frequency/intensity influences regrowth and animal performance. 3.5.2 Systematically compares SDG cell configurations to conventional grazing, weighing forage utilisation against cattle gains for cost-effective stocking recommendations. 3.14.1 Factors inter-annual precipitation uncertainty into economic evaluation by calculating Critical Stocking Rate (CSR) under 70 % utilisation constraint, optimising long-term stand persistence and cattle output. 4.3.4 Implicitly uses wagon-wheel paddock layout logic to optimise SDG cell design. 4.4.1 Treats cattle movement through paddocks as material flow, minimising wasted travel distance and maximising forage consumption efficiency via SDG design parameters. 5.1.2.7 Employs GLM to quantify effects of stocking rate, paddock number, and rotation on G and ADG; 5.1.2.7 Fits ADG vs HA regressions for fast vs slow rotation to determine production efficiency (E). 5.3.2.4 Rank main and interaction effects on livestock & forage outputs, ensuring reliability of model predictions across scenarios. 7.1.2 Predicts seasonal outputs (G, ADG) under varying stocking/paddock scenarios and precipitation inputs. 7.3.1 Designs rotation schedules to balance forage availability and animal intake. 7.12.3 Computes $E = 100 \% \times G / H$ to measure system effectiveness, guiding selection of SDG over season-long grazing under resource constraints. 8.2.1 Parallels forage flow from paddock “nodes” to the “market” (animal gain), modelling how paddock network design influences throughput (kg beef/ha). 8.2.10 Conceptualises paddock arrangement and movement timing as a supply chain network, optimising herd distribution akin to facility location/flow in product distribution. 9.3.1 Integrates simulation framework to plan SDG strategies. 9.6.4 Develops multi-year grazing plans accounting for precipitation variability, optimising herd size and paddock use. 9.6.7 Translates simulation findings into actionable SDG management guidelines for ranchers. 11.3.5 Eliciting & Gathering Requirements – identifies data needs (initial weights, forage curves, precipitation inputs) to parameterise simulations. 11.5.4 Refers to high-volume simulation runs and storage of multi-year model outputs (forage and cattle metrics). 11.17.4 Generates and interprets output to reveal system “sweet spots” and emergent behaviours under SDG designs. 14.2.3 Defines SDG system requirements (number of paddocks, stay duration, precipitation thresholds) to meet stand replacement and production goals. 14.3.1 Outlines integrated model architecture combining forage growth, animal growth, and grazing interface components. 14.9.3 Uses simulation outputs to refine SDG cell parameters for maximal G and CSR under risk constraints. 14.10.2.2 Quantifies trade-offs between higher stocking under SDG versus potential forage depletion, optimising economic and ecological outcomes.	

No.	BOK categorisations	Reference
77	1.1.2 Contrasts management objectives (improved ENU - Efficiency of Nutrient Utilisation, measured as kilograms of liveweight sold per 100 kg of dry matter consumed., CPI - Cow Productivity Index measured as kilograms of liveweight sold per cow exposed to breeding.) with simulation-based measurement of outputs (liveweight sold, DM consumed). 1.4.1 Uses monthly forage intake, animal growth and reproduction schedules as recording tools to track “flow” through the production system. 1.13.1 Employs the Texas Cattle Production Model as a tool to collect, integrate and analyse data on herd performance. 2.1.1 Applies a dynamic cattle production simulation to represent the integrated animal–forage system. 2.10.1 Evaluates trade-offs among breeding season, breeding age, weaning age and supplementation scenarios to identify the highest ENU and CPI. 2.10.3 Incorporates variability in annual forage availability (dry vs. average vs. wet years) and management changes to predict robust performance outcomes. 2.14.1 Captures feedback loops between forage supply (monthly DM availability) and cattle nutrient requirements, simulating herd response to changing strategies over time. 3.5.2 Compares alternative management strategies (e.g., breed Sept–Nov vs. Jul–Sep; wean at 5, 6 or 7 months old; various supplementation regimes) to select those maximising ENU (kg liveweight sold per 100 kg DM) and CPI (kg sold per cow exposed). 3.14.1 Accounts for forage availability uncertainty when computing Critical Stocking Rate implicitly via simulation-estimated ENU and CPI under each strategy. 7.1.2 Project seasonal and annual herd performance (liveweight sold, calf survival) under each management scenario using simulation. 7.3.1 Designs breeding windows and weaning schedules as part of system control. 7.12.3 Uses ENU and CPI as key performance indicators to assess system effectiveness. 9.3.1 Integrates genotype, forage and management data into the simulation framework to plan improvement strategies. 9.6.4 Formulates multi-year herd plans (e.g., calving at 3 years, calves weaned at 7 months old) based on model outputs. 9.6.7 Translates simulation-recommended breeding/weaning/supplementation protocols into actionable guidelines. 11.3.5 Identifies data inputs (growth-curve parameters, forage CP - Crude Protein, DIG - Digestible Organic Matter in the forage, DM availability - Dry Matter availability, meaning the kilograms of forage accessible to the herd each month.) needed to parameterise the model. 11.5.1 Executes thousands of simulation iterations to generate performance metrics. 11.17.4 Interprets output tables to reveal how each strategy affects ENU and CPI.	(Abassa, et al., 1987)
78	1.1.2 Contrasts management goals (maintain cow-calf performance, supply SG (Switch Grass) biomass, reduce GHG) with quantitative tracking of forage yield, cattle liveweight sold, and GHG emissions. 1.4.1 Uses FORCAP to log monthly forage production, hay/biomass harvest events, and cattle intake as recorded procedures. 2.1.1 Implements the cow-calf simulator to represent interactions among pasture forage, SG dual-use, and cow nutrition. 2.10.1 Evaluates trade-offs among calving season (autumn vs spring), hay land species, fertiliser rates (N, poultry litter), and supplemental corn to identify scenarios maximising farm profit and net GHG reduction. 2.10.3 Incorporates year-to-year variability in DM (Dry matter) availability (dry, average, wet) to test robustness of SG adoption under uncertain forage yields and cattle performance. 2.13.1 Simulates stochastic weather/forage scenarios over ten-year runs to assess variability in SG yield, forage intake, and cattle	(Popp, et al., 2021)

