



Assessing the influence of maintenance strategies and feed formulation practices on operational efficiency in African poultry feed manufacturing

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“It always seems impossible until it’s done”... Nelson Mandela

Completing this MBA has been one of the most rewarding experiences of my life. Returning to academic study after fourteen years was a great challenge, yet it is often through difficult times that true character is revealed. Throughout this journey, I was shaped, supported, and inspired by my peers and my incredible “Incredibles” team. Achievements of this nature are never accomplished alone. Thank you to each of my group members for your commitment, collaboration, and for making this 4x4 journey both meaningful and memorable.

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ABSTRACT

Africa's population is growing rapidly. The consequence is an increased demand for affordable protein sources. Within this rising demand, poultry meat remains the preferred choice, due to its affordability compared to red meat and its freedom from most cultural or religious restrictions. However, local production volumes continue to be insufficient. This creates reliance on imports to meet the increasing demand. As a result, Africa cedes a substantial part of the market share. Central to this challenge is the poultry feed manufacturing industry, which underpins the poultry value chain. Since feed represents about 70% of total poultry production costs, improving operational efficiency within feed mills is vital to reducing costs, enhancing competitiveness, and supporting food security across the continent.

This study aimed to examine the influence of maintenance strategies, feed formulation accuracy, and technology adoption on operational efficiency in African poultry feed manufacturing. The study was of a quantitative, non-experimental correlational design, using structured surveys distributed to mid-level and senior managers across eight African countries. The analysis was guided by the Resource-Based View (RBV), which emphasises strategically developed internal capabilities as drivers of sustainable competitive advantage.

Although literature highlights strong positive relationships among the three constructs, empirical results revealed that only feed formulation accuracy had a statistically significant influence on operational efficiency. While maintenance strategies and technology adoption did show positive correlations, their effects were not statistically significant. This divergence between theory and practice highlights the complexity of operational environments in African feed mills.

This study critically contributes to the African poultry feed industry by integrating these three constructs into a single framework, despite traditionally being examined in isolation. The study provides empirical and practical insights which can be used to guide managers, engineers, and policymakers in improving productivity, reducing operational costs, and strengthening the poultry sector's role in achieving Africa's long-term food security goals.

Keywords: Resource-Based-View (RBV); operational efficiency; maintenance strategies; feed formulation; technology adoption; poultry feed manufacturing

LIST OF ABBREVIATIONS

CAGR	Compound Annual Growth Rate
CBH	Country Bird Holdings
CEO	Chief Executive Officer
CFA	Confirmatory Factor Analysis
CMMS	Computerised Maintenance Management Systems
EMS-REC	Economic and Management Sciences Research Ethics Committee
HR	Human Resources
ISO	International Organisations for Standardisation
Mt	Million metric ton
NWU	North-West University
OEE	Overall Equipment Effectiveness
PLC	Programmable Logic Controllers
POPIA	Protection of Personal Information Act
SD	Standard Deviation
TPM	Total Productive Maintenance
USD	United States Dollar
VIF	Variance Inflation Factors

LIST OF KEY DEFINITIONS

Resource-Based-View (RBV)

The Resource-Based-View refers to an organisation's ability to achieve and sustain a competitive advantage by strategically leveraging its unique and valuable internal resources and capabilities (Kero & Bogale, 2023:3137).

Poultry feed manufacturing

According to You *et al.* (2024:643), poultry feed manufacturing involves the processing of diverse raw materials to meet the nutritional requirements of birds, drawing on the knowledge of both animal nutrition and mechanical engineering.

Operational efficiency

Operational efficiency refers to the ratio between the outputs generated by business activities and the inputs required to carry out those operations (Dilshani *et al.*, 2019:46).

Maintenance strategy

Shafiee and Sørensen (2019:9) delineate that maintenance strategy encompasses “a set of policies and actions that are used to ‘retain’ or ‘restore’ equipment as well as the decision support system in which maintenance activities are planned”

Feed formulation

Feed formulation refers to the process of creating nutritionally balanced diets that support the optimal growth, health, and productivity of livestock (Baghli *et al.*, 2024:2).

Technology adoption

Granic (2023:184) defines technology adoption as “the acceptance, integration, and embracement of new technology”

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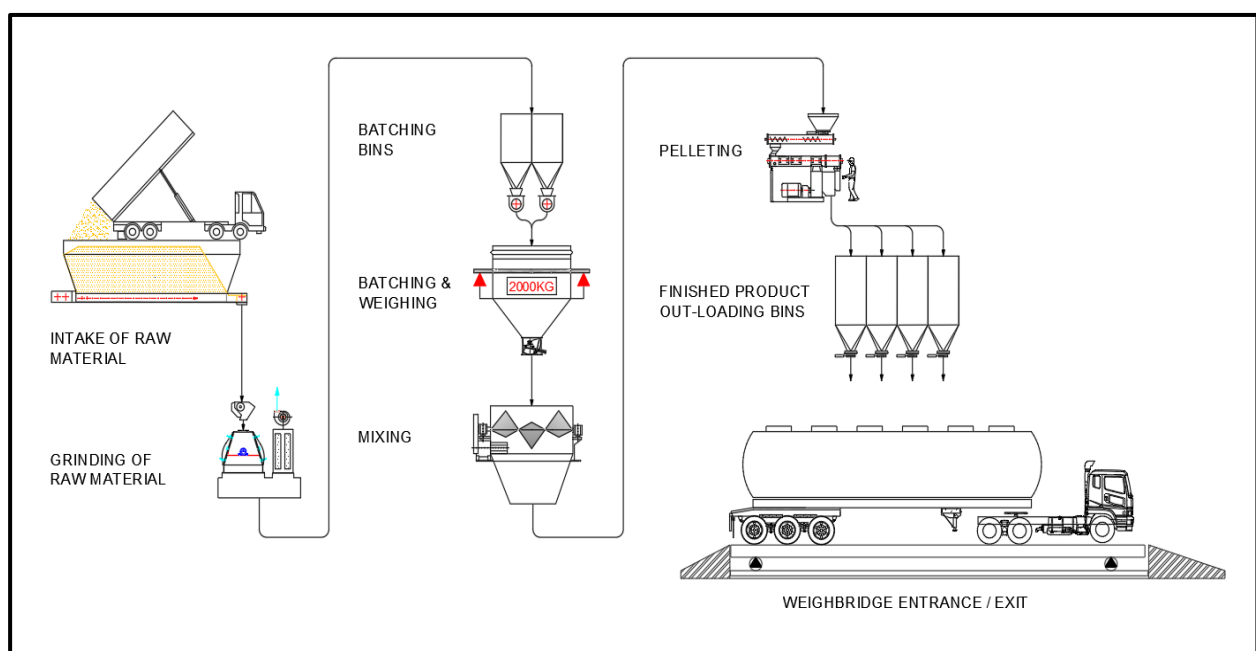
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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION AND CONTEXT

Poultry feed manufacturing is a multifaceted and dynamic process, that involves a wide variety of raw materials, specialised equipment, precise formulations, and complex process flows (Olson *et al.*, 2022:378). Figure 1-1 illustrates the fundamental operational sequence, beginning with the intake of raw materials, progressing through several processing stages, and concluding with the outloading of the final product.

Figure 1-1: Feed manufacturing process



Source: Researcher's own compilation.

The production of poultry feed can be compared to other precision-driven manufacturing processes, where product quality, volume and cost efficiency are critically dependent on the input accuracy and equipment availability (Amin & Sobhi, 2023:1). In such environments, even minor deviations in formulation, process control, or equipment settings and performance can result in cumulative downstream effects that compromise product quality and throughput (Sudha *et al.*, 2016:5). These inefficiencies often require reprocessing, which results in increased operational costs, reduction in productivity, and negatively affects overall plant efficiency (Abdullahi *et al.*, 2022:61; Öztürk, 2021:1).

Considering poultry feed represents approximately 70 percent of overall poultry production costs (Nkukwana, 2018:870; Stark & Fahrenholz, 2017:1), the optimisation of feed mill operations is a

critical aspect to be addressed in achieving sustainable and cost-efficient poultry meat supply (Ponnampalam & Holman, 2023:1; Sudha *et al.*, 2016:1).

There are myriad factors that can influence poultry feed mill efficiency. This study will focus on maintenance strategies, feed formulation accuracy and technology adoption and the extent to which these factors affect efficiency in these operations.

The subsequent sections of this chapter present the background and rationale for the study, followed by a detailed deconstruction of the research problem, aim, and objectives. The study's hypotheses and the conceptual framework underpinning the investigation are also discussed. The chapter concludes with a brief overview of the remaining chapters, outlining the structure and flow of the dissertation.

1.2 BACKGROUND AND RATIONALE

Africa's population is projected to grow to approximately two billion people by 2050 (Kleyn & Ciacciariello, 2021:267). This demographic expansion is expected to increase the demand for affordable and accessible sources of animal protein, particularly poultry meat, which remains the primary protein source for the majority of the continent's population (Faye *et al.*, 2025:6; Kleyn & Ciacciariello, 2021:268). However, local poultry production is lagging in comparison to this rising demand, resulting in a growing reliance on imported poultry products to bridge the supply gap (Erdaw & Beyene, 2022:835).

Maize is a scarce resource and considering it makes up approximately 70 percent of poultry feed, its scarcity creates an additional challenge for poultry feed production (Andam *et al.*, 2017:21). Limited availability of this essential input places pressure on feed manufacturing and, ultimately, the entire poultry value chain (Erdaw & Beyene, 2022:835). In this context, operational efficiency becomes critical in maximising output from constrained resources (Abdullahi *et al.*, 2022:61). By improving formulation accuracy, minimising waste, and optimising process performance, feed mills can achieve optimised yields from the same quantity inputs (Akintan *et al.*, 2024:2). This can boost local poultry production capacity, reduce reliance on imports, and create a supply that will meet the growing demand.

Operational efficiency is the ratio between outputs achieved and inputs utilised within a production process (Dilshani *et al.*, 2019:46). In feed manufacturing, it refers to maintaining high throughput and consistent quality while minimising waste and resource consumption (Abdullahi *et al.*, 2022:61). Operational efficiency is frequently measured using the Overall Equipment Effectiveness (OEE) framework (Ullah *et al.*, 2023:26), this evaluates three aspects of production: equipment availability, performance, and output quality (Corrales *et al.*, 2020:2). OEE is reduced

by lowered production volumes, increased production downtime, and declining product quality collectively, which in turn raises the cost per ton of feed produced (Singh *et al.*, 2018:249).

A key determinant of operational efficiency is production uptime (Ullah *et al.*, 2023:29). Maintenance strategies play a critical role in minimising the risk of unplanned downtime and ensuring a stable and constant production performance (Jane, 2025:2). Reactive maintenance, the practice of repairing machinery only after failure, has proven costly and unsustainable due to the duration of unplanned stoppages and equipment deterioration (Ahuja & Gupta, 2024:286; Jane, 2025:1; Lewele & Steenkamp, 2024:231). To avoid this, focus has shifted to proactive maintenance strategies which include preventive, predictive, and Total Productive Maintenance (TPM) (Lewele & Steenkamp, 2024:224). Introduced by Ikuta and Nakajima (1985), TPM promotes shared responsibility for equipment upkeep across all organisational levels, integrating planned maintenance, employee participation, and continuous improvement (Wardhani & Widjajati, 2023:585). Predictive maintenance acts as an additive measure to TPM by employing real-time monitoring, sensors, and analytics, enabling organisations to predict equipment failures before they occur (Habeeb, 2025:6; Lee *et al.*, 2019:507).

Feed formulation accuracy also plays a pivotal role in operational performance (Betangcor *et al.*, 2024:41). Accuracy in formulation ensures appropriate nutrient composition, minimises ingredient wastage, improved product quality and consistent outputs (Betangcor *et al.*, 2024:41), all factors that directly influence feed performance and machinery efficiency. Inaccurately formulated feed can cause inconsistent texture, blockages, or rejected batches, disrupting production, increase waste and raising costs (Chikwado, 2015:1165; Muramatsu *et al.*, 2015:717).

The adoption of technology holds the potential to enhance both maintenance and formulation practices (Mallioris *et al.*, 2024:81; You *et al.*, 2024:643). Technology such as digital monitoring systems, Computerised Maintenance Management Systems (CMMS), and automation allows manufacturers to track performance metrics, schedule maintenance, and achieve precise formulation in real time (Habeeb, 2025:7; Onkey, 2025). Although African feed mills are slow to adopt such technologies, great potential lies in the use of these tools to enhance reliability, reduce waste, and improve operational efficiency (Arthur *et al.*, 2024:1).

1.3 PROBLEM STATEMENT

The demand for poultry meat in Africa continues to increase as populations continue to grow and dietary preferences place emphasis on affordable protein sources (Faye *et al.*, 2025:6; Kleyn & Ciacciariello, 2021:268). However, production inefficiencies and limited resources in the poultry feed manufacturing sector are creating a supply deficient which cannot meet the growing demand (Abdullahi *et al.*, 2022:60; Magrini, 2024:2; Moreki *et al.*, 2025:8). Feed accounts for the largest

share of total poultry production costs, and high feed prices remain a key constraint on profitability and supply (Afodu *et al.*, 2024:183; Chiekezie *et al.*, 2022:14; Folorunso *et al.*, 2024:33).