No.	BOK categorisations	Reference
	liveweight outcomes. 2.14.1 Captures feedback loops between DM availability (forage/SG regrowth, poultry litter application) and herd nutrient demands, simulating how SG dual use affects forage supply → cow intake → calf weaning performance → replacement rate over time. 3.5.2 compares conventional hay vs SG dual-use scenarios by computing economic returns from calf sales, cull sales, excess hay, and SG biomass sales, selecting the strategy that maximises profit at a given biomass price. 3.14.1 Accounts for uncertain forage DM yields (via stochastic weather inputs) to estimate Critical Stocking Rate (CSR) that keeps seasonal herbage utilisation ≤ 70 % and maintains stand persistence, balancing economic vs ecological risk. 5.1.2.3 Analysis of distributions of SG yield and hay yield under variable weather. 5.1.2.5 Tests whether net GHG emissions differ significantly between conventional and SG scenarios across calving seasons. 5.3.2.4 Model relationships between fertiliser inputs, SG hay & biomass yields, and GHG emissions per kg of cattle sold to evaluate the reliability of simulation predictions. 7.1.2 Projects monthly and annual herd outcomes (liveweight sold, weaning rates, forage deficits) under each hay-land management and calving season scenario via forecasts. 7.3.1 Designs hay harvest schedule: SG first cut mid-June for hay, second cut Oct–Nov for biomass; conventional two cuts in May and August; aligns feed availability with cow nutrient needs (by month). 7.12.2 Measures per-unit cost of production: \$/cow, \$/ha, \$/Mg biomass. 7.12.3 Tracks ENU and CPI as operational KPIs, ensuring target herd requirements are met each month. 7.12.6 Quantifies kg of beef sold per ha of land and per Mg of forage provided (hay + SG biomass). 9.3.1 Designs farm plan integrating cattle herd, forage systems, poultry litter supply, and simulated output to justify SG adoption. 9.6.4 Formulates multi-year operating plans covering fertiliser timing, SG establishment, hay/biomass harvest timing, and calf sale schedules to optimise returns. 9.6.7 Translates simulation recommendations (breakeven SG price, fertiliser rate, harvest calendar) into farm management actions. 11.3.5 Identifies input data: 20-yr monthly forage quality, SC yield-response to N, cattle growth curves, poultry litter nutrient content. 11.5.4 Handles multi-year, multi-scenario FORCAP outputs (forage production, cattle performance, GHG emissions) requiring substantial computing resources. 11.6 Stores monthly forage yield, cattle inventory, fertiliser use, and GHG emissions in structured tables for scenario comparison.	
79	2.11 Assigns calving-probability distributions derived from liveweight–fertility curves to capture the risk of conception under seasonal nutritional stress. 2.13 Implements and validates a deterministic simulation of individual cow intake, liveweight change and calving rate, comparing simulated versus observed weight gains. 7.1.2 Uses the model to project herd liveweight and calving outcomes over multiple seasons. 7.3.1 Structure a two-phase grazing schedule (native savanna in dry season; molasses grass in wet season) to optimise nutritional intake. 11.3 Compiles liveweight, diet-quality (N, DOM) and physiological-state data as model inputs. 11.10 Converts farm production parameters into simulation specifications (weight-change and intake algorithms). 11.15.2 Verifies and validates model outputs against independent herd and steer trial data. 14.2 Defines functional requirements (intake, maintenance, calving-rate rules) from field trials. 14.6 Validates model by comparing simulated versus observed liveweight changes and calving rates. 14.7 Refines	(Levine & Hohenboken, 1981)

No.	BOK categorisations	Reference
	diet-quality submodels to address discrepancies in extreme weight change periods. 14.9 Conceptualises “farm as a production system,” mapping inputs (roughage, minerals, pasture quality) through the “machine” (cow metabolism) to outputs (calf crop, weight gain). 14.10.17.4 Tracks model performance and guides future pasture-research priorities.	
80	3.2 Comparison of on-chain gas costs for event-based vs state-based storage (minimises blockchain fees). 7.6 Tracks herd size via “Total Tokens,” “Active Tokens,” “Deactivated Tokens”. 7.12 Visualises counts of farm activities (birth, feeding, movement) to measure throughput. 8.2.10 Monitors cattle token movements (birth → events → burn) for traceability. 8.4 Logs/visualises livestock lifecycle events and custody transfers end-to-end. 11.3 Defines data fields (timestamps, event types) needed for real-time monitoring. 11.6 Uses MongoDB (NoSQL) to store/query append-only event logs. 11.17.4 Generates dashboard plots showing volumes and trends of cattle events. 14.2 Specifies functional requirements for ETL, filtering, and dashboarding. 14.3 Designs multi-layer architecture (IoT → smart contract → ETL (Extract, Transform, Load, like “cow born” or “cow moved”) → MongoDB → Streamlit UI). 14.5 Implements Solidity contracts, Web3py ETL, MongoDB schema, and Streamlit front-end.	(Yap, et al., 2023)
81	4.6.8 Describes waste removal methods (regular removal, rotational grazing, systematic disposal) to maintain hygiene and prevent environmental contamination. 7.6 Compares herd size (by age categories) to available land area to plan feeding, breeding, and space allocation. 7.12.6 Report numbers of calves, yearlings, and adults as output metrics of each farm’s productivity. 9.6.2 Conducts SWOT analyses to assess farm strengths, weaknesses, opportunities, and threats. 10.3 Implements regular health assessments and vaccination protocols to prevent disease outbreaks across rearing systems. 11.3. Identifies key data fields (herd numbers, age distribution, feeding methods, housing, waste management) needed to evaluate management practices. 11.5.1 Uses farm records, official statistics, and on-site visits to verify and organise collected data. 14.1 Defines the purpose of each farm (maximise calf or meat output given inputs: feed, pasture, labour). 14.2 Feeding regimes (semi-intensive vs extensive vs intensive), housing types, waste-disposal methods, and veterinary care tailored to each farm’s context. 14.9.3 Interprets age-distribution tables and SWOT results to guide resource allocation and process adjustments.	(Ṭenu, et al., 2024)
82	7.1.4 Highlights demand uncertainty (local + international) driven by globalisation and weather, requiring producers to adapt inputs (feed, pasture) and processes (cow as “machine”) to meet shifting output (calf/ fattened beef) needs. 7.6.4 Discusses how producers adjust herd numbers (machine capacity) and feeding strategies (input mix) to remain flexible under variable market conditions. 7.12 Defines and measures four SCP (Supply Chain Performance) indicators (flexibility, efficiency, food quality, responsiveness) via a survey to quantify farm-level throughput performance. 8.5.1 Identifies diverse customer segments (feedlots, processors, wholesalers, retailers, live exporters) and their distinct requirements, implying producers must classify inputs (feed, genetics) and processes (production systems) accordingly. 8.5.3 Emphasises CRM (Customer Relationship Management) practices (e.g., on-time delivery, product consistency) as critical to maintaining relationships and enabling flexible production planning. 8.6.2 Investigates	(Jie & Parton & Mustafid, 2016)

No.	BOK categorisations	Reference
	SSP (Strategic Supply Partner) (e.g., trust, coordination, joint problem solving) with feed, veterinary and logistics providers, showing that strong upstream collaboration enhances downstream flexibility. 9.6.2 Examines how globalisation, competitive pressures and supply-side volatility (e.g., extreme weather) constitute external environmental factors that shape strategic decisions on farm inputs (e.g., forage, seed, supplements), process design (rearing system), and output targets (carcass specs). 11.3.1 Defines what producer-level data (e.g., order forecasts, herd size, feeding schedules) must be captured to support supply chain decisions and flexibility analysis. 11.5.1 Describes the use of survey data, official statistics and on-farm records to compile and process (transform) information for regression analysis. 11.17.4 Applies Pearson correlations and stepwise regression to summarise relationships between SC practices (inputs/process variables) and flexibility (output performance).	
83	1.1.1 Frames the buyer-driven beef value chain (retailers, slaughterhouses, producers, NGOs, government) as a complex work system involving multiple stakeholders seeking sustainability. 1.1.2 Contrasts sustainability goals (deforestation reduction, GHG mitigation) with measurement systems. 2.10.1 Analyses trade-offs among government policies, retailer requirements, and producer compliance to minimise deforestation while maintaining beef throughput. 2.10.3 Incorporates uncertainty in enforcement (illegal deforestation risk, variable compliance rates) and climate pressures into decision frameworks for supply-chain actors. 3.9.2 Tracks the annual beef chain value, splitting costs among producers, processors, retailers, and sustainability investments. 3.14.1 Uses probabilistic estimates of deforestation fines, compliance costs, and GHG (Greenhouse Gas) penalties to guide producer decisions under uncertainty. 5.4.1.8 Implies a continuous improvement cycle where supply-chain audits drive Define–Measure–Analyse–Improve–Control of sustainable practices. 5.5.1 Applies basic probability/statistics to monitor deforestation rates, GHG emission trends, and compliance frequencies for reliability of reporting systems. 7.1.4 Examines how transnational supermarket chains (Walmart, Carrefour, etc.) set new requirements (CDP scores) that ripple through the Legal Amazon beef market. 8.1.1 Describes the flow from cattle ranches (Legal Amazon) → slaughterhouses → retailers, showing how sustainability certifications are embedded. 8.6.3 Outlines how retailers score suppliers on compliance, driving the exclusion of non-compliant ranches. 8.6.7 Details how large retailers demand CAR registration, effectively vetting all upstream producers. 9.3.1 Lays out a governance framework combining MLP (Carbon Disclosure Project) and TIS (GIS tracking) as institutional innovations in beef supply chains. 9.6.4 Integrates public policy with retailer standards to plan sector-level transitions toward deforestation-free beef. 10.4.5 Evaluates the environmental and reputational hazards (illegal deforestation, GHG non-compliance) that threaten corporate viability, driving governance tools. 11.2.5 GIS relies on spatial networks to map ranch boundaries and deforestation alerts. 11.3.3 Identifies the need for high-resolution geo-referenced data to inform sourcing decisions. 11.6.2 Stores and manages CAR registry data, supplier compliance records, and CDP disclosures in relational databases. 11.10.3 Requirements define system needs for traceability (which fields, layers, and attributes GIS must capture). 11.14.1 Standardises reporting templates for CDP submission and CAR data uploads.	(Makiya & Fraisse, 2015)

No.	BOK categorisations	Reference
	14.1.1 Articulates the purpose: transition Legal Amazon beef cluster to deforestation-free, low-carbon production. 14.2.3 Translates retailer and government mandates into specific ranch requirements: no deforestation since 2009. 14.3.1 Lays out the hybrid governance architecture: overlaying MLP (Multi-Level Perspective - institutional levels) with TIS (Technological Innovation System - GIS technology) to monitor and enforce sustainability. 14.9.3 Uses GIS-derived deforestation maps plus CDP scores to identify non-compliant ranches and adjust sourcing strategies. 14.10.2.2 Weighs costs of GIS implementation and certification versus access to premium markets and avoidance of fines; identifies economically optimal compliance path.	
84	1.1 Frames cattle testing and slaughter as a routine “work system” for bTB (Bovine tuberculosis) detection among farm herds. 1.1.2 Contrasts the objective of “early outbreak warning” with quantitative measurement of monthly reactor counts. 2.10.3 Uses ARIMA-based monthly forecasts of bTB reactors to guide “test & slaughter” deployment under uncertain future incidence. 2.11 Applies time-series methods (ARIMA - Autoregressive Integrated Moving Average) to capture random fluctuations in bTB incidence. 5.1.2.3 Assumes normality of residuals in ARIMA; checks via white noise. 5.1.2.5 Applies Bartlett’s test for variance stationarity and ADF (Augmented Dickey–Fuller) unit-root test for mean stationarity. 5.1.2.4 Calculates RMSE (Root Mean Square Error) to evaluate prediction error. 7.1.2 Uses ARIMA to forecast future bTB reactors, informing how many herds to test. 7.12.6 Tracks monthly throughput of “tested heads” and “reactors” to monitor program effectiveness. 9.8.3 Implicitly addresses resource allocation for “test & slaughter” versus predicted outbreak costs (discussion suggests ARIMAX to incorporate economic factors). 9.8.4 Forecasts used to assess bTB-control program risk. 11.1 Extracts monthly reactor counts from GIS-based registry. 11.3 Defines the need for monthly bTB data to feed ARIMA. 11.6 Relies on a “Geographical Information System (GIS)” registry of PPD-tested cattle for data storage and retrieval. 11.10 Uses time-series methodology to transform raw counts into actionable forecasts. 11.17.7 Employs ARIMA to predict next-12-month reactor incidence. 14.9.3 Analysing Model Output for System Design Decisions – Advises using ARIMA outputs (“forecasted reactors”) to design a fast-alert surveillance system. 14.10.4 Interprets how predicted bTB spikes translate to outbreak risk, guiding policy.	(Esmaeilzadeh, et al., 2022)
85	1.3 Employs ADG, DMI, and days on feed to compare calf-fed vs. yearling systems. 1.4 Uses limit-feeding records and intake logs for feedlot and grazing phases. 2.10.1 Balances feed cost, days on feed, grazing days, and grid vs. live pricing to identify the most profitable sorting strategy. 3.9.2 Itemises feed, yardage, interest, health, and death-loss costs for each production system. 7.4 Production allocates steers to calf-fed, summer-yearling, or fall-yearling slots to optimise feedlot throughput. 7.12 Measures profit per steer, feed efficiency, and carcass value as key performance indicators. 8.4.1 Manages flow of cattle from weaning through grazing to finishing to avoid overweight carcasses. 11.17.4 Process performance and profitability data (ADG, costs, grid discounts) to evaluate sorting outcomes. 14.9 Uses simple economic and performance models to simulate and compare entire beef production pathways (calf-fed vs. yearling).	(Adams, et al., 2010)

No.	BOK categorisations	Reference
86	2.13 Builds and validates a system dynamics model of cattle and agritourism interactions using causal loop and stock-and-flow structures; performs sensitivity analysis via Monte Carlo to capture parameter uncertainty. 3.3 Discount future revenues and costs using the price index to convert historic data into present values. 3.4 Simulates farm cash flows under scenarios with and without agritourism, capturing investment costs, operating expenses, and revenues from both livestock and accommodation. 3.4.5 Compares agritourism net revenue to investment and operational expenses. 3.4.6 Implicit in cash-flow projections to identify break-even timelines for lodging investments. 3.14 Applies Monte Carlo sensitivity to assess the robustness of diversification benefits under stochastic inputs. 3.15 Evaluates agritourism scenarios under COVID lockdown uncertainty (varying occupancy drops and reopening dates) to determine the long-term viability of diversification. 7.1.2 Projects herd size, occupancy rates, and cash flows over a 10-year horizon to compare “with/without tourism” scenarios. 7.3.1 Represents lodging occupancy as a dynamic schedule constrained by bed capacity and seasonality. 7.5 Considers herd capacity and land constraints when allocating resources between livestock and agritourism. 8.1 Discusses short distribution channels (farm-to-table) as a diversification strategy; evaluates how agritourism leverages existing farm buildings and labour for direct marketing of beef to tourists. 8.5 Highlights synergy between agritourism guests and meat sales, reinforcing customer loyalty and alternative sales channels. 8.4 Considers herd availability and final liveweight for efficient cattle dispatch and distribution timing. 8.4.4 Discusses transport logistics for moving finished cattle to processing facilities under varying herd sizes. 9.6 Frames diversification into agritourism as a strategic pivot to mitigate market risk, leveraging family-farm resources and EU subsidy timing. 9.8 Runs a management flight simulator for a case farm, planning phased investments in lodging and stable expansion, and managing loan timelines for capital projects. 11.3 Identifies required data sets: herd demographics, land holdings, lodging capacity, occupancy rates, subsidy levels, and price indices. 11.10 Translates causal loop diagrams and interviews into stock-and-flow equations; parametrises variables from official statistics. 11.15 Implements the dynamic model in software with >1,800 variables, enabling scenario “what-if” analyses. 11.17.4 Generates time-series outputs and sensitivity bands to visualise cash-flow uncertainty under lockdown and reopening scenarios. 14.2 Elicits model requirements via farmer focus groups and interviews, defining endogenous (fixed capital, herd capacity, occupancy) and exogenous (prices, subsidies) boundaries. 14.3 Constructs architecture comprising livestock and agritourism subsystems, linking causal loops to stock-flow diagrams; models feedback between herd growth and lodging revenue. 14.6 Calibrates and tests model against historical occupancy and herd data, ensuring simulated vs. real data match. 14.7 Refines model structure (diet, herd turnover, occupancy dynamics) to address discrepancies observed in extreme scenarios and lockdown simulations. 14.9 Conceptualises “farm as factory”: inputs (land, feed, lodging capital, subsidies), process (cow metabolism & lodging operations), and outputs (calving rates, liveweight, lodging occupancy); uses system dynamics to make management decisions. 14.10.17.4 Embeds monitoring loops in FARMASIM to track ongoing cash flows, herd size, and occupancy, enabling continuous improvement of management strategies under changing conditions.	(Pitrova, et al., 2020)