Magrini (2024:2) further explains that the reliance on traditional reactive maintenance strategies exacerbates the operational challenges faced by feed mills. These reactive maintenance strategies often result in costly equipment downtime, unplanned repairs, and inefficient utilisation of resources (Magrini, 2024:2). Along with maintenance strategies, another key player in operational efficiency is feed formulation (Muramatsu *et al.*, 2015:721). Feed formulation involves the development of precise recipes to produce feed that is nutritionally balanced for poultry (Bhamare, 2023:75). Accurate formulation ensures that optimal quantities of raw materials are utilised, thereby minimising waste and preventing the excessive use of costly ingredients (Bhamare, 2023:75). If formulation practices are not accurate, feed mills risk compounding existing inefficiencies through material wastage, elevated costs, and reduced product quality (Akintan *et al.*, 2025:1).

Another compounding factor is the slow technology adoption rate across Africa (Balehegn *et al.*, 2020:6). Despite technology offering benefits of improved efficiency, reduced material waste, and improved product quality, many African countries have not yet integrated technology into their operations (Adeyeye *et al.*, 2025:237; Klenam *et al.*, 2025:1). As a result, the African feed manufacturing industry continues to face persistent operational challenges that limit its contribution to food security and broader economic development (Abdullahi *et al.*, 2022:65; Afodu *et al.*, 2024:26183).

To narrow the gap between supply and demand and contain rising production costs, enhancing operational efficiency within feed manufacturing has become essential (Folorunso *et al.*, 2024:33; Magrini, 2024:2). However, despite the strategic importance of this sector, limited empirical research has examined how maintenance strategies, feed formulation accuracy, and technology adoption collectively influence operational efficiency in the African contexts. Most existing studies focus on general poultry production or on isolated operational aspects, neglecting the integrated dynamics within feed manufacturing operations.

1.4 RESEARCH AIM

The aim of this study is to assess the influence of maintenance strategies, feed formulation accuracy, and technology adoption on operational efficiency in African poultry feed manufacturing.

The study sought to generate empirical evidence that could aid the design of integrated operational systems with the purpose of enhancing productivity, reliability, and competitiveness within Africa's poultry feed manufacturing sector.

1.5 RESEARCH QUESTIONS

The following research questions guided the study which were formulated in line with the research aim and conceptual framework:

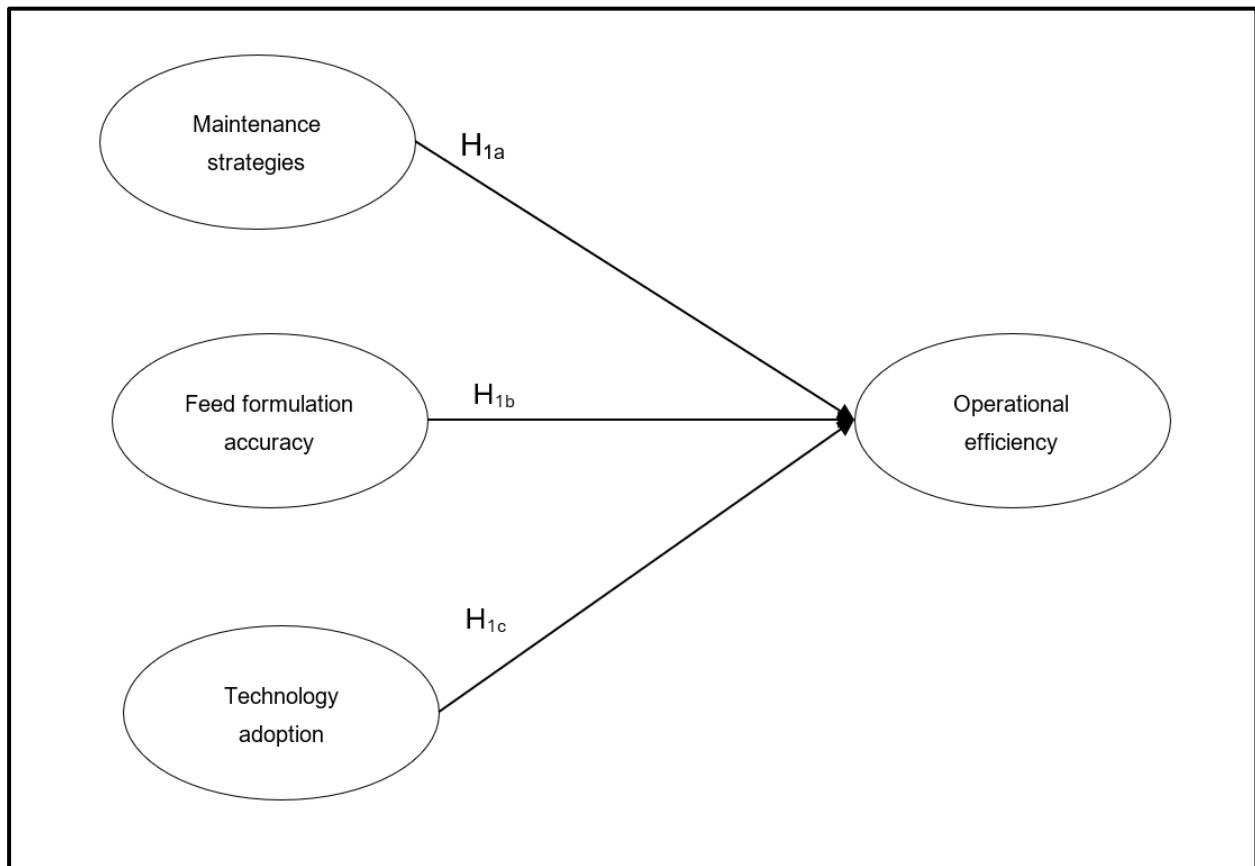
1. How do maintenance strategies influence operational efficiency in African poultry feed manufacturing firms?
2. How do feed formulation practices influence operational efficiency in African poultry feed manufacturing firms?
3. How do technology adoption influence operational efficiency in African poultry feed manufacturing firms?

These research questions supported the empirical testing of the conceptual framework.

1.6 HYPOTHESES

Based on the theoretical framework and the research questions, the following hypotheses were tested (the conceptual framework is illustrated in Figure 1-2):

- (i) **H₀ (Null hypothesis):** There is no significant relationship between maintenance strategies, feed formulation accuracy, technological adoption, and operational efficiency in African poultry feed manufacturing.
- (ii) **H₁ (Alternative hypothesis):** Maintenance strategies, feed formulation accuracy, and technological adoption significantly influence operational efficiency in African poultry feed manufacturing.
 - H_{1a}: Maintenance strategies have a positive and significant effect on operational efficiency in African poultry feed manufacturing.
 - H_{1b}: Feed formulation accuracy has a positive and significant effect on operational efficiency in African poultry feed manufacturing.
 - H_{1c}: Technology adoption has a positive and significant effect on operational efficiency in African poultry feed manufacturing.

Figure 1-2: Conceptual framework of the study

1.7 RESEARCH OBJECTIVES

The primary and secondary objectives of the study support the research aim and will test the hypotheses. The objectives also formed the foundation of the study's design, data collection and analytical framework described in Chapter 3.

1.7.1 Primary objective

The primary objective of this study is to:

1. Determine the influence of maintenance strategies, feed formulation accuracy, and technology adoption on operational efficiency in African poultry feed manufacturing. This objective directs the study towards empirically examining how these three operational constructs, individually and collectively, contribute to improving production performance, reducing operational waste, and enhancing cost efficiency within feed mills. By investigating these relationships, the study aims to provide evidence-based insights into how internal operational capabilities, as framed by the Resource-Based View, can be leveraged to strengthen efficiency and competitiveness within the African poultry feed manufacturing sector.

1.7.2 Secondary objectives

Table 1-1: Secondary objectives

Secondary objectives:	Description
Theoretical secondary objectives:	
Objective 1	Conduct a literature review on the African poultry feed manufacturing industry.
Objective 2	Conduct a literature review on the Resource-Based-View
Objective 3	Conduct a literature overview about the key constructs of this study, namely operational efficiency, maintenance strategies, feed formulation accuracy and technology adoption.
Empirical secondary objectives:	
Objective 4	To compile a sample profile of the respondents who participated in the study.
Objective 5	Determine the maintenance strategies of feed mills in Africa.
Objective 6	Determine the feed formulation accuracy of feed mills in Africa.
Objective 7	Determine the technology adoption of feed mills in Africa.
Objective 8	Determine the operational efficiency of feed mills in Africa.
Objective 9	Examine the interrelationships among maintenance strategies, feed formulation accuracy, technology adoption and operational efficiency.
Objective 10	Explore regional and organisational contextual factors, such as firm size, managerial experience, geographic location, that may moderate the relationship between operational efficiency and maintenance strategies, feed formulation accuracy and technology adoption, respectively.

1.8 SIGNIFICANCE OF THE STUDY

The findings of this study hold significance in both academic and industry settings. Academically, this study contributes to the expanding knowledge base available in operations and technology management. This will be achieved by assessing maintenance strategies and feed formulation accuracy within the context of African poultry feed manufacturing, as well as by demonstrating how technology adoption interacts with maintenance and formulation practices to influence operational efficiency.

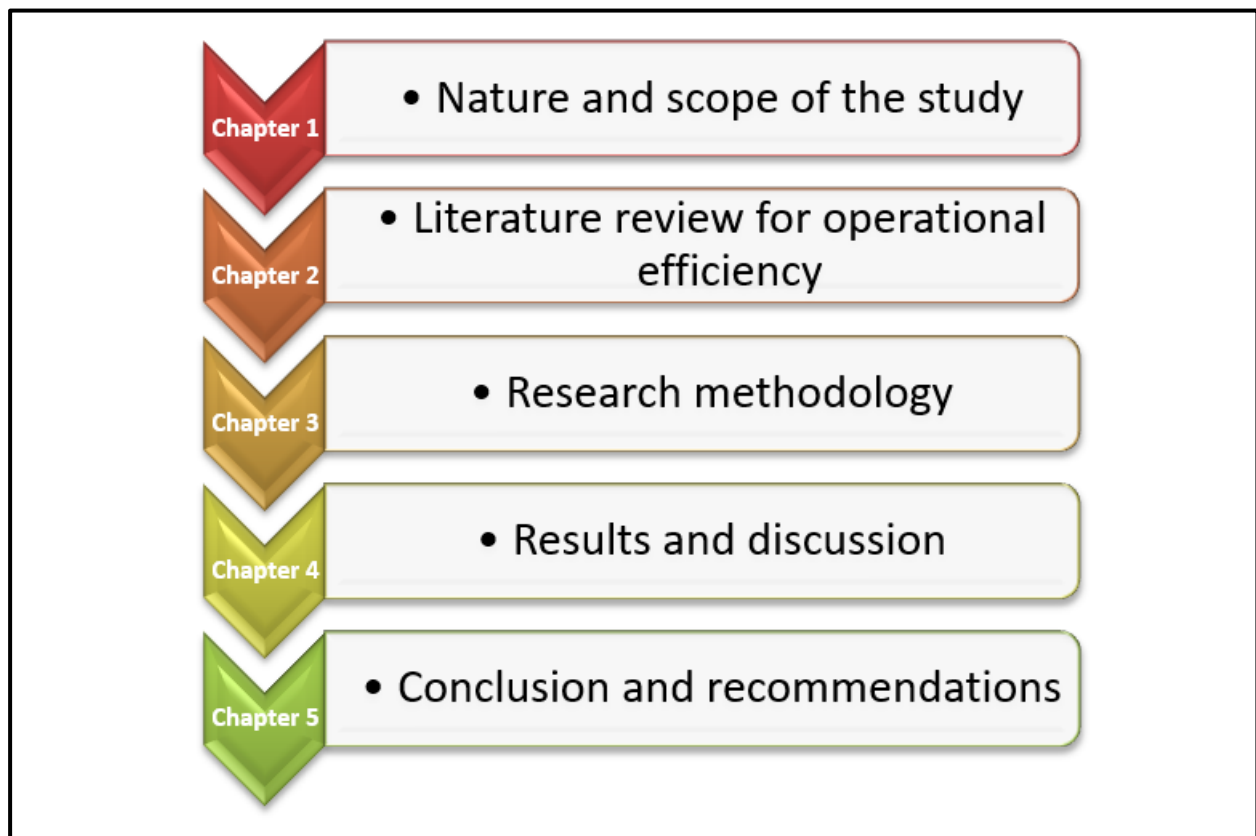
From an industry perspective, the study provides practical insights for feed mill managers, engineers, and policy stakeholders who aim to improve performance by challenging current maintenance strategies and formulation techniques. The study will identify factors that influence throughput, downtime, and cost per ton of feed, providing the sector with the information that will support data-driven decision-making.

On a higher level, this study will contribute to regional policy objectives aimed at strengthening agricultural value chains, promoting industrial efficiency, and contributing to Africa's long-term food security and sustainable development goals.

1.9 CHAPTER OUTLINE

This mini-dissertation will be structured into five chapters, logically progressing from the identification of the research problem to the formulation of evidence-based recommendations. Each chapter builds on from one another to form a coherent argument grounded in empirical findings. Figure 1-3 provides a depiction of the chapter outline.

Figure 1-3: Chapter outline



- **Chapter 1: Introduction** – The background, problem statement, research aim, objectives, and significance of the study are presented. This chapter establishes the study contextual and defines the key constructs that underpin the investigation.
- **Chapter 2: Literature review** – Existing literature surrounding feed mills in Africa, operational efficiency, maintenance strategies, feed formulation accuracy, and technology adoption is reviewed and examined. The chapter identifies gaps in the currently available literature and knowledge base and develops the study's conceptual framework and hypotheses.
- **Chapter 3: Research methodology** – The study's philosophical orientation, research design, population, sampling strategy, data collection and analysis, and ethical considerations are described.
- **Chapter 4: Results and discussion** – The results obtained through descriptive and inferential statistical analysis are presented and interpreted. The findings are discussed with respect to the conceptual framework and existing literature.
- **Chapter 5: Conclusions and recommendations** – This chapter summarises the key findings, highlights theoretical and practical implications of the study outcomes, acknowledges limitations, and proposes recommendations for future research and industry practice.

1.10 CONCLUSION

This chapter provided an overview of the study and context, background, problem statement, and rationale. The chapter identified maintenance strategies, feed formulation accuracy, and technology adoption as critical determinants of operational efficiency within the African poultry feed manufacturing industry. The study was aligned with the Resource-Based-View which positions it to address an important gap in both theory and practice by examining how maintenance strategies, feed formulation accuracy, and technology adoption influence operational efficiencies within feed mills in Africa. The study's research aim, objectives, questions, and hypotheses were defined in this chapter. The next chapter builds on this foundation by reviewing relevant literature and developing the conceptual framework that underpins the empirical analysis.

CHAPTER 2 LITERATURE OVERVIEW OF KEY THEORIES AND CONSTRUCTS

2.1 INTRODUCTION

Since 1943, the United Nations has aspired to achieve a world with “a secure, adequate, and suitable supply of food”, where this vision is regarded as “a cardinal aim in every country” (Clapp *et al.*, 2022:2). Yet, more than eight decades later, this goal remains unrealised. Global food systems reveal drastic imbalances in production and distribution, with poverty and hunger persisting at alarming levels (World Food Programme, 2023). In Sub-Saharan Africa, the average food supply stands at 2 229 calories per person per day, while actual availability reaches only 1 570 calories per person per day (World Food Programme, 2023). This deficit contributes to an acute hunger crisis affecting 319 million people across 67 countries (World Food Programme, 2023). The situation continues to worsen, with food insecurity rising steadily since 2015 (Wudil *et al.*, 2022:2).

A contributor to this crisis is the insufficient poultry production capacity in Africa, which fails to meet growing consumer demand (Abdullahi *et al.*, 2022:60). The gap between supply and demand forced some countries to rely on costly poultry imports, placing further strain on already vulnerable economies (Bremner & van der Weijden, 2023:4).

The chapter begins with an overview of the feed manufacturing market, the poultry value chain, and the Resource-Based-View, which unpacks how a company can achieve a sustainable competitive advantage through internal resources and capabilities. The chapter continues with constructs that form the conceptual framework, namely operational efficiency, maintenance strategies, feed formulation accuracy, and technology adoption. The chapter will present a comprehensive and insightful conceptual framework and hypotheses that will encapsulate the constructs and relationships that the study aims to examine.

2.2 MARKET OVERVIEW

The feed manufacturing industry plays a foundational role in agricultural and livestock production (Alnafissa *et al.*, 2024:1). Total global feed output reached 1.380 billion metric tons in 2023, increasing by 1.2% to 1.396 billion metric tons in 2024 (Alltech, 2024:296; Feed Additive, 2025). Of this 1.396-billion-ton total, poultry feed contributes 42.7% to 45%, highlighting its critical role in the sector (Alltech, 2024, 2025). Africa only makes up 4% of the global feed production (Alltech, 2024). Despite this small contribution, the African poultry feed market is projected to reach 22.6

billion USD by 2025. Growth in this market is largely driven by rising demand for poultry products (Mordor Intelligence, 2025).

On a global scale, the feed manufacturing industry is expected to grow at a Compound Annual Growth Rate (CAGR) of 4.19% between 2023 and 2025 (Mordor Intelligence, 2025). Africa and the Middle East were reported as countries with the highest percentage growth increase of 5.4% in 2024, according to the Alltech 2025 Agri-Food Outlook report. Considering that global economic growth generally ranges between 2% and 3% (World Bank Group, 2025), a global CAGR of 4.19% and a 5.4% growth rate shown by the African market represents a strong and stable performance, particularly for a mature sector like feed manufacturing. This growth indicates sustained demand for poultry products in years to come. The driving forces behind this growth can be attributed to the following factors:

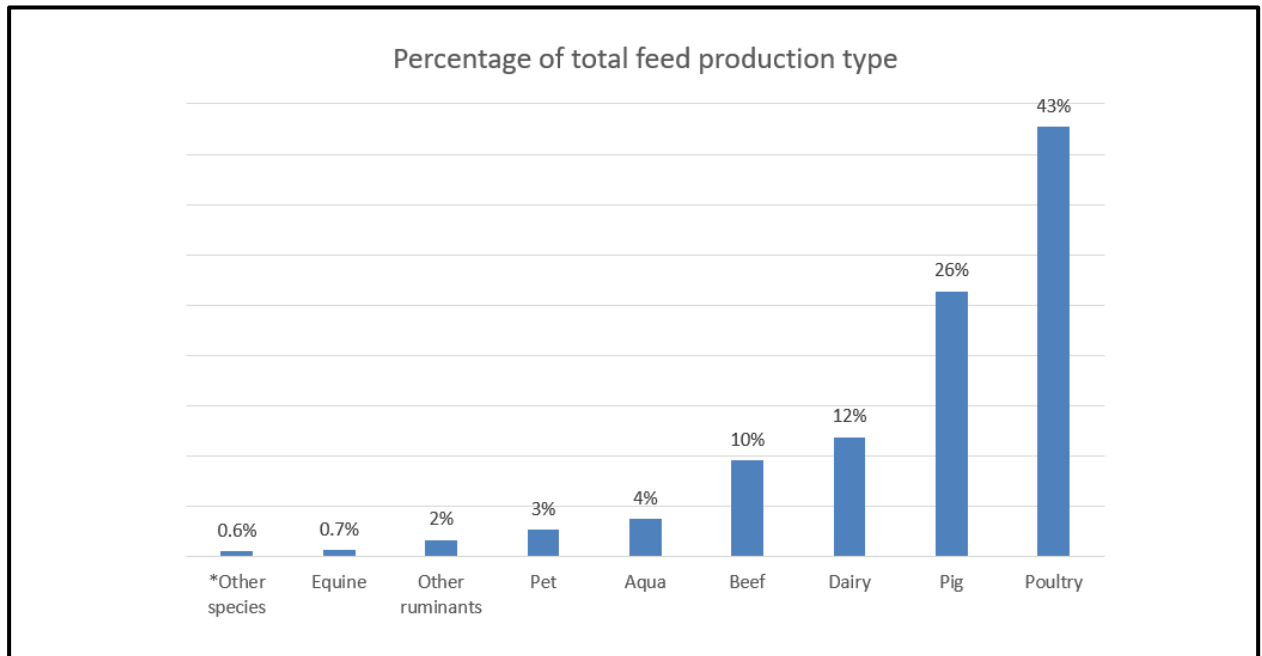
- Population growth and urbanisation (Ncube *et al.*, 2016:1), which is creating a greater demand for affordable protein sources (Food Business, 2024; Morgan & Farris, 2024).
- Rising disposable income enables more consumers to purchase poultry products (Food Business, 2024; Morgan & Farris, 2024).
- The perceived affordability and health benefits of poultry in comparison to red meat (Food Business, 2024; Tabler *et al.*, 2021:2).
- Poultry is widely accepted in many cultural and religious settings, creating an appeal across diverse populations (Tabler *et al.*, 2021:2).

Africa's increasing demand for chicken meat and eggs has spurred growth in poultry production, which, in turn, has led to the expansion of the poultry feed market (Mordor Intelligence, 2025; Nanda Kumar *et al.*, 2022:229). Additionally, poultry meat is a more affordable protein source, is perceived as healthier and is free from major cultural or religious restrictions (Tabler *et al.*, 2021:2). However, with local production being insufficient in meeting the growing demand, the shortfall is supplanted with substantial chicken imports (Morgan & Farris, 2024). Africa's poultry imports grew by over 850% over the past two decades, from 0.2 million metric tons in 1999 to more than 1.5 million metric tons in 2022 (Morgan & Farris, 2024). The dependency on imports highlights the untapped potential for expanding Africa's poultry and feed production capacities (Mordor Intelligence, 2025). Ncube *et al.* (2016:1) confirmed that poultry farming in Africa is emerging as a significant business opportunity.

These trends highlight the strong growth potential of the feed manufacturing industry, particularly in Africa. The need to reduce reliance on chicken imports, coupled with global drivers of demand,

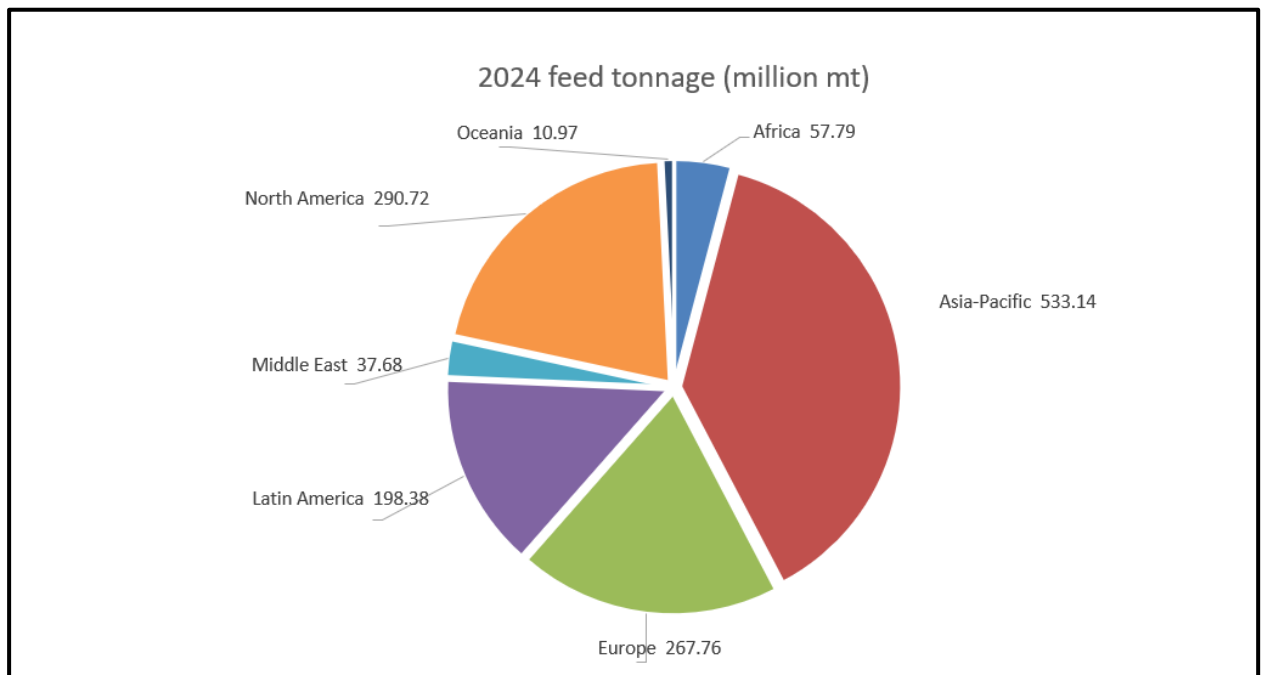
places the African feed manufacturing industry in a position of holding massive opportunity for investment and development (Ncube *et al.*, 2016:23). Alltech (2025) Agri-Food Outlook provides statistics on global feed manufacturing trends, as illustrated in Figure 2-1 and Figure 2-2.

Figure 2-1: Percentage feed production per type



Source: Altech (2025).

Figure 2-2: Total tonnage per region



Source: Altech (2025).

Figure 2-1 and Figure 2-2 provide valuable insight into global feed production dynamics. Figure 2-1 depicts the dominance of poultry feed within the feed industry, accounting for 43% of global feed production. This reinforces the importance of poultry as a key driver of growth within the sector, particularly in emerging markets where affordability, cultural acceptance, and nutritional value make it a preferred protein source. Figure 2-2 highlights Africa's relatively small share in the market at only 4% of total global feed output, demonstrating considerable room for growth and regional capacity development. This highlights a strategic opportunity for African countries to expand local feed manufacturing in response to rising demand for animal protein. Together, these statistics support the case for targeted investment in poultry feed production and improved efficiency strategies with the goal to develop Africa's food security and economy.

Investments of this nature need to be coupled with an understanding of the global picture of the industry to target investment, as well as sound maintenance practices to ensure investment safety.