No.	BOK categorisations	Reference
87	3.4 Converts estimated percentage of losses in cattle inventory and hay yield into direct dollar losses using regional price/production data. 3.8 Assesses how reduced cattle and hay output reduces community welfare via lower household spending and tax revenue, computing total economic losses (direct + indirect + induced) of US\$8.212 M (cattle) and \$ 0.387 M (hay). 5.3.2 Uses panel data econometric models with current/lagged PDSI, lagged cattle inventory, and trend variables to estimate the elasticity of cattle inventory and hay yield, including lagged drought duration effects on cattle. 11.3 Identifies needed data: yearly cattle inventory (head), hay yield (ton/acre), PDSI (Palmer Drought Severity Index), and constructed DryDur/WetDur variables. 11.10 Translates causal relationships (drought → inventory/yield decline) into panel-data model specifications; organises input data across 34 counties over 36 years. 11.17.4 Summarises time series (In Cattle, In HayYield, PDSI, DryDur, WetDur) and computes scenario-based percentage impacts for use in input-output analysis.	(Drugova, et al., 2021)
88	2.13 Uses the ILCA (International Livestock Centre for Africa) Bio-Economic Herd Model to project herd structure, offtake and input needs over 10 years under deterministic parameters (mortality, fertility, drug treatment rates). 3.2 Distinguishes veterinary drug costs, herding, paddocking and capital costs. 3.3 Applies 10 % opportunity cost to discount streams. 3.4 Converts outputs (milk, beef offtake, final herd value) and inputs (livestock purchases, labour, veterinary services) into annual cash flows. 3.4.5 Compares discounted net benefits to discounted net investments per herd. 3.4.6 Implicitly derived from cash-flow projections for herd replacement. 3.8 Evaluation of Public Activities – Assesses national welfare impacts of reduced cattle output under trypanosomosis risk. 3.14 Performs sensitivity analysis on trypanocide price increases to test robustness of private returns. 3.15 Simulates economic returns under varying exchange-rate premiums to account for the shadow pricing of imported inputs. 7.5 Models herd inventory (by age/sex class) and annual off-take rates. 7.6 Adjusts herd size and structure according to land and labour constraints under high trypanosomosis pressure. 8.1 Supply Chain Management derives the beef shadow price via export parity pricing to value live-cattle sales in the absence of domestic distortions. 11.3 Identifies needed data: monthly herd size, mortalities, offtake, milk yield, drug treatments, local beef and milk prices, PDSI indices. 11.10 Translates epidemiological and production records into panel-data regression specifications to estimate drought/disease impacts on yields. 11.17.4 Summarises time series of herd dynamics, milk offtake, mortality and computes scenario-based elasticities for input–output impact analysis. 14.2 Defines model requirements: demographic parameters, mortality, fertility, drug efficacy, price indices. 14.3 Structures ILCA herd model linking demographic flows (birth, mortality, offtake) and economic parameters. 14.6 Calibrates model outputs (herd size, offtake, milk yield) against observed field data. 14.7 Refines biological submodels and economic submodels (shadow pricing) to correct discrepancies. 14.9 Conceptualises Inputs (feed/grazing, veterinary drugs, labour), Process/'Machine' (cow metabolism, reproduction, disease treatment), Outputs (calf crop, fattened cattle, milk). 14.10.17.4 Embeds model monitoring loops to track herd performance under scenarios of drug resistance and variable market conditions.	(Itty, et al., 1995)

No.	BOK categorisations	Reference
89	1.4 The study used a structured questionnaire with Likert-scale scoring to record on-farm agribusiness sub-systems for each input factor (breed, forage, concentrate, medicine, reproduction, labour). The Likert responses were recorded on paper forms during interviews, then digitised into a spreadsheet for analysis. 1.13 Collected actual labour hours per week via face-to-face survey; recorded weekly labour usage (family vs. hired) in Excel before regression. 2.1 Adopted a Cobb-Douglas log-linear production function to model. 2.14 Computed Returns-to-Scale (RTS) by summing regression coefficients. 3.4 Computed total revenue minus total cost to determine profitability. 3.5 Financial Employed marginal value product vs input price to assess economic efficiency. 5.3.2 Used multiple linear regression to identify significant production factors (farm scale, forage, etc.). 7.12 Measured input metrics (forage, concentrate, health, labour) vs output; calculated reproduction efficiency. 7.1.4 Discussed competitiveness and policy impacts on beef production efficiency. 9.4 Differentiated “upper-agribusiness” (overall on-farm agribusiness sub-systems managed by farmer group/extension—e.g., access to breed stock, feed availability, medicine supply) vs. “on-farm” (individual farm’s use of inputs). The “upper” subsystem refers to group-level support (farmer organisations, access to markets), while “on-farm” refers to an individual farm’s operational execution. 11.3 Designed a questionnaire to collect specific data fields: number of cows, forage quantity, concentrate, medicine costs, reproduction metrics, and labour hours. 11.6 Entered survey responses into a digital spreadsheet with separate columns per variable. Data cleaning and tabulation were done in Excel before exporting. 14.9 Conceptualised farm as a system via production model. 14.10.4 Assessed production risk through efficiency ratios.	(Ekowati, et al., 2018)
90	2.1 Employed GLEAM (life-cycle assessment) in Excel to simulate baseline GHG emissions for each herd system (enteric, feed-related, manure). Each shortlisted mitigation option is modelled in isolation to determine its change in farm GHG emissions and its incremental cost. 2.10.3 Calculated cost-effectiveness to compare mitigation options. 3.4 Determined annual revenue (milk + meat sales) and costs (feed, health, vector control) for each mitigation measure package; calculated profit differences. 3.5 Ranked measures by CE (Cost Effectiveness). 3.14 Applied 10% discount rate over 30 years to NPV (Net Profit Value) the tsetse eradication costs and benefits. 7.12 Computed herd-level protein productivity and Ei (Emissions Intensity); used fertility rates and body weights as metrics for efficiency. 7.1.4 Contextualised mitigation in terms of rising local beef/milk demand and food-security needs in Senegal. 11.3 Identified key model inputs: milk yield, bodyweight, diet DE% (Digestible Energy), disease prevalence, herd structure (breeder vs young stock). 11.5 Entered household survey data (feed rations, herd metrics) into Excel for GLEAM. 11.12 Validated sensitivity to justify model reliability. 14.9 Treated each herd as a production system (inputs = feed, health, genetics; process = animal metabolism; output = milk/meat); GLEAM acted as the system model. 14.10.4 Conducted sensitivity analysis on production parameters to assess Ei uncertainty and risk of mitigation impacts.	(Salmon, et al., 2018)
91	1.4 Employed walk-over weighing with RFID ear tags and UHF reader to automatically record each cow’s bodyweight in real time; stored raw weight logs on the cloud. 1.13 Used embedded microcontroller to process weight data before transmission, ensuring accuracy	(Noinan, et al., 2022)