2.3 POULTRY VALUE CHAIN

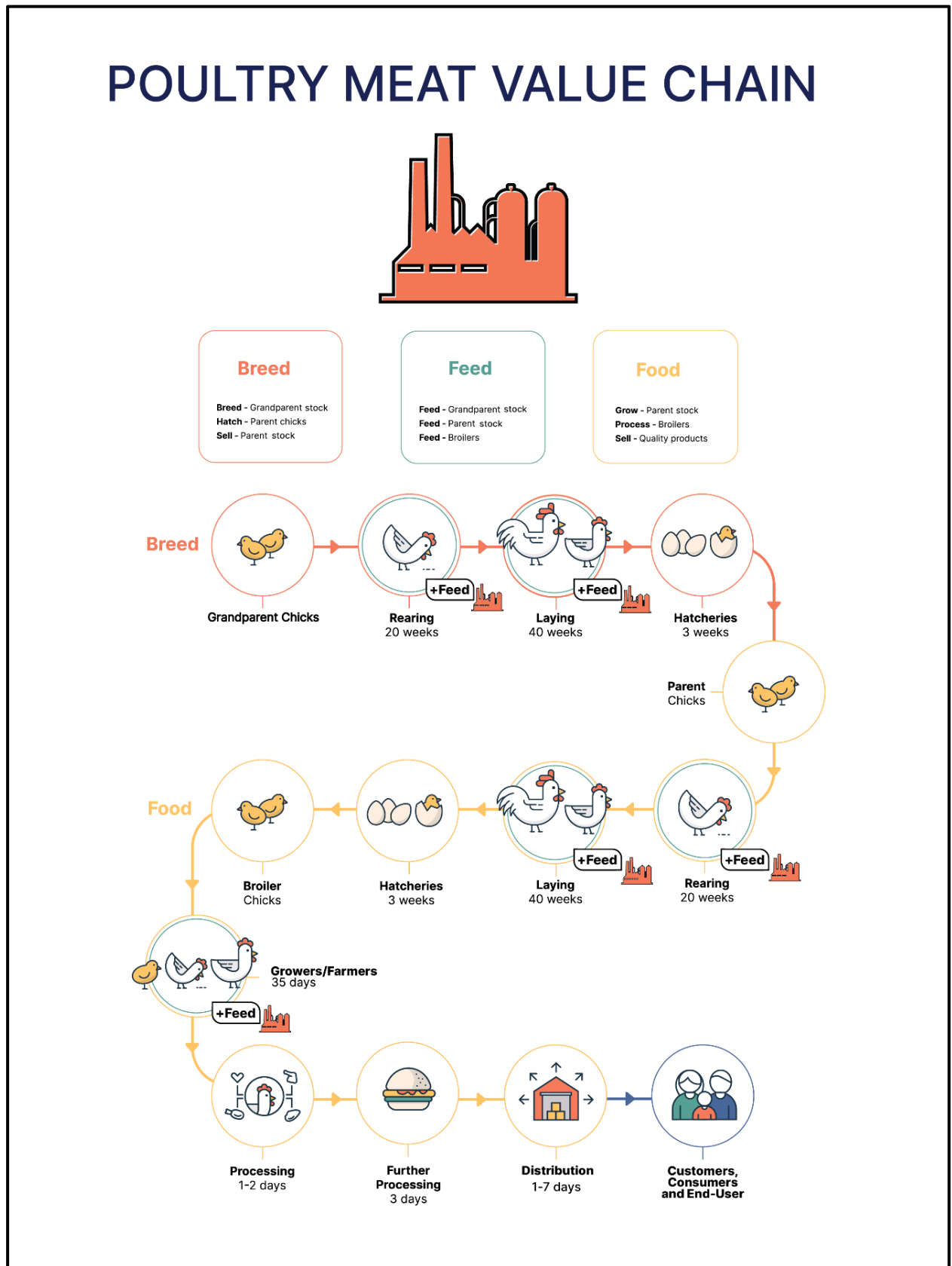
Glin *et al.* (2016:82) defines the agricultural value chain as “the set of steps and processes that a commodity goes through from its production to consumption”. For the poultry meat industry, the value chain is depicted in Figure 2-3. It is important to differentiate between commercial animal production versus mere low level subsistence farming. The focus of this review is not on subsistence farming, but on large scale operations where poultry can be mass produced by means of scientifically sound procedures to enhance sustainable food production. This is done to ensure that an economical case can be made for poultry production as well as aid in the eradication of world hunger.

The poultry value chain begins with grandparent stock, which consists of specialised breeding chicks, typically imported at a high cost due to their genetic value (Adeyonu *et al.*, 2021:300; Thirumalaisamy *et al.*, 2016:80). These birds are reared for approximately 20 to 24 weeks before they commence egg-laying to produce the parent stock for broilers (Adeyonu *et al.*, 2021:300; Nielsen *et al.*, 2023:25). Grandparent stock (also known as breeder layers) have an average lifespan of around 64 weeks (Nielsen *et al.*, 2023:25; Sarica *et al.*:153), meaning that they require sustained access to high-quality, nutrient-rich feed to ensure optimal health and productivity throughout their breeding cycle (Schippers USA, 2025). These birds hold a heightened sensitivity to nutrient imbalances and contaminants. Therefore, the type of feed produced for breeder layers must be manufactured with utmost care to avoid any effect on egg production, bird health, and life expectancy (Poultry World, 2024).

Parent stock follows a similar life cycle and expectancy as grandparent stock, further prolonging the feeding period required for these birds (Nielsen *et al.*, 2023:25).

Once parent stock has matured, they lay fertilised eggs that hatch into broiler chicks, which are then raised for meat production (Nielsen *et al.*, 2023:25). Broilers grow for an average of 30 days, depending on the desired market weight and size (Four-paws, 2023; Nielsen *et al.*, 2023:24). Feed quality is a critical factor during this short and intense growth period. Feed quality not only influences growth rate and feed conversion efficiency, it also impacts chick health and overall mortality rates (Behnke & Beyer, 2002:1; Brickett *et al.*, 2007:2172; Dhanasekaran *et al.*, 2009:385). This emphasizes the critical role feed plays in ensuring both the efficiency of poultry meat production and the consistent availability of chicken as a protein source.

Figure 2-3: Poultry value chain



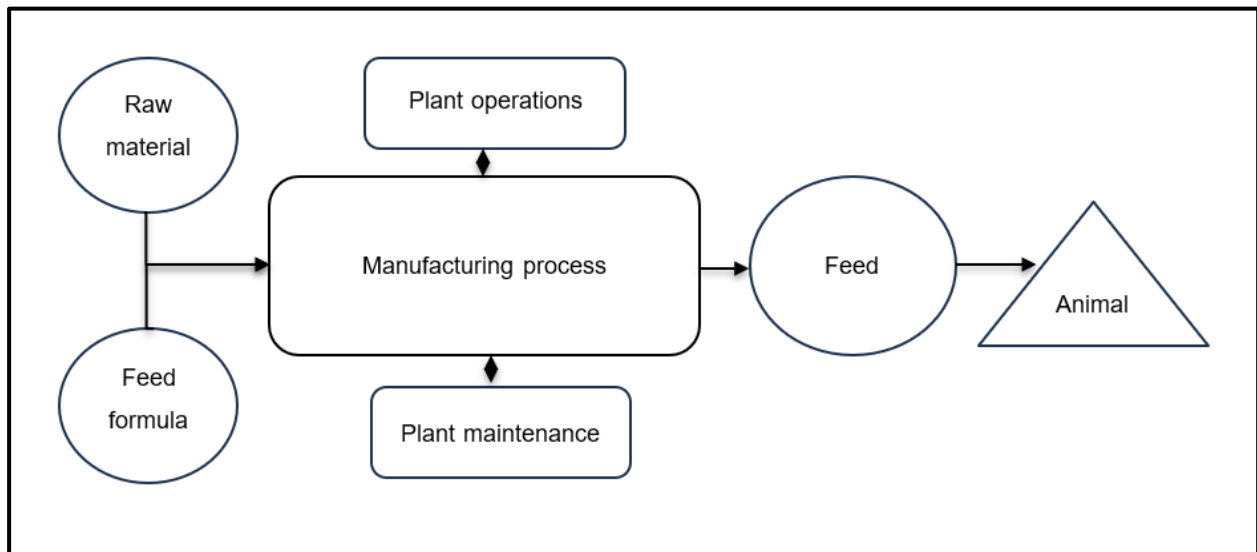
Source: CBH Africa (2023).

2.3.1 Factors contributing to quality in the value chain

It is well established that high-quality feed is a key component in the efficiency and success of the poultry value chain (Uduma *et al.*, 2021:601), and feed quality is ultimately determined by the performance of the animal consuming it (Coleman & Moore, 2003:17).

Mortality at any point in the poultry value chain, whether among grandparent stock, parent stock, or broilers, has severe consequences for overall production timelines and market supply (Behnke & Beyer, 2002:1; Brickett *et al.*, 2007:2172; Dhanasekaran *et al.*, 2009:385). This is shown in a case study from Cameroon where the bird mortality rate was most strongly attributed using poor quality feed compared to high quality feed (Tambi & Nadege, 2024:126). These losses can be credited to poor nutritional quality, contamination, or inaccurate dosing of raw materials and medicine. The impact is particularly detrimental. In the case of grandparent or parent stock, a reduction in the number of birds delays egg production, ultimately compromising the consistent supply of broiler chicks and causing a bullwhip effect that disrupts downstream meat production. In broilers, high mortality rates or poor performance due to substandard feed can delay slaughter schedules, reduce meat yield, and increase production costs. These interruptions not only affect the efficiency of poultry operations but also threaten the stability of meat availability in the market. This highlights the critical importance of consistent, high-quality feed throughout the entire poultry value chain. In the case of Cameroon, this does not only affect the investor, but also 70% of the population that is directly economically dependent on agriculture and 100% of the population that relies on agriculture for sustenance (Tambi & Nadege, 2024:117).

Several factors influence the production of poultry feed, in order to sustainably produce high quality poultry. These elements are illustrated in Figure 2-4 below and will be discussed in the ensuing sections. It is important to note that no one element is more important than the others as the different elements need to work in cohesion to create quality animal feed throughout the growth cycle of the chicken, from day old chick to broilers that are ready for market and consumption.

Figure 2-4: Holistic feed manufacturing process

Source: Researcher's own compilation.

Figure 2-4 indicates that raw material is allocated by means of feed formulation. The exact formula is processed through a manufacturing plant. This plant consists of machines that need to be operated and maintained within manufacturer specifications. The end product is specifically formulated and manufactured animal feed that is then distributed to poultry producers to rear chickens for market.

2.4 RESOURCE-BASED-VIEW

The Resource-Based View (RBV) posits that a firm's ability to achieve and sustain competitive advantage hinges on its unique and inimitable resources and capabilities (Kero & Bogale, 2023:3137). This perspective highlights how a distinct combination of assets that may not be a standard among competitors, can drive superior performance when managed effectively (Alonso-Martínez *et al.*, 2024:4). In the context of operations, the RBV framework helps explain how a unique set of operational capabilities can enhance competitive operational performance (Peng *et al.*, 2008:730). The RBV proposes that the differences in performance standards among competitors operating in the same domain can be explained by the diverse resources and capabilities unique to each firm (Rishi *et al.*, 2022:139). These valuable, rare, inimitable, and non-substitutable resources provide firms with a lasting competitive edge by enabling them to recognise and leverage opportunities while mitigating threats (Kero & Bogale, 2023:3137). These resources comprise of both tangible assets and intangible elements such as organisational processes, knowledge, and relationships, all of which contribute to a firm's sustained effectiveness, competitiveness, and profitability (Kero & Bogale, 2023:3137). Recent research into the application of RBV in operations management research shows evidence of operational

functions and capabilities being linked to overall business performance (Chahal *et al.*, 2020:13). In the feed manufacturing industry, the development of operational capabilities such as advanced maintenance strategies, sophisticated technology adoption, and the optimisation of feed formulation and process practices, prove to be critical resources that result in significant efficiency advantages (Liu & Liang, 2015:1019).

2.5 OPERATIONAL EFFICIENCY

Operational efficiency is the ratio between the outputs generated by business activities and the inputs required to carry out those operations (Dilshani *et al.*, 2019:46). In the context of feed manufacturing operations, outputs refer to the volume of feed produced, while the inputs are all the resources required to generate the feed. These inputs can comprise both financial and non-financial elements. It includes operating hours, equipment, raw materials, labour, property (whether owned or rented), technology, and the associated operational costs (Sunday *et al.*, 2021:1). Inputs can further be classified into two categories: fixed and variable. Fixed inputs remain constant regardless of production volume, for example, the 24 operational hours per day (non-financial), equipment, labour salaries (fixed salaries), and property rental or depreciation costs. On the other hand, variable inputs fluctuate in relation to production volumes. Raw materials comprise the most significant proportion of variable cost. Other variable costs may include overtime wages (often incurred during breakdowns or production delays), utility usage, and maintenance expenses.

This distinction becomes particularly important when considering economies of scale. Economies of scale refers to “reductions in average unit costs as output increases” (Healey, 2015:2). In a production environment, this occurs when fixed costs are distributed across a larger volume of output, thereby lowering the cost per unit produced. Operational efficiency can, therefore, be enhanced by maximising output while maintaining the input structure. These practices enable organisations to achieve cost advantages and strengthen their competitive position.

Equipment availability plays a critical role in this context given that it can only operate for a finite number of hours per day. Ensuring that maximum uptime of this equipment is achieved directly supports higher production volumes. Breakdowns or failures in critical machinery can bring production to a halt which will result in reduced output and operational efficiency (McCoy, 2024). For this reason, equipment and its maintenance are critical inputs in feed production, directly influencing output performance and overall efficiency.

Katta and Devaraju (2021:296) defines production downtime as “any time during which the manufacturing equipment is not running and directly affects output, cost and overall efficiency”. The reduction of downtime, particularly the minimisation of unplanned production stops, is a

critical factor in attaining consistently high levels of operational efficiency (Magrini, 2024:8). Extended uptime in a manufacturing environment allows for greater throughput, which in turn drives down fixed input costs, also known as economies of scale (Habeeb, 2025:2; Heizer *et al.*, 2020). When a higher feed tonnage is produced over the same operational period, fixed costs are distributed across a larger output volume, thereby reducing the cost per unit of production and attaining a higher profitability.

In feed manufacturing, downtime can be a result of both planned and unplanned activities. Planned activities include scheduled maintenance, cleanouts, and line flushes, whereas unplanned disruptions include equipment breakdowns, chokes, utility failures, and delayed raw material delivery (Habeeb, 2025:5). Planned downtime typically results in significantly lower total disruption and costs than unplanned downtime (Habeeb, 2025:2; Sheng, 2018:13). Scheduled interventions can be anticipated, controlled, and aligned with production cycles, whereas unexpected stoppages often subject organisations to extended delays which have a cascading effect on the production line and cause further operational instability (Stefano, 2020:139). This demonstrates that structured planning of downtime is a critical tool in improving overall operational efficiency (Stefano, 2020:165).

Another key dimension of operational efficiency is systematic waste reduction, which directly improves productivity, cost performance, and resource utilisation (Taher & Bashar, 2024:339). Lean manufacturing principles highlight that operational waste extends beyond material losses, encompassing unnecessary motions, idle time, overproduction, excess inventory, and rework (Taher & Bashar, 2024:340). Strategic identification and elimination of these non-value-adding activities can assist organisations in streamlining process flows, increasing throughput, and optimising resource utilisation. Not only does waste reduction improves process reliability, and it also enhances cost competitiveness by lowering input intensity per unit of output (Taher & Bashar, 2024:344). Time-based waste can be reduced by minimising unplanned disruptions and aligning planned interventions with production cycles, ultimately strengthening overall operational stability. The deliberate elimination of inefficiencies supports operational efficiency by promoting higher asset utilisation, leaner operations, and more predictable performance outcomes.

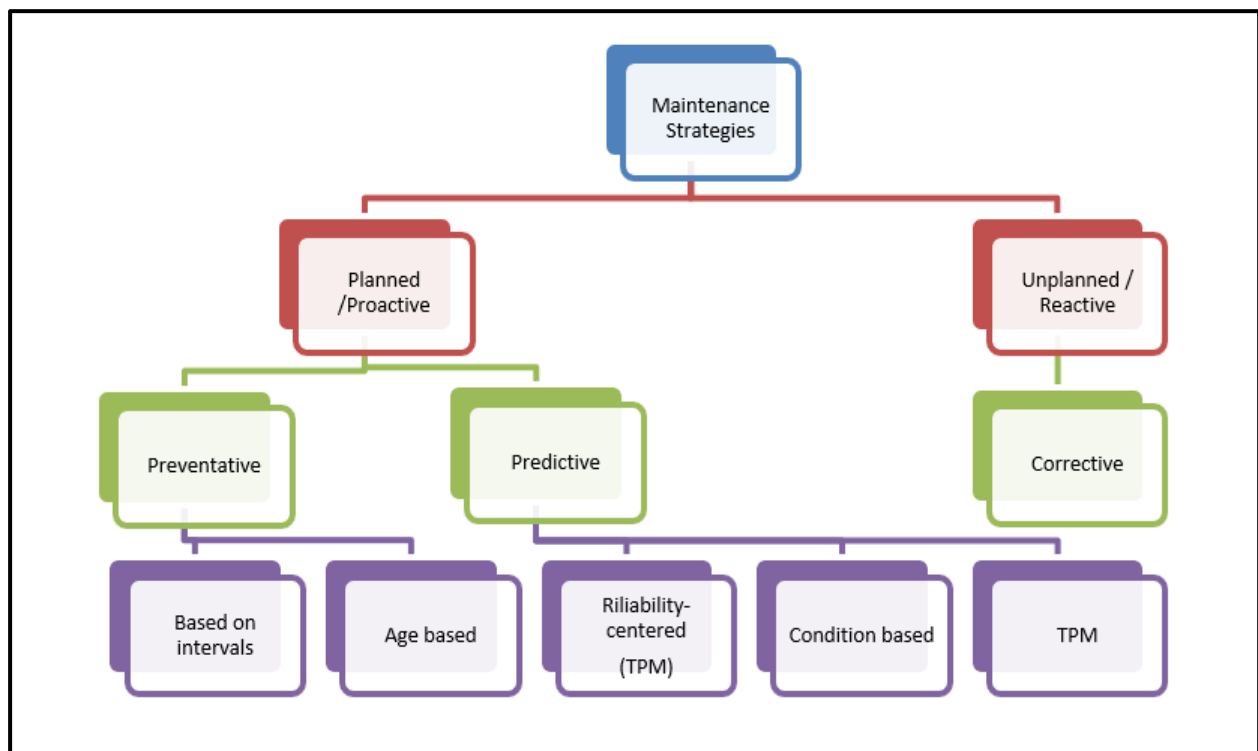
It can, therefore, be concluded that enhancing operational efficiency requires a deliberate focus on increasing output volumes while reducing equipment downtime and operational waste. Organisations can achieve this by prioritising strategies that ensure stable, uninterrupted production and optimal resource utilisation. This study will focus on maintenance strategies, examining their critical role in maximising uptime and minimising unplanned stoppages. Feed formulation practices will be explored in parallel as a means for reducing waste, promoting efficient use of raw materials, and supporting low-cost production. Finally, the adoption of enabling

technologies will be examined as a critical driver of improved process control, resource efficiency, and operational performance. Digital tools and automation provide real-time insight into production processes, enabling organisations in the implementation of faster decision-making, predictive interventions, and better alignment between input utilisation and output targets. By integrating technology, sound maintenance strategies and efficient feed formulation practices, organisations can create production systems that are adaptive and resilient. These three constructs form the strategic foundation for operational efficiency in poultry feed mills.

2.6 MAINTENANCE STRATEGIES

Shafiee and Sørensen (2019:9) delineate that maintenance strategy encompasses “a set of policies and actions that are used to ‘retain’ or ‘restore’ equipment as well as the decision support system in which maintenance activities are planned”. According to the ISO 13306:2017, maintenance is defined as “all the operations required to retain or restore an equipment's ability to perform its task” (Ferreira *et al.*, 2019:1428). Figure 2-5 provides a hierarchical illustration of the different maintenance strategies.

Figure 2-5: Hierarchical illustration of maintenance strategies



Source: Hamasha *et al.* (2023) and Ojobo *et al.* (2024).

The fundamental choice in maintenance strategy lies between planned and unplanned maintenance (Gackowiec, 2019:132; Hamasha *et al.*, 2023:3). Neither approach is inherently right or wrong; the suitability depends on several contextual factors. Planned maintenance follows a

proactive approach, where unexpected failures are avoided by scheduling and executing work in advance (Hamasha *et al.*, 2023:3). Unplanned maintenance—often referred to as run-to-failure—relies on a reactive approach, where equipment operates until it breaks down, after which corrective action is taken (Hamasha *et al.*, 2023:3). Maintenance activities can be classified as either proactive or reactive (Ahuja & Gupta, 2024:287).

- a **Proactive maintenance** is defined by Ferreira *et al.* (2019:1428) as “maintenance that is undertaken before any breakdown or stoppage occurs”. A proactive approach to maintenance improves operational reliability and extends the lifespan of critical machinery by detecting and addressing potential issues before escalation to failures (Ahuja & Gupta, 2024:287; Magrini, 2024:8). This approach decreases long-term maintenance costs and reduces the frequency of unplanned disruptions, which improves both productivity and equipment efficiency (Habeeb, 2025; Magrini, 2024:6). Magrini (2024:2) emphasises that a proactive maintenance strategy, implemented using planned maintenance, significantly reduces equipment downtime, as opposed to a reactive strategy in which action is taken upon equipment breakdown. Proactive maintenance encompasses strategies such as preventative maintenance, predictive maintenance (condition monitoring), and TPM (Habeeb, 2025:2).
- (i) Preventive maintenance involves routine inspections, equipment servicing, and the timely replacement of components to avoid unexpected breakdowns (Habeeb, 2025:6). The most basic form of planned maintenance involves scheduling tasks at fixed time or usage intervals. This approach reduces the incidence of unexpected failures, but may lead to over- or under-maintenance if not carefully managed (Limble CMMS, 2025). Planned preventative maintenance for unexpected breakdowns generally requires less time than emergency repairs (Ahuja & Gupta, 2024:287). These routine inspections allow maintenance teams to identify faults early and secure replacement parts in advance (Ahuja & Gupta, 2024:290). Research has shown that preventive maintenance can reduce equipment failure rates by 30 to 50 percent, however, its effectiveness is dependent on proper scheduling, adequate resource allocation, and continuous performance monitoring (Habeeb, 2025:6). Habeeb (2025:6) emphasises that proper scheduling is a key component in the effectiveness of preventive maintenance. To support this, Computerised Maintenance Management Systems, such as Onkey, can be adopted to provide maintenance teams with structure and oversight. These systems maintain a detailed asset register, schedule maintenance activities at specified intervals, assist in supplier management, track maintenance-related expenses, and facilitate data-driven decision-making (Onkey, 2025). Facilities that incorporate such systems into their workflow report improved asset availability and

performance, enhanced team productivity, and extended equipment lifespan (Ahuja & Gupta, 2024:287; Onkey, 2025).

- (ii) Predictive maintenance, also referred to as condition monitoring, utilises real-time data, sensors, and analytics to anticipate and address potential equipment failures before they occur (Ahuja & Gupta, 2024:287; Habeeb, 2025:6). This maintenance strategy harnesses monitoring technologies (e.g., vibration, temperature, ultrasound) to assess equipment condition. A deviation of performance indicators from normal operating parameters will trigger maintenance tasks (Limble CMMS, 2025). Common predictive maintenance techniques include the use of vibration sensors to detect imbalances or misalignments in rotating machinery, as well as thermal imaging to identify heat-related anomalies (Habeeb, 2025:6). These monitoring devices can be integrated with programmable logic controllers (PLCs) or alarm systems which will alert operators upon detection of deviations from normal operating conditions. In poultry feed manufacturing, these techniques can typically be applied to key production equipment such as pellet mills and hammer mills, which are essential to maintaining consistent output. Studies suggest that predictive maintenance in feed manufacturing environments can reduce unplanned downtime by 30 to 40 percent and lower overall maintenance costs by 20 to 30 percent, contributing significantly to operational efficiency (Ahuja & Gupta, 2024:290).
 - (iii) TPM emphasises employee involvement and shared responsibility in equipment care (Habeeb, 2025:6). The TPM approach is centred on continuous improvement, waste reduction, and empowering operators to take ownership of routine maintenance tasks (Habeeb, 2025:6), thereby contributing to enhanced OEE and greater production efficiency (Habeeb, 2025:7). In poultry feed manufacturing, a practical example includes training pellet mill operators to perform routine greasing of the equipment at fixed intervals or after producing a predetermined quantity of feed, ensuring consistent performance and preventing premature wear.
- b In contrast, **reactive maintenance** often results in prolonged delays, particularly when spare parts are unavailable at the time of failure. This scenario can lead to increased downtime, reduced throughput, and potential financial losses. Reactive maintenance, often referred to as a “run-to-failure” approach, involves addressing equipment issues only after a failure or breakdown has occurred (Ahuja & Gupta, 2024:287). While simple and low-cost upfront, this approach often results in unplanned downtime and higher long-term costs (Limble CMMS, 2025).

These strategies may differ across organisations, depending on the strategic objectives the company seeks to achieve (Shafiee & Sørensen, 2019:8). The decision to adopt a maintenance

strategy is far more complex than simply selecting and implementing. According to Hamasha *et al.* (2023:1), the following factors should be considered in this decision-making process: the scale of the business, machine failure cost implications, the impact of equipment breakdowns on the production schedule, potential effects on worker safety and the workplace environment, spare part availability, expected equipment lifespan, and the nature of the manufacturing process (Hamasha *et al.*, 2023:1).

Hamasha *et al.* (2023:1) further delineates that “maintenance extends far beyond simple repairs and upkeep. It serves as a key determinant of operational efficiency and longevity in any industrial process”. Maintenance strategies directly influence the uptime and longevity of machinery, minimising disruptions and maximising productivity in feed manufacturing (Hamasha *et al.*, 2023:1). This strategic approach to equipment upkeep directly enhances operational efficiency by ensuring consistent production throughput and reducing unforeseen costs associated with breakdowns (Hamasha *et al.*, 2023:1). Moreover, by optimising maintenance schedules and employing predictive analytics, feed manufacturers can proactively address potential equipment failures, further solidifying their competitive advantage through uninterrupted operational flow (Hamasha *et al.*, 2023:3). These advanced maintenance regimes minimise downtime and optimise resource utilisation, thereby directly contributing to cost reduction and improved output quality, both of which are critical for sustained profitability in a competitive market (Hamasha *et al.*, 2023:2). These proactive maintenance strategies, therefore, constitute a unique and valuable resource (Sousa *et al.*, 2024:91). Therefore, it is possible to present the following hypothesis:

H_{1a}: Maintenance strategies have a positive and significant effect on operational efficiency in African poultry feed manufacturing.