No.	BOK categorisations	Reference
	of each measurement. 2.10.2 Applied deterministic feed-consumption formula to estimate daily and 120-day feed needs. 3.4 Calculated net profit per head. 3.7 Computed feed and operation cost per kg weight gain. 7.12 Computed feed-conversion efficiency and cost per kg weight gain for each breed group. 7.1.4 Discussed growing regional export demand from Thailand to China, influencing the scale of fattening operations. 9.3 Developed cloud-based data repository for RFID-collected weights; centralised dashboard for farm decision support. 9.8 Implemented IoT pilot within 120-day feeding cycle; coordinated hardware, software, and farmer training. 11.2 Designed system architecture: RFID ear tags + walk-over weighing scale + microcontroller + UHF reader + GPRS/SMS to cloud. 11.3 Identified required fields: tag ID, timestamp, weight, feeding group, breed, cost parameters. 11.14 Programmed microcontroller firmware for real-time data capture and cloud API. 13.1.4 Verified that off-the-shelf RFID and scale components can be integrated on a local farm with available TMR feed; ensured ROI within one fattening cycle. 14.2 Elicited farmer needs (breed, feeding, weight targets) via interviews to specify system functional requirements. 14.5 Integrated hardware (RFID, scale, microcontroller) developed a cloud data pipeline, and tested in an actual paddock environment. 14.9 Used feed-consumption and weight-gain equations as the core model for predicting fattening outcomes.	
92	1.2.2 Implements a controlled-environment trial (ear-bags, enclosures) to standardise tick attachment procedures and minimise observational bias. 1.2.4 Introduces a plant-based feed supplement (Garlium) to optimise animal wellness and the production environment. 1.13.1 Uses ear-bags, controlled-environment acaridariums, and Genstat to standardise tick-count procedures and minimise bias. 2.10.3 Evaluates economic trade-offs and uncertain biological responses when using Garlium versus chemical acaricides. 3.3. Discusses potential long-term economic benefit of reducing acaricide use. 3.5.2 Compares Garlium's economic viability against conventional acaricides, factoring in feeding-trial costs, potential productivity gains, and risk of acaricide resistance. 4.2.3 Equipment Selection & Describes housing (individual pens, tick-perimeter deltamethrin barrier) and precision tick-application mechanisms (ear-bags) to ensure consistent challenge. 4.6.8 Details use of a deltamethrin-treated perimeter and controlled-humidity acaridariums to maintain hygiene and reproducibility. 5.1.2 Reports means $\pm$ SD, implying approximate normality. 5.1.2.5 Uses two-sample t-test to compare Control vs. Garlium groups for tick counts and blood values. 5.2.3.4 Implements a standardised feed, restricted intake, and ear-bag protocols to minimise variability. 5.3.1.1 Blocks 16 bulls by live weight, randomises into two groups of 8, defines a 21-day adaptation period and a 22-day assessment period to ensure balanced starting conditions. 5.3.1.3 Eight replicates per treatment, random allocation to reduce bias. 5.3.1.2 Use of Fisher's protected LSD implies a preliminary ANOVA to test overall variance before pairwise comparisons. 7.6.2 Ear-bags, individual pens, and a caridarium represent "machine capacity" for tick-life-cycle observation; their design dictates the throughput of tick data collection. 7.12.1 Tracks operational outputs: live weight gain, feed intake, number of attached ticks, total eggs per host, larvae count; these throughput metrics measure productivity and effectiveness of the Garlium intervention. 8.1.5 Supply Chain Considers acaricide resistance as a systemic risk,	(Hagg, et al., 2024)

No.	BOK categorisations	Reference
	proposing diversification (Garlium + rotational acaricide strategy) to mitigate long-term supply-chain disruption. 9.6.2 Identifies history of acaricide resistance as an external driver for alternative strategies. 9.6.6 Recommends integrating garlic-based supplements seasonally to delay resistance, reduce chemical dependency, and sustain long-term cattle health. 10.3.2 Although not a mechanical hazard, lowering tick burden reduces anaemia and stress, improving animal welfare/safety. 10.3.8 By controlling ticks biologically, Garlium indirectly lowers the risk of tick-borne bacterial infections (e.g., anaplasmosis), safeguarding meat safety downstream. 10.4.4 Encourages responsible garlic usage to reduce the frequency of chemical dips, thereby lowering farm-worker exposure to acaricide hazards. 11.3 Information Requirements for Organisations – Specifies required data: live weight, tick counts, egg counts, larvae counts, egg hatchability%, haematocrit, haemoglobin, segmented neutrophils. 11.5.1 Leverages Genstat to perform two-sample t-tests, LSD, and descriptive stats. Data sources include day 1 live-weight records, ear-bag tick counts, lab egg/larvae counts, and blood analyses. 11.17.3 Designs the trial (Control vs. treatment) as an experimental model to test “2 g Garlium/d reduces tick burden without compromising production.” 11.17.4 Summarises outcomes, interprets non-significant trends to suggest potential commercial relevance. 12.11.8 Evaluates the cost effectiveness of Garlium vs. conventional acaricides, factoring in feedlot integration and potential dip-frequency reductions. 13.3.5 Conducts a replicated feeding trial, measuring safety and efficacy (tick counts, egg/larvae production) under controlled conditions. 14.2.3 Defines dosage, trial duration, controlled tick challenge (ear-bags with set tick counts). 14.5. Integrates ear-bags, pens acaridariums, and Genstat into a coherent data-collection and analysis system. 14.10.4 Identifies variability (large SDs), confinement artefacts (ear-bag vs. field), and seasonal hatchability influences (shortened daylight) as risks to data validity. 14.10.17.4 Uses repeated measures to continuously track intervention performance and safety.	
93	3.3 Uses IRR/NPV to compare costs of raising cattle under informal contracts vs. outright purchase, treating future returns as discounted cash flows. 3.4 Projects annual costs (transport, pasture rent, health) and revenues (offspring share, final herd value) over a 10-year horizon to compute NPV. 3.5.2 Compares three herd-growth pathways (pure breeding herd, rancher under contract, outside investor) using IRR as the decision metric. 3.14.1 Probabilistic Methods Related to Acknowledges price-sensitivity and mortality-risk factors when forecasting IRR and NPV under varying beef-price scenarios. 5.1.2 Reports mean $\pm$ SD for herd sizes, contract percentages, and price ranges, assuming approximate normality in survey measurements. 5.1.2.5 Uses t-test logic implicitly when comparing IRR/NPV between contract designs (e.g., who pays health costs). 5.3.1.1 Design a focused survey to gather contract parameters, blocking by community and herd-size strata to capture variability. 5.3.1.3 Interviews 142 ranchers across 20 communities, random selection to reduce sampling bias. 7.1.4 Reviews fluctuating beef prices and interprets how price volatility affects small-rancher returns under informal contracts. 7.6 Examines how herd size influences the proportion of animals in contract and the rancher’s ability to absorb risk. 7.12.6 Tracks “head under contract” and “offspring returned” as throughput measures;	(Merry, et al., 2004)