2.7 FEED FORMULATION ACCURACY

Feed formulation is the process of quantifying the amount of individual feed ingredients that supply all the nutrients needed by birds (Mallick *et al.*, 2020:10). It involves creating nutritionally balanced diets that support the optimal growth, health, and productivity of poultry birds (Baghli *et al.*, 2024:2). The increasing global demand for high-quality animal products, especially dairy, highlights the need for precision in livestock feed formulation to optimise the health of livestock (Akintan *et al.*, 2025:162). Producing feed in a commercial feed mill is a complex process based on animal nutrition and mechanical engineering principles (Shrinivasa & Mathur, 2020:553). Formulating diets that meet the nutritional requirements of poultry at any given time of their life cycle is a critical factor in achieving environmental, social, and economic sustainability (Bazer *et al.*, 2019:556). Formulating a diet for poultry needs to consider four aspects: 1. the nutrient

requirements of the birds, 2. the nutrient composition of available feed ingredients, 3. the cost of those feed ingredients, and 4. the availability of feed ingredients (Pathumnakul *et al.*, 2011:244).

Due to the complexity of breeding programs in the poultry value chain, the application of feed differs between grandparent- and parent stock (that is focussed on long term production) and broiler chickens (that need to be prepared for market in a shorter time span). It is, furthermore, universally agreed upon that the carcass quality has a direct correlation to poultry price (Yue *et al.*, 2024:1). Yue (2024:3) further distinguishes that several factors are regarded in the evaluation of carcass quality. Feed content (determined by raw materials and formulation) has a direct impact on the attributing factors of carcass quality, as an example, concentration and quality of protein contributes to functional nutritional units in the final product (Leinonen *et al.*, 2025:4).

The primary elements in poultry feed are maize, soya and additional additives (Alshelmani *et al.*, 2021:19). These need to be procured from high-quality sources (Haerunianti, 2021:65). The reality in Africa, however, is that maize is typically procured from local sources (Erem & Nakkazi, 2024:106) and often government structures intervene in this endeavour (Amewu *et al.*, 2021:1). Examples of this may include moratoriums on genetically modified organisms, preferential procurement and prescriptions on quantities. As such, the quality of the raw materials cannot solely be relied on to determine feed quality, and feed formulation becomes increasingly important in elevating feed quality (Tanjung *et al.*, 2025:456), as quantities used in feed formulation become dependent on the varying quality of the raw materials (Shrinivasa & Mathur, 2020:72).

Formulation accuracy enhances operational efficiency by reducing material wastage, reprocessing requirements, and energy consumption (Amin & Sobhi, 2023:1). Formulation inaccuracies increase variability in feed texture, moisture content, and nutrient balance, resulting in higher rates of batch rejection and product rework (McCafferty & Purswell, 2024:1). These issues reduce production yield and inflate both material and labour costs. When viewed through the OEE framework, poor formulation accuracy primarily affects the quality and performance dimensions and the resulting blockages or stoppages influence availability (Corrales *et al.*, 2020:1). Considering this, formulation accuracy acts as a determinant of all three OEE dimensions, reinforcing its strategic importance in achieving operational efficiency (Corrales *et al.*, 2020:1).

Feed formulation accuracy constitutes both a technical and managerial capability that underpins operational efficiency (Pesti & Choct, 2023:71). Amin and Sobhi (2023:2) demonstrated in a commercial Egyptian poultry feed mill setting that optimising parameters linked to formulation such as conditioning temperature, pressure and die configuration improved pellet quality, increased hourly throughput, and lowered specific energy consumption. All of these factors are

clear indicators of enhanced operational efficiency when formulation precision and equipment settings are correctly aligned. Similarly, in a large commercial mill handling 2 691 production batches, You *et al.* (2025:1) found that variables related to formulation and processing significantly predicted pellet durability which is a key quality metric affecting fines, rework, and throughput. The study reported that maintaining accurate formulation control maintains yield stability and line performance. Extending this to diet design itself, Svihus *et al.* (2025:1) reported that ingredient particle size, inclusion levels, and binder choices, which are all core formulation decisions, had a joint effect in determining pellet macro-structure, influencing feed intake, wastage, and operational efficiency within mills. Based on the above-mentioned studies, it can be assumed that the reported influence between feed formulation accuracy and operational efficiency can also be applicable in the poultry feed mill industry in Africa. Therefore, the following hypothesis is formulated:

H_{1b}: Feed formulation accuracy has a positive and significant effect on operational efficiency in African poultry feed manufacturing.

2.8 TECHNOLOGY ADOPTION

Granic (2023:2) defines technology adoption as “the acceptance, integration, and embracement of new technology”. In today’s rapidly evolving digital landscape, both individuals and organisations are increasingly compelled to adopt new technologies in order to remain relevant and competitive (Kumar, 2024:1). Technology holds the potential to enhance process efficiency and reduce operational costs (Urbano O *et al.*, 2021:1656). Organisations that fail to adapt risk losing their competitive advantage. Such cases have been illustrated through Blockbuster, which collapsed after failing to transition to digital streaming (ENEB, 2025), and Nokia, which lost its dominant market position due to its slow response to smartphone innovation (Conant, 2024). The manufacturing industry is no exception.

In the poultry feed manufacturing sector, process automation is one of the most significant advantages of adopting new technologies. Process automation reduces the need for excessive manual intervention and, therefore, lowers the probability of human error (Tabaku *et al.*, 2025:2324). Automation enhances operational efficiency and productivity by streamlining workflows, improving product consistency and traceability and reducing costs associated with rework or quality issues (Tabaku *et al.*, 2025:2324). Process automation also aligns closely with Lean manufacturing principles by reducing waste, limiting time delays, and optimising resource utilisation.

Automation is complemented by asset improvement programmes, which provide a structured approach to planning and executing maintenance activities. In feed manufacturing, the nature of the equipment in terms of its complexity and scale, makes manual maintenance planning inefficient and prone to error. To overcome this, organisations are adopting maintenance systems that hold technology that enables data-driven planning, real-time monitoring, and predictive analytics to optimise intervention intervals and prioritise critical assets (Bokrantz & Skoogh, 2023:1; Gomaa, 2025:18). Systems of this nature are able to automate scheduling, issue alerts, and synchronise maintenance activities with production operations, which results in improved asset reliability and a reduction in unplanned downtime (Grooss, 2024:3). This transition reflects the shift from traditional reactive and preventive maintenance to predictive and prescriptive approaches, with the goal of enhancing OEE, thereby extending asset life cycles, and supporting stable, cost-efficient production (Gomaa, 2025:18).

Technology adoption also improves formulation accuracy through the integration of advanced formulation software. These intelligent systems generate precise feed formulations that meet nutritional specifications at the lowest possible cost by making use of real-time data and optimisation algorithms (Akintan *et al.*, 2025:1). Automating complex calculations and ingredient balancing, ensures consistency and allow manufacturers to respond quickly to fluctuations in raw material quality or price (Akintan *et al.*, 2025:9). This results in more stable final products, reduced waste, and improved overall cost efficiency in feed manufacturing (Akintan *et al.*, 2025:9).

The adoption of new technologies holds widely recognised benefits; however, it also poses a host of challenges. Barriers to technology adoption include high capital investment requirements, the need for extensive training, and user acceptance (Taher & Bashar, 2024:345). Employees may exhibit a natural preference for familiar processes, resisting change, and ultimately limiting an organisation's ability to fully leverage technology for improved performance (Gomaa, 2025:19). Moreover, in the African context, the adoption process is made more complex and resource-intensive due to limited availability, infrastructure gaps, and high import costs (Kalumendo, 2023:1).

Based on the above premise, technology adoption serves as a critical enabler of operational efficiency. Therefore, it is possible to present the following hypothesis:

H_{1c}: Technology adoption has a positive and significant effect on operational efficiency in African poultry feed manufacturing.

2.9 CONCLUSION

This chapter has reviewed the available literature around the subject and provided a thorough overview of the relevant theories and the importance of the constructs related to the study. The Resource-Based-View establishes the interrelation of maintenance strategies, feed formulation accuracy, technology adoption and operational efficiency. This comprehensive literature review has formed a theoretical foundation for exploring operational efficiency in poultry feed manufacturing in Africa.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

Methodology refers to the entire process of conducting a research study (Mustafa, 2023:1). This section outlines the study's methodological framework and details the research design, population, sampling approach, data collection strategy, and ethical considerations. This section ensures the study's transparency, replicability, and alignment with established academic protocols.

The study follows a positivist research philosophy, which assumes that knowledge can be objectively measured and analysed using empirical methods (Toyon, 2023:3; Wilson, 2014:19). A deductive approach is applied, which entails the testing of theoretical propositions regarding operational efficiency using quantitative data collected from industry professionals (Creswell & Creswell, 2017:60; Wilson, 2014:19).

3.2 RESEARCH DESIGN

According to Toyon (2023:3) research design is “the blueprint for performing the investigation, and it specifies the methods, procedures, and techniques that will be utilised to gather and analyse the data”. The study is of a quantitative, non-experimental, correlational research design. This design enables the identification and statistical testing of relationships between the dependent variable (operational efficiency) and independent variables (maintenance strategies, feed formulation accuracy, and technology adoption) (Creswell & Creswell, 2017:60; Toyon, 2023:6). The data will be collected using a structured, online survey. The numerical data will undergo analysis, and the results will be generalised to the African poultry feed manufacturing sector.

3.3 TARGET POPULATION

The population includes mid-level and senior professionals employed in poultry feed manufacturing companies in Africa. Targeted roles comprise:

- Operations Managers
- Maintenance Managers
- Technical Advisors
- Senior Executives

Excluded from the population are individuals not involved in technical or strategic operational decision-making, including administrative personnel, machine operators, and support staff.

3.4 SAMPLE SIZE AND SAMPLING FRAMEWORK

A total of 250 questionnaires were distributed across 14 poultry feed companies operating in nine African countries. The expected response rate of 60 – 70% was based on similar industry studies and professional engagement levels, which yields 150–175 usable responses. This exceeds the threshold for correlation and regression analysis with 95% confidence and 80% statistical power (Cohen *et al.*, 2018:802; Field, 2013).

Table 3-1: Sampling framework

Company	Country/Region	Planned Participants
RCL Foods Ltd. – Epol & Molatek	South Africa	16
Astral Foods – Meadow Feeds & Tiger Feeds	South Africa, Zambia	20
Country Bird Holdings – Nutri Feeds	South Africa, Botswana, Zambia, Mozambique	66
Afgri	South Africa	20
Quantum Foods – Nova Feeds	South Africa	20
Itau Feeds	South Africa	15
Irvine's	Botswana, Zambia	15
Breedwell Feeds	Nigeria	15
Top Feeds	Nigeria	10
Novatech	South Africa, Zambia, Zimbabwe	25
De Heus Feeds	South Africa, Kenya	10
Namib Mills – Voer Meester	Namibia	5
New Hope Feeds	Nigeria	3
VKB – Qpro Feeds	South Africa	10
Total Identified Participants	Across 8 Countries	250

This sampling framework ensures representation across company size, geography, and professional function, in order to achieve both scientific rigour and practical relevance.

3.5 SAMPLING METHOD

Rahi (2017:3) defines sampling as “the process of selecting segment of the population for investigation”. Sampling is beneficial to reduce the workload as well as the costs for the research (Rahi, 2017:3). For this study, the researcher employed a multistage procedure (Creswell &

Creswell, 2017:247) with non-probability judgement, also known as purposive sampling method (Rahi, 2017:3). This entail the discretion of the researcher to select a group of people that has knowledge or experience with the problem and where the participants are selected for a specific purpose (Rahi, 2017:3). This sampling method is ideal because the researcher has extensive experience in the industry and has developed a network of knowledgeable contacts.

A multi-stage non-probability sampling method was employed (Creswell & Creswell, 2017:247), combining:

- Judgement (purposive) sampling to identify initial participants through industry contacts and internal company gatekeepers (Rahi, 2017:3).
- Snowball sampling to allow initial respondents to refer qualified colleagues, enhancing reach and relevance while mitigating non-response bias (Rahi, 2017:3).

This approach is justified given the technical nature of the study, the need for domain-specific expertise, and limited accessibility to senior personnel.

3.6 RECRUITMENT STRATEGY

Recruitment was carried out in three phases:

1. Formal authorisation was obtained from Chief Executive Officers (CEOs) or gatekeepers within each targeted company.
2. Participant invitations were sent via email, facilitated through Human Resources (HR) departments or designated internal representatives.
3. Follow-up reminders were issued weekly to improve response rates. Participants were informed that participation was voluntary and were assured of anonymity and data confidentiality.

Where access barriers arose, professional networks and snowball referrals supplemented recruitment.

3.7 DATA COLLECTION

According to Mwita (2022:532) data collection methods are “means, tools or techniques that researchers use to collect data in their respective research projects”. Data were collected through a self-administered online survey, hosted on Google Forms, see Annexure A. The survey consisted of closed-ended items using a five-point Likert scale. This method generated numeric data, at a specific point in time (Wang & Cheng, 2020:65), providing a snapshot of the influence

of maintenance strategies, feed formulation accuracy and technology adoption on operational efficiency for the poultry feed manufacturing industry in Africa. This method did not make provision to track changes over time.