No.	BOK categorisations	Reference
	uses these metrics to project 10-year herd growth for each scenario. 8.1.5 Supply Chain identifies lack of formal credit structures as systemic risk; informal contracts emerge to diversify capital inputs. 8.6.2 Characterises “sociedades” as a risk-sharing arrangement: investors supply calves, ranchers supply labour/land, then split offspring. 9.6.2 Surveys the historical context of Amazonian cattle to justify why informal contracts persist. 9.6.6 Suggests that, despite negative IRR for small ranchers, ownership of livestock confers non-financial benefits (liquid assets, social status), shaping long-term strategic decisions. 10.3 Describes floodplain-specific hazards (drowning risk, bites/stings during cut-and-carry) that ranchers face when managing cattle under flood conditions. 10.4.4 Highlights that informal contracts shift mortality risk of cattle to ranchers, compelling careful husbandry to minimise losses (a safety incentive). 11.3 Identifies required data fields for financial modelling and survey. 11.5.1 Uses survey forms, community interviews, and spreadsheet software to organise cost/return data for IRR/NPV calculations. 11.17.4 Summarises survey findings in tables and frequency distributions. 14.9.3 Interprets herd-projection outputs to recommend adjustments in contract design. 14.10.4.1 Evaluates key risks: high thumb-rule mortality rates, beef-price volatility, and variability in who pays maintenance costs, then assesses how each influences NPV/IRR. 14.10.17.4 Uses repeated survey waves and 10-year financial-model checkpoints to monitor herd development/reinvestment cycles across successive three-year contracts.	
94	5.1.2.4 Applied: descriptive statistics to characterise farm size, herd size, land-use percentages, etc. 5.1.2.5 Applies Chi-square tests to compare categorical variables (e.g., use of electric fencing, soil analysis) across years; uses t-tests for pairwise continuous-variable comparisons. 5.3. Employs Student–Newman–Keuls post-hoc comparisons or Kruskal–Wallis tests to identify differences in means for continuous variables (e.g., pasture area, herd size) across farm groups and survey years. 7.1.1.3 Surveys across 2009–2015 track system evolution over time. 7.1.4 Examines how foreign beef imports, high land costs, and droughts have driven farm specialisation; typology informs niche-market strategies. 7.5.2 Implicit in the discussion of herd reductions due to market pressures. 7.6.4 Discusses the need to align grazing intensity with forage seasonality. 7.12.1 Compares investments in pasture reclamation vs. returns, descriptive but no formal cost equations. 8.1.5 Identifies risk of importing cheap beef driving domestic decline; suggests diversifying through niche products. 8.2.10 Recommends shorter chains (direct producer–retailer links) to improve margins. 9.4.2 Use of soil analyses, electric fencing as process controls (management metrics). 9.6.2 Analysis of external drivers (trade policy, drought) to guide strategy. 9.8.4 Discusses risk of drought and import competition, but no formal risk models. 11.3.5 Data collected through standardised surveys (2009–2015) with consistent closed questions. 11.10.3 Requirements Implicit: identification of variables (land area, herd composition, management practices) to define group typology. 11.10.4 Data & Process Multivariate factor analysis and clustering are used to model farm “types”. 11.11.3 Surveys instrument design with 148–191 questions ensured a consistent data structure. 11.17.7 Principal component scores used to predict group membership in later years (discriminant analysis). 14.2.4 Identifies key farm attributes (size, pasture types, herd composition) as system	(Toro-Mujica, et al., 2019)

No.	BOK categorisations	Reference
	requirements. 14.3.3 Choice of 4-group typology (ranked by size and activity orientation) based on variance explained by PC. 14.4.2 Implicit in grouping variables to delineate farm “modules”. 14.6.1 Discriminant analysis correctly assigns 91.6% of farms to groups. 14.7 Typology refined from initial factor analysis → 4 groups after hierarchical clustering. 14.9.1 Farm surveys represent the “actual” system; typology is the abstract “model.” 14.10.4.1 Discusses drought and import competition as performance risks; no quantitative risk analysis.	
95	5.1.1 Defines intrinsic (colour, juiciness, fat, texture) vs extrinsic (price, brand, presentation, establishment cleaning) quality cues as perceived by consumers. 5.1.2.4 Uses non-parametric tests (Mann–Whitney, Kruskal–Wallis) to compare cue valuations among chain actors. 7.1.4 Assesses how consumer quality-preference signals propagate upstream through four actor layers. 7.12 Counts distorted vs undistorted cues to measure information distortion by actor distance from consumers. 8.1.1 Examines flow of “demand information indirectly related to material flow” across the beef chain. 8.2.10 Models actors (farmers, agro-industrials, retailers, consumers) as network layers and evaluates information distortion by adding links. 8.4.1 Bullwhip-like effect discussed for quality information rather than orders. 9.3.1 Develops surveys and data-gathering instruments to capture consumer quality cues. 9.4.2 Compares perceived vs actual consumer needs to identify gaps and guide chain coordination. 9.2.4 Highlights how miscommunication among actors leads to distortion. 11.3.3 Identifies consumers’ quality information needs to inform upstream actors. 11.5.1 Collects and processes survey data for analysis. 11.17.4 Presents mean ratings of cues. 11.17.7 Uses chi-square tests to predict distortion trends. 14.2.8 Shows how slight changes in actor perceptions amplify distortion upstream. 14.10.4 Assesses the risk of misaligned quality cues as new actors join the chain. 14.9.1 Compares theoretical information flow to observed distortions.	(Mancilla & Sepúlveda, 2017)

ANNEXURE C: INTERVIEW PROTOCOL

The interview structure is as follows (Adapted from (Creswell J. W., Research Design: Qualitative, quantitative, and mixed methods approaches, 2017))

“Good morning/afternoon/evening...”

“Thank you for being prepared to do this interview with me today.”

“I am Hermé van der Westhuyzen, a researcher at the North-West University who is part of a team of researchers who want to contextualise the Industrial Engineering body of knowledge (IISE-BOK) within red-meat cattle production systems in South Africa. From our experience and from what we know, we understand that cattle farming is a cornerstone of South Africa's economy, playing a vital role in job creation, foreign exchange, and food security. However, red meat cattle farmers experience various production challenges impacting their profitability.

“The purpose of our interview today is to understand a little more about the system challenges that Beef cattle farmers experience.”

“I will be conducting several interviews to understand the challenges beef cattle farmers struggle with, in their production systems.”

“We will probably take about 30 – 60 minutes to complete our interview.”

“Everything that you say is confidential and we will not tell anyone your name.”

“It might be that I will take a few notes during our interview so I can follow what we talk about.”

“You have given me written permission to do this interview with you and I just need to confirm that this is OK...”

“If at any time you would like to stop or no longer wish to do the interview, you can withdraw at any time.”

“Do you have any questions that you would like to ask me? ...”