Data collection spanned over a three-month period and was supported by continuous engagement to maximise participation.

3.8 SURVEY INSTRUMENT DESIGN AND JUSTIFICATION

The survey instrument was specifically designed to align with the study's quantitative, non-experimental, correlational research design. Its primary purpose is to measure the relationships between operational efficiency (dependent variable) and three independent variables: maintenance strategies, feed formulation accuracy, and technology adoption, as identified in the research objectives and hypotheses (Creswell & Creswell, 2017:60; Toyon, 2023:6).

The instrument includes structured, closed-ended, Likert-type questions which were designed to achieve demographic profiling and contextual insights. This approach ensures both standardisation for quantitative analysis and depth where appropriate, enhancing the validity of the research findings (Bryman *et al.*, 2014:162; Creswell & Creswell, 2017).

3.9 CONSTRUCT OPERATIONALISATION

Each of the study's four constructs was operationalised using multiple-item Likert-type questions to ensure conceptual clarity and to allow for statistical reliability testing (Rahi, 2017:4). This approach follows the recommendation of Nunnally and Bernstein (1994) that internal consistency should be confirmed with Cronbach's alpha coefficients of 0.70 or higher (Hussey *et al.*, 2023:2). The constructs were derived from established theoretical and industrial literature; however, no previously validated measurement scales were found for direct use. Consequently, items were developed from the conceptual indicators identified in the literature.

3.9.1 Operational efficiency (dependent variable)

Operational efficiency was measured using five items (3.1–3.5) that address production target attainment, equipment downtime, waste reduction, input-cost management, and cost competitiveness.

These indicators are consistent with efficiency dimensions discussed in studies on manufacturing performance (Abubakar, 2017; Mitau, 2023; Singh *et al.*, 2023; Susilawati, 2021), which conceptualise efficiency in terms of throughput, cost, quality, and delivery. As these studies provide conceptual rather than validated survey instruments, the current items were designed to

capture respondents' perceptions of these factors within poultry-feed manufacturing. Reliability and construct validity will be evaluated through internal consistency and factor analysis procedures.

3.9.2 Maintenance strategies (independent variable 1)

Maintenance strategy was measured with five items (4.1–4.5) that reflect structured maintenance planning, preventive scheduling, predictive technologies, and operator participation.

The foundation of the concept draws from TPM theory (Nakajima, 1988) and subsequent developments in maintenance management (Ahuja & Khamba, 2008; Ghazi, 2016; Jonsson, 1999; Pintelon & Parodi-Herz, 2008).

Gania *et al.* (2017) described principles of reliability-centred maintenance which further inform this construct, emphasising that maintenance is a strategic contributor to system reliability and operational performance. These sources do not provide survey validation data; however, they do establish the conceptual parameters that guided item development. Empirical reliability and validity will be confirmed using the study's primary data.

3.9.3 Feed formulation accuracy (independent variable 2)

No validated measurement instrument for feed-formulation accuracy was identified by the author in existing literature. Therefore, this construct was developed specifically for this study, drawing on technical and scientific work in poultry-feed formulation (Haryuni & Alam, 2024; Pesti & Choct, 2023; Tansil, 2021) that highlighted the importance of batch consistency, ingredient-quality control, nutrient precision, and cost optimisation.

The five associated items (5.1–5.5), therefore, capture these operational dimensions within commercial feed-mill settings. Reliability (target $\alpha \geq 0.70$) and construct validity will be established through Confirmatory Factor Analysis (CFA) to confirm that all items load appropriately on a single latent factor (Hair *et al.*, 2019:10).

3.9.4 Technology adoption (independent variable 3)

Technology adoption was assessed through five items (6.1–6.5) with focus being placed on automation, predictive analytics, digital monitoring, employee readiness, and strategic investment in technological systems.

Conceptually, these items align with frameworks on digital transformation and servitisation (Almehairbi *et al.*, 2022; Baines *et al.*, 2017). The ICCCNET (2024) conference paper further

supports these themes, describing efficiency improvements in emerging-market manufacturing that was enabled by technology. Although these sources do not provide validated scales, they do provide conceptual guidance and offer a robust theoretical base for the construct. Empirical reliability and validity will be determined through factor-analysis techniques.

3.9.5 Validation procedure

The following steps will be implemented to ensure that each construct accurately represents its intended concept:

- **Content Validity:** Alignment of all survey items with constructs described in the relevant peer-reviewed and technical literature (Boateng *et al.*, 2018:5).
- **Internal Consistency:** Calculation of Cronbach's alpha for each construct (target ≥ 0.70) (Boateng *et al.*, 2018:13).
- **Construct Validity:** Assessment through CFA to confirm one-dimensionality and item loadings (≥ 0.50) (Boateng *et al.*, 2018:5).
- **Convergent and Discriminant Validity:** Examination of inter-construct correlations to ensure conceptual distinction between variables (Boateng *et al.*, 2018:14).

All items were measured on a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Negatively worded items (e.g. Item 4.5) were reverse coded before analysis.

3.9.6 Response format

A five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) was used to measure attitudes and perceptions across constructs in a consistent manner (Boateng *et al.*, 2018:6). This scale format has been proven for its sensitivity and ease of interpretation in applied industrial contexts (Joshi *et al.*, 2015:397).

3.9.7 Demographic and contextual items

Initial questions in the survey capture participant demographic details such as roles, years of experience, firm size, and country of operation. These variables provide context that will assist in analysing subgroup differences and ensuring external validity across African feed mills.

3.9.8 Instrument validation

A confirmatory factor analysis was conducted to assess the validity of the main theoretical constructs. This analysis evaluated how well the observed variables represented their underlying latent factors, thereby confirming the hypothesised measurement model derived from the literature.

- The scales for maintenance strategies were adapted from existing literature by Ahuja and Khamba (2008); Ghazi (2016); Jonsson (1999); Pintelon and Parodi-Herz (2008).
- The scales for feed formulation accuracy were adapted from existing literature by Haryuni and Alam (2024); Pesti and Choct (2023); Tansil (2021).
- The scales for technology adoption were adapted from existing literature by Almehairbi *et al.* (2022); Baines *et al.* (2017).
- The scales for operational efficiency were adapted from existing literature by Abubakar (2017); Mitau (2023); Singh *et al.* (2023); Susilawati (2021).

3.10 DATA STORAGE AND CONFIDENTIALITY

Survey responses were automatically recorded and stored in a secure, password-protected Google Drive folder, using the infrastructure provided by Google Forms. Access was restricted to the researcher and supervisor. Data were anonymised during cleaning and analysis and will be securely retained for five years, in compliance with NWU policy and the Protection of Personal Information Act (POPIA), Act 4 of 2013. Thereafter, data will be permanently deleted.

No personal identifiers were collected. Data were analysed and presented in aggregate form, thereby safeguarding confidentiality and ensuring that individual responses could not be traced.

3.11 ETHICAL CONSIDERATIONS

Ethical clearance was granted by the EMS-REC Committee of North-West University. An informed consent form (Annexure B) accompanied the online survey, outlining the study's purpose, data handling procedures, voluntary participation, and the right to withdraw. Only respondents who provided consent were able to access and complete the survey.

This study was conducted in full compliance with the ethical guidelines and policies of North-West University, including adherence to the principles of voluntary participation, informed consent, confidentiality, data protection, and scientific integrity.

3.11.1 Ethics clearance

Prior to data collection, ethical approval was obtained from the Economic and Management Sciences Research Ethics Committee (EMS-REC) at North-West University. The ethics application included the survey instrument, informed consent form, data management plan, and relevant recruitment materials. Data collection commenced only after official clearance had been granted.

3.11.2 Informed consent

All prospective participants were provided with an electronic informed consent form (Annexure B) embedded in the online survey platform. The form clearly communicates:

- The purpose and scope of the study
- The voluntary nature of participation
- The right to decline or withdraw at any stage without penalty
- Assurance of anonymity and confidentiality
- Details of data handling and storage
- Contact details for the researcher and ethics committee

Participants were required to provide explicit consent (by ticking a confirmation box) before proceeding to the questionnaire.

3.11.3 Voluntary participation and right to withdraw

Participation was entirely voluntary. No coercion, pressure, or inducement was applied. Respondents could exit the survey at any point without consequence. No follow-up was pursued in cases of withdrawal.

3.11.4 Confidentiality and anonymity

The survey was administered using Google Forms without collecting names, email addresses, or IP addresses. All responses were anonymised and reported in aggregated form. The researcher ensured that no data could be linked to any individual participant or company.

3.11.5 Data protection and storage

In line with the Protection of Personal Information Act 4 of 2013, and NWU data governance requirements:

- Data is securely stored on a password-protected Google Drive folder, accessible only to the researcher and supervisor.
- Raw data were anonymised and securely retained for five years following completion of the research.
- Thereafter, all data will be permanently deleted.
- No physical data or hard-copy materials were used.

3.11.6 Risk and harm mitigation

This study posed no foreseeable physical, psychological, financial, or reputational risk to participants. The questionnaire content focused exclusively on professional practices and perceptions within the poultry feed manufacturing industry. No sensitive or personal data were requested.

Participants were informed before the study that should they have experienced discomfort; they were free to withdraw without completing the survey.

3.12 DATA ANALYSIS

This section outlines the data analysis techniques that were applied to examine the relationships between the independent variables (maintenance strategies, feed formulation accuracy, technology adoption) and the dependent variable (operational efficiency).

3.13 DATA PREPARATION

Once data collection was complete, responses were loaded into Microsoft Excel and subsequently imported into SPSS Statistics software (version 28) and Jamovi for analysis. Prior to statistical analysis, the dataset underwent cleaning and preparation, including:

- Verification for completeness – Partial or inconsistent responses were removed.
- Reverse-coding – Where applicable, negatively worded items were reverse-coded to align with the Likert scale direction.
- Reliability testing – Internal consistency of multi-item constructs was assessed using Cronbach's alpha, with a threshold of 0.7 indicating acceptable reliability (Nunnally & Bernstein, 1994).

3.14 DESCRIPTIVE STATISTICS

Descriptive statistics summarised the demographic characteristics of respondents and provided an overview of the dataset. This included measures such as:

- **Frequencies and percentages** for categorical variables (e.g. job role, experience, size of organisation, geographic location)
- **Means and standard deviations** for continuous variables (e.g., scale-based responses)

These results created the context for the interpretation of the inferential findings.

3.15 INFERENTIAL STATISTICS

To examine relationships between the independent and dependent variables, the following statistical techniques were applied:

3.15.1 Correlation analysis

Pearson correlation coefficients were calculated to determine the strength and direction of linear relationships between operational efficiency and each independent variable. This analysis assisted in identifying significant pairwise associations within the dataset.

3.15.2 Regression analysis

Multiple linear regression analysis was conducted to determine the extent to which the independent variables predict operational efficiency. The model assessed:

- **The individual contribution** of each predictor variable
- **Overall model fit**, as indicated by R^2 and adjusted R^2 values
- **Statistical significance** of the regression model (p-values and F-statistic)
- **Multicollinearity diagnostics**, using variance inflation factors (VIFs), to ensure the reliability of parameter estimates

This approach provided evidence-based insights into the operational drivers of efficiency in the sector.

3.16 ASSUMPTION CHECKING

The assumptions of regression analysis, namely normality, linearity, homoscedasticity, and independence of residuals were tested. Specifically:

- **Histogram and Q-Q** plots were used to assess the normality of residuals
- **Scatterplots** were examined to test for homoscedasticity and linearity
- **Durbin-Watson statistic** was applied to assess autocorrelation
- **VIF scores** were calculated to test for multicollinearity

Where violations were identified, appropriate statistical techniques (e.g., data transformation or model adjustment) were considered.

3.17 SIGNIFICANCE THRESHOLDS AND EFFECT SIZES

The significance level for all statistical tests was set at 5% ($p < 0.05$). Effect sizes were also reported (e.g., Cohen's f^2 for regression), providing an indication of practical relevance beyond statistical significance (Cohen, 1988).

3.18 INTERPRETATION AND REPORTING

Results were presented in tabular format and were accompanied by narrative explanations which interpreted the statistical outcomes and translated these outcomes to practical poultry feed manufacturing scenarios operating in diverse African contexts.

3.19 BENEFIT TO PARTICIPANTS AND THE INDUSTRY

While no financial or material incentives were offered to participants. Participants were able to request a summary report of the research findings. This report provided practical insights into operational efficiency trends, potentially supporting internal benchmarking and strategic improvement.

3.20 RESPONSIBLE RESEARCH CONDUCT

The researcher conducted this study in accordance with NWU's research ethics code of conduct, and the principles of transparency, rigour, and accountability. Data were truthfully reported and accurately interpreted without fabrication, falsification, or misrepresentation.

3.21 DELIMITATIONS AND LIMITATIONS

3.21.1 Delimitations

Delimitations define the boundaries of the study as intentionally set by the researcher to maintain focus and manage scope. The following delimitations apply:

- **Industry scope:** The study is confined to the poultry feed manufacturing industry in Africa, not extending to broader agricultural or general animal feed sectors.
- **Geographic scope:** The study includes selected companies from Southern, West, and East Africa, with focus placed on firms with established operations in feed formulation and production.
- **Respondent profile:** Only mid-level and senior professionals involved in operations, maintenance, and technical advisory roles are included. Entry-level staff and non-technical personnel are excluded to ensure domain-specific insights.
- **Thematic focus:** The study specifically examines operational efficiency in relation to maintenance practices, feed formulation accuracy, and technological adoption.
- **Methodology:** A cross-sectional, quantitative design is used. The study does not incorporate longitudinal tracking or qualitative exploration of individual company practices.