“You are a small holder/commercial beef cattle farmer/producer in the Highveld area of KZN.” We know that you also have some challenges in your production system. I would like you to tell me more about your experiences with these challenges.

Basic information – information used for record keeping (date, interview number, where farm is located)			
Introduction – Researcher explains the study. (explained above)			
Guiding research question – The aim of the interview is to answer this question. (explained above)			
Research question 1 – What challenges do farmers currently experience with the farm's processes and systems?	Research question 2 - How were the farmers taught to deal with the challenges?	Research question 3- How do these challenges impact the farm's processes and systems?	Research question 4 – What causes these challenges?
Interview question – 1. Do you experience any challenges on your farm? 2. What challenges would you say are the most frequent? 3. What challenges are the most challenging?	Interview question – 1. How do you work around the challenges? 2. Are there some challenges that you have not found a solution to? 3. When you are looking for solutions, where do you go to ask for help?	Interview question – 1. How does the challenges impact your business? 2. How does the challenge impact the farm's everyday operations? 3. How does the challenges impact your profit?	Interview question – 1. Why is the challenge a problem? 2. Why? 3. Why? 4. Why? 5. Why?
Closing of interview – Thank the participant, assure confidentiality and anonymity, ask if researcher can contact participant again for follow ups.			

ANNEXURE D: INFORMED CONSENT



Faculty of Engineering

Tel: 018 299 2645

NWU-ENG-REC Stamp

INFORMED CONSENT ¹

Title of the research study: Knowledge transfer: Industrial Engineering body of Knowledge applied to red meat cattle production systems

Ethics reference numbers:

Student (researcher): Hermé Nel

Study leader(s)/promoter(s): Prof Rojanette Coetzee and Dr Mia Mangaroo Pillay

Contact number: 076 948 7589

Email address: nelherme@gmail.com

You are invited to take part in a **research study** that forms part of a Masters study in Industrial Engineering. Please take some time to read the information presented here, which will explain the details of this study. Please ask the researcher any questions about any part of this study that you do not fully understand. It is very important that you are fully satisfied that you clearly

¹ The Faculty of Health Ethics Office of the North-West University is acknowledged for the use of their document with minor adjustments made by the North-West University Engineering Ethics Committee (NWU-ENG-REC).

understand what this research is about and how you might be involved. Also, your participation is **entirely voluntary**. If you decide not to participate, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point.

This study has been approved by the North-West University Engineering Research Ethics Committee and will be conducted according to the ethical guidelines and principles applicable to this study. It might be necessary for the research ethics committee members or other relevant people to inspect the research records.

What is this research study all about?

- *The aim of this research is to explore how Industrial Engineering tools/body of knowledge can be used to enhance red meat cattle production approaches for farmers in South Africa.*

Why have you been invited to participate?

- *You have been invited to be part of this research because you are a South African cattle farmer.*

What will be expected of you?

- *You will be expected to answer the interview questions asked by the researcher.*

Will you benefit anything from taking part in this research?

- *There will be no direct gains for you in the study, however the indirect gains associated with this study are likely to help find out more about how Industrial Engineering tools/body of knowledge can be used to enhance red meat cattle production approaches.*

Are there risks involved in you taking part in this research and what will be done to prevent them?

- The potential risks of this study are sharing business secrets, but will be controlled by: Sending the transcribed response of the participant, back to the participant to check if everything said, can be shared with the research.

How will we protect your confidentiality and who will see your findings?

- *Anonymity of your view will be protected by not disclosing your name or anything that can implicate you are the participant. Therefore, you will be given a number and will be referred to as a number in the research.*
- *Your privacy will be respected by not collecting any personal information and you will receive your detailed interview response via email to check whether everything shared in the interview can be shared in the research.*

What will happen with the findings or data?

- *The data collected from this study will strictly be used for purposes of this study.*
- *The data collected from the participants will be kept confidential when transferred to the researcher's personal computer and it will be password protected. As soon as the recording has been transcribed it will be deleted from the recorders. The transcribed data of your interview, in which all identifying information has been removed.*
- *The data will be retained until the exam board confirms the results of the dissertation*
- *Extracts from the interview and the findings of this study may be quoted in the dissertation, conference presentation and published papers, but without mentioning the participants' identity*

How will you know about the results of this research?

- *The researcher will provide the results of this research via email after the data collection process and data analysis process have been completed*

Is there anything else that you should know or do?

- *You can contact Hermé at 076 948 7589 or nelherme@gmail.com if you have any further questions or have any problems.*
- *You can also contact the North-West University Engineering Research Ethics Committee: Mrs Bettie Handford at 018 299 2645 or ENG-REC@nwu.ac.za if you have any concerns that were not answered about the research or if you have complaints about the research.*
- *You will receive a copy of this information and consent form for your own purposes.*

Declaration by participant

By signing below, I agree to take part in the research study titled: An exploration of how IE tools/body of knowledge can be used to enhance red meat cattle production approaches for South African farmers.

I declare that:

- I have read this information/it was explained to me by a trusted person in a language with which I am fluent and comfortable.
- The research was clearly explained to me.
- I have had a chance to ask questions to both the person getting the consent from me, as well as the researcher and all my questions have been answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be handled in a negative way if I do so.
- I may be asked to leave the study before it has finished, if the researcher feels it is in the best interest, or if I do not follow the study plan, as agreed to.

Signed at (*place*) on (*date*) 20....

.....

Signature of participant

.....

Signature of witness

ANNEXURE E: SURVEY QUESTIONS

The evaluation of Industrial Engineering Bodies of Knowledge contextualisation tables: Applications in KwaZulu-Natal Red-Meat Cattle Production.

Thank you so much for your time and willingness to participate in this study.

This study forms part of an Engineering Masters dissertation: The value of industrial engineering body of knowledge in South African beef cattle production systems (Ethics reference number: NWU-00499-24-A3)

The purpose of this survey is to verify and validate the framework (IISE-BOK contextualisation tables for cattle production) as part of the aforementioned study.

Participant Inclusion Criteria:

To participate in this study, you must meet the following criteria:

1. You are a qualified engineer.
2. You have practical knowledge of cattle farming/production systems (e.g., lived on a farm, worked with cattle operations, family farming background, or professional exposure to cattle production).

If you do not meet both criteria, unfortunately, you will not be able to participate in this survey.

Please note the following:

You may ask the researcher any questions about any part of this study that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research is about and how you might be involved. Also, your participation is entirely voluntary. If you decide not to participate, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point.

By continuing with the survey, you agree to take part in the research study titled: Contextualising the Industrial and Systems Engineering Body of Knowledge (IISE-BOK) within red-meat cattle production systems in KwaZulu-Natal. You declare that:

- You have read the information above
- You clearly understand the research
- You have asked questions to the researcher and all your questions have been answered
- You understand that taking part in this study is voluntary
- You may choose to leave the study at any time and will not be handled in a negative way if you do so
- You may be asked to leave the study before it has finished, if the researcher feels it is in the best interest, or if you do not follow the study plan, as agreed to.

* Indicates required question

Participant information

Please provide the following details, which is for record-keeping purposes only. Please note that your biographical data will be kept confidential and will not be shared.

a. Title, name and surname *

Your answer



b. Email address *

Your answer

c. How many years of experience do you have as an engineer? *

☐ 0 - 2 years

☐ 2 - 4 years

☐ 4 - 6 years

☐ 6 - 10 years

☐ 10+ years

d. What type of cattle farming/production experience do you have? (Select all that apply) *

☐ Grew up on a cattle farm

☐ Currently live/work on a cattle farm

☐ Worked professionally with cattle operations (e.g., consultant, supplier, researcher)

☐ Family farming background (parents/grandparents/relatives farm cattle)

☐ Academic/research exposure to cattle production systems

☐ Other: _____

The IISE-BOK contextualisation tables: Applications in KwaZulu-Natal Red-Meat Cattle Production

In order to answer the following questions, kindly access the pdf document at: [Contextualisation tables](#)

Please Note: This framework covers 12 BOK areas with 35 tables in total. You are not required to evaluate every table. Instead, please focus your evaluation on the BOK areas and tables where you have the strongest expertise or feel most comfortable assessing the content regarding the applicability of IE concepts to cattle production contexts. Quality feedback in your areas of knowledge is far more valuable than attempting to evaluate unfamiliar areas.

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Confirmation of the Design requirements

Please rate your level of agreement to each of the following statements, regarding the design and appearance of the contextualisation tables.

Design requirements
Please select one per row.

1 - The framework is simple in design. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

2 - The framework is visually intuitive. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

3 - The framework is legible. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

4 - The framework shows how the Industrial Engineering Bodies of Knowledge can link to real cattle-farm practices. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

5 - The framework explains why each specific Body of Knowledge area is relevant to cattle production. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

6 - The framework is understandable to both industrial engineering and agriculture professionals. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

Please provide comments (Optional)

Your answer

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Confirmation that the contextualisation framework addresses the research problem

Please rate your level of agreement regarding the ability of the contextualisation tables to address the research problem.

Research problem and framework
Please only mark one circle per row.

7 - Industrial engineering knowledge is not as widely applied in cattle production and structured methods for applying IE to cattle production are limited. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

8 - Challenges in cattle production could benefit from industrial engineering solutions. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

9 - The framework provides a valid approach for transferring industrial engineering knowledge into cattle production. *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

10 - To the best of your knowledge, would you say the construction and integration of the contextualisation framework is an original design (as opposed to just a duplication of other previous work)? *

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

Please provide comments (optional)

Your answer

Closure

Thank you very much, once again, for your time and effort in completing this survey. I really appreciate your valuable input into my research.

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i. Please mark which BOK you evaluated from the document: *

- ☐ BOK 1
- ☐ BOK 3
- ☐ BOK 4
- ☐ BOK 5
- ☐ BOK 6
- ☐ BOK 7
- ☐ BOK 8
- ☐ BOK 9
- ☐ BOK 10
- ☐ BOK 11
- ☐ BOK 13
- ☐ BOK 14

ii. Would you be available for follow-up questions relating to this survey? *

- ☐ Yes
- ☐ No
- ☐ Maybe

ii. Would you be available for follow-up questions relating to this survey? *

- ☐ Yes
- ☐ No
- ☐ Maybe

iii. Would you like to receive an electronic copy of this research. *

- ☐ Yes
- ☐ No
- ☐ Maybe

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ANNEXURE F: SURVEY FEEDBACK FROM PARTICIPANTS

Survey statements	Participants																	Avg	%
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Level of experience	2-4y	2-4y	6-10y	6-10y	0-2y	2-4y	2-4y	10+y	2-4y	4-6y	0-2y	0-2y	0-2y	4-6y	2-4y	2-4y	10+y		
1 - The matrix is simple in design.	4	5	4	4	5	5	5	5	3	4	5	3	5	4	5	4	4	4.35	87.06
2 - The matrix is visually intuitive.	4	4	5	4	4	4	5	5	3	3	5	4	5	4	4	4	4	4.18	83.53
3 - The matrix is legible.	5	4	5	4	5	4	5	5	5	3	5	5	5	4	5	4	4	4.53	90.59
4 - The matrix shows how the Industrial Engineering Bodies of Knowledge can link to real cattle-farm practices.	5	5	5	4	5	5	5	5	4	3	5	5	5	4	5	5	4	4.18	83.53
5 - The matrix explains why each specific Body of Knowledge area is relevant to cattle production.	5	5	5	4	5	5	5	5	4	3	5	5	5	3	5	4	4	4.53	90.59
6 - The matrix is understandable to both industrial engineering and agriculture professionals.	4	3	5	4	5	5	5	5	3	4	5	4	5	4	4	4	4	4.65	92.94
7 - Industrial engineering knowledge is not as widely applied in cattle production and structured methods for applying IE to cattle production are limited.	5	4	3	5	2	5	4	5	4	4	5	5	4	4	5	4	3	4.53	90.59
8 - Challenges in cattle production could benefit from industrial engineering solutions.	5	4	4	5	5	5	5	5	5	3	5	5	5	4	5	5	4	4.29	85.88
9 - The matrix provides a valid approach for transferring industrial engineering knowledge into cattle production.	5	3	5	4	5	5	5	4	4	3	5	5	5	4	5	5	4	4.53	90.59
10 - To the best of your knowledge, would you say the construction and integration of the contextualisation matrix is an original design (as opposed to just a duplication of other previous work)?	4	4	5	3	5	5	5	5	3	4	5	5	5	4	5	4	3	4.29	85.88

ANNEXURE G: CRONBACH ALPHA CALCULATION

No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Total score per participant	
1	4	4	5	5	5	4	5	5	5	4		46
2	5	4	4	5	5	3	4	4	3	4		41
3	4	5	5	5	5	5	3	4	5	5		46
4	4	4	4	4	4	4	5	5	4	3		41
5	5	4	5	5	5	5	2	5	5	5		46
6	5	4	4	5	5	5	5	5	5	5		48
7	5	5	5	5	5	5	4	5	5	5		49
8	5	5	5	5	5	5	5	5	4	5		49
9	3	3	5	4	4	3	4	5	4	3		38
10	4	3	3	3	3	4	4	3	3	4		34
11	5	5	5	5	5	5	5	5	5	5		50
12	3	4	5	5	5	4	5	5	5	5		46
13	5	5	5	5	5	5	4	5	5	5		49
14	4	4	4	4	3	4	4	4	4	4		39
15	5	4	5	5	5	4	5	5	5	5		48
16	4	4	4	5	4	4	4	5	5	4		43
17	4	4	4	4	4	4	3	4	4	3	38	
Variance of total score											23.404	
Variance per question	0.493	0.404	0.390	0.368	0.515	0.471	0.779	0.368	0.515	0.618	Sum of variance per question	4.919

$$\alpha = \left(\frac{k}{k-1} \right) \left(\frac{s_y^2 - \sum s_i^2}{s_y^2} \right)$$

$$\alpha = \frac{17}{17-1} \left(\frac{23.404 - 4.919}{23.404} \right)$$

$$\alpha = 0.839$$

ANNEXURE H: LANGUAGE EDITING CERTIFICATE



Certificate of Language Editing

I confirm that I, Luan Krige, edited the document entitled:

**Contextualising the Industrial Engineering body of
knowledge within red-meat cattle production systems in
KwaZulu-Natal**

By **Herme Nel**

On 10 June 2026. The document was edited with respect to
English grammar and spelling, and limited lay-out changes
were made in keeping with standard practices.

A handwritten signature in black ink, appearing to read "L. Krige".

Mr Luan Krige

10 June 2026

*(Professional Editors' Guild
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