These delimitations were established to maintain relevance, ensure methodological coherence, and deliver actionable insights, specific to operational management in poultry feed manufacturing.

3.21.2 Limitations

Limitations are factors beyond the researcher's control that may affect the generalisability, accuracy, or scope of findings (Jegede & Isiugo-Abanihe, 2020:841). The key limitations are:

- **Non-probability sampling:** The use of purposive and snowball sampling, while justified, may potentially introduce selection bias and limit the generalisability of results beyond the sampled network to the population as a whole (Shamsudin *et al.*, 2024:1).
- **Self-reported data:** Data are self-reported and based on participants' perceptions, which may be influenced by personal bias, organisational loyalty, or recall inaccuracies (Akbulut, 2025:115).

- **Language and interpretation:** The survey was administered in English only. Participants who do not speak English as their native tongue may have interpreted certain terms differently, despite the author's efforts to ensure clarity when developing the questions (Benlidayi & Gupta, 2024:1).
- **Access and participation constraints:** Limited access to company decision-makers or low response rates may affect the representativeness of the sample (Taherdoost & Madanchian, 2025:186). Despite mitigation strategies (e.g., follow-ups and referrals), some variation in participation across countries is expected.
- **Common method bias (CMB):** As the data for both the independent variables (maintenance strategies, feed formulation accuracy, and technology adoption) and the dependent variable (operational efficiency) were collected from the same respondents using a single survey instrument at a single point in time, there is a risk that the observed relationships may be inflated due to shared measurement context rather than reflecting true underlying associations (Podsakoff et al., 2003:879).
- **Cross-sectional design:** As a cross-sectional study, data represent a single point in time, meaning that causal inferences and trends over time cannot be examined (Cummings, 2018:2).

3.22 CONCLUSION

This research methodology chapter described this quantitative, correlational study in terms of the philosophy behind the design and methodology, study sample and sample size establishment, data collection and analysis techniques, ethical considerations and study limitations. The information in this chapter ensures that this research is replicable, ethical and scientifically rigorous.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 INTRODUCTION

The chapter discusses the results of the data analysis outline in the research methodology chapter (Chapter 3). The sample realisation rate, and overview of the respondents who participated in the study will be discussed, followed by the assessment of the reliability and validity of the measurement scales used. Thereafter, the chapter will conclude with the hypothesis testing and presentation of the moderation results (e.g. firm size, managerial experience, geographic location) that may moderate the relationship between maintenance strategies, feed formulation accuracy, technology adoption and operational efficiency.

4.2 SAMPLE REALISATION

As outlined in Chapter 3, 250 questionnaires were distributed across 14 poultry feed companies operating in eight African countries, with the goal of receiving 150 returned and completed questionnaires. Based on similar industry studies and professional engagement levels, a response rate of 60–70% was expected. However, only 82 questionnaires were returned.

Table 4-1: Sample realisation

Target sample size	150
Total number of completed responses	82
Discarded questionnaires due to incomplete responses	1
Total of used responses	81
Sample realisation rate	54%

As presented in Table 4-1, only 82 responses were collected, which was lower than the intended 150 target sample size. The lower-than-expected response rate was primarily influenced by the competitive nature of the industry. Several companies expressed concerns about participating in a research study initiated by a rival in the same industry, which likely discouraged broader engagement. Furthermore, one questionnaire was discarded due to incomplete responses, which resulted in a sample realisation rate of 54%.

4.3 DEMOGRAPHIC PROFILE OF RESPONDENTS

The demographic profile of the respondents who participated in the study, as presented in Table 4-2 to Table 4-6, will now be discussed.

Table 4-2: Current job role

Sample Profile	Frequency	Percentage
Engineer	4	4.9%
Maintenance Manager	13	16.0%
Managing Director	1	1.2%
Operations Manager	32	39.5%
Production Manager	3	3.7%
Senior Executive	14	17.3%
Technical Advisor	12	14.8%
Technical Manager	2	2.5%

Table 4-2 shows the majority of the sample were Operations Managers (39,5%), followed by Senior executives (17%), and Maintenance managers (16%).

Table 4-3: Years experience in the poultry feed manufacturing

Sample Profile	Frequency	Percentage
1–3 years	6	7.4%
4–6 years	11	13.6%
7–10 years	16	19.8%
Less than 1 year	1	1.2%
More than 10 years	47	58.0%

Table 4-3 illustrates the respondents' years of experience in poultry feed manufacturing, majority of respondents indicated that they have more than 10 years of experience. This is followed by 7 – 10 years of experience (19.8%) and 4 to six years of experience (13.6%). This can also be interpreted that majority of the sample (77.8%) have 7 years or more of experience in the poultry feed manufacturing industry.

Table 4-4: Size of poultry feed mill

Sample Profile	Frequency	Percentage
Small (1–50 employees)	4	4.9%
Medium (51–200 employees)	48	59.3%
Large (201+ employees)	29	35.8%

From Table 4-4 shows that majority of the respondents are currently employed at a medium company with 51 to 200 employees. This is closely followed by respondents who are currently employed at a large poultry feed mill with more than 201 employees.

Table 4-5: Number of tons feed produced per month

Sample Profile	Frequency	Percentage
1 001 – 5,000 tons	5	6.2%
10,001 – 20,000 tons	16	19.8%
20,001 – 30,000 tons	23	28.4%
5,001 – 10,000 tons	22	27.2%
More than 30,000 tons	15	18.5%

Table 4-5 indicates the number of tons of feed produced by the mills per month, the majority of the respondents indicated that their poultry feed mill produces 20,001 – 30,000 tons of feed (28.4%), followed by 5,001 to 10,000 tons (27.2%), and 10,001 – 20,000 tons (19.8%). This shows that majority of the sample (75.4%) currently produces at least 5,001 tons of poultry feed per month.

Table 4-6: Country in which the company is based

Sample Profile	Frequency	Percentage
Botswana	4	4.9%
South Africa	70	86.4%
Zambia	6	7.4%
Zimbabwe	1	1.2%

Table 4-6 illustrates most of the respondents are based in South Africa (86.4%). The sample mainly comprises Operations managers in South Africa, with 7 years and more experience in the poultry feed manufacturing industry, currently employed at a medium sized mill with 51 to 200 employees, who currently produce at least 5001 tons of poultry feed per month.

The researcher distributed the questionnaire in collaboration with the African Feed Manufacturers Association (AFMA) to feed manufacturing operations across African countries. Although the survey reached a broad regional audience, responses were received from participants in only four countries. This limited geographic representation is attributed to the highly competitive nature of the feed manufacturing industry, where operational practices, maintenance strategies, and formulation approaches are often regarded as commercially sensitive information. Consequently, some organisations were reluctant to participate in the study despite the assurance of anonymity and confidentiality. This outcome is recognised as a limitation of the study and is acknowledged in the interpretation of the findings.

The main findings pertaining to the demographic profile of respondents are, therefore:

1	Majority of the participants in the sample were Operations Managers (39,5%).
2	Majority of respondents indicated that they have more than 10 years of experience (58%).
3	Majority of the respondents are currently employed at a medium company with 51 to 200 employees (59.3.7%).
4	Majority of the respondents indicated that their poultry feed mill produces 20,001 – 30,000 tons of feed (28.4%), followed by 5,001 to 10,000 tons (27.2%).
5	Majority of the respondents are based in South Africa (86.4%).

The descriptive results for each of the constructs will be presented in the following section.

4.4 DESCRIPTIVE DATA ANALYSIS

The describe data analysis of the 4 key constructs included in the study, namely, maintenance strategies, feed formulation accuracy, technology adoption and operational efficiency will be presented.

4.4.1 Maintenance strategies

The objective of the measure was to determine the extent to which respondents perceive the provided statements regarding maintenance strategies. Maintenance strategies perceptions were measured on a 5-point Likert scale, where 1 was Strongly Disagree, and 5 was Strongly Agree. The scales were adapted from existing literature (Ahuja & Khamba, 2008; Ghazi, 2016; Jonsson, 1999; Pintelon & Parodi-Herz, 2008).

Table 4-7 provides the standard deviation and mean scores of each of the statements that measured provided information around maintenance strategies in poultry feed manufacturing mills.

Table 4-7: Maintenance strategies in poultry feed manufacturing mills

Statement		N	Mean	Standard Deviation (SD)
Maintenance strategies			3.32	0.679
MS1	Our plant follows a structured maintenance plan.	81	4.04	0.887
MS2	Preventive maintenance is carried out on a regular basis.	81	3.90	0.875
MS3	We use condition-monitoring tools or sensors to predict failures	81	3.07	1.138
MS4	Operators are trained to perform basic maintenance tasks	81	3.23	1.099

MS5	Equipment failures significantly disrupt production. (<i>Reversed Item</i>)	81	2.33	1.162
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Table 4-7 indicates that the mean values for the five statements (MS1 – MS5) ranged from 2.33 to 4.04. The standard deviation values suggested low variability in responses as they ranged from 0.875 to 1.138. Respondents expressed the highest agreement with statement MS1, “*Our plant follows a structured maintenance plan*” (mean = 4.04). The respondents agreed least with statement MS5 (mean = 2.33), “*Equipment failures significantly disrupt production. (Reversed Item)*”.

Furthermore, the overall mean score of maintenance strategies was 3.32 (SD 0.679), indicating that respondents neither agreed nor disagreed with the items measuring the construct.

The main findings pertaining to the extent of maintenance strategies about poultry feed manufacturing mills are:

6	Respondents agreed the most that their plant follows a structured maintenance plan.
7	Respondents agreed the least that equipment failures significantly disrupt production.

4.4.2 Feed formulation accuracy

The objective of the measure was to determine the extent to which respondents perceive the statements measuring feed formulation accuracy. Feed formulation accuracy was measured on a 5-point Likert scale, where 1 was Strongly Disagree, and 5 was Strongly Agree. The scales were adapted from existing literature (Haryuni & Alam, 2024; Pesti & Choct, 2023; Tansil, 2021).

Table 4-8 provides the standard deviation and mean scores of each of the statements that measured feed formulation accuracy in poultry feed manufacturing mills.

Table 4-8: Feed formulation accuracy in poultry feed manufacturing mills

Statement		N	Mean	Standard Deviation (SD)
Feed formulation accuracy			4.21	0.561
FFS1	Feed batches are consistent in composition and quality.	81	4.23	0.785
FFS2	We regularly optimise feed formulations to reduce costs.	81	4.40	1.785
FFS3	Ingredient quality variability affects batch consistency.	81	3.90	1.079
FFS4	Nutrient levels in formulations are accurately calculated and delivered.	81	4.41	0.648

FFS5	Our feed formulation system is automated or digitally supported.	81	4.12	1.029
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Table 4-8 indicated that the mean scores for the five statements (FFS1 – FFS5) ranged from 3.90 to 4.41. The standard deviation values suggested low variability in responses as they ranged from 0.648 to 1.785. Respondents expressed the highest agreement with statement FFS4 (mean = 4.41), “*Nutrient levels in formulations are accurately calculated and delivered.*” Followed by statement FF2 (mean = 4.40), “*We regularly optimise feed formulations to reduce costs.*” The respondents agreed least with statement FFS3, “*Ingredient quality variability affects batch consistency*” (mean = 3.90).

Furthermore, the overall mean score of feed formulation accuracy was 4.21 (SD 0.561), indicating that respondents mostly agreed with the items measuring the construct.

The main findings pertaining to the extent of feed formulation accuracy in poultry feed manufacturing mills are:

8	Respondents agreed the most that their nutrient levels in formulations are accurately calculated and delivered.
9	Respondents also agreed that they regularly optimise feed formulations to reduce costs.
10	Respondents agreed the least that ingredient quality variability affects batch consistency.

4.4.3 Technology adoption

The objective of the measure was to determine the extent to which respondents perceive the statements measuring technology adoption. Technology adoption was measured on a 5-point Likert scale, where 1 was Strongly Disagree, and 5 was Strongly Agree. The scales were adapted from existing literature (Almehairbi *et al.*, 2022; Baines *et al.*, 2017).

Table 4-9 provides the standard deviation and mean scores of each of the statements that measured technology adoption in poultry feed manufacturing mills.

Table 4-9: Technology adoption in poultry feed manufacturing mills

Statement	N	Mean	Standard Deviation (SD)
Technology adoption		3.75	0.644
TA1 We use automated systems for monitoring feed production.	81	4.27	0.758

TA2	Predictive analytics inform our maintenance decisions.	81	3.12	1.077
TA3	Technology adoption has improved our overall efficiency.	81	3.94	0.842
TA4	Our staff are trained to use modern technologies effectively.	81	3.46	0.909
TA5	Investment in technology is a strategic priority in our organisation.	81	3.98	0.806

Table 4-9 indicates that the mean values for the five statements (TA1 – TA5) ranged from 3.12 to 4.27. The standard deviation values suggested low variability in responses as they ranged from 0.758 to 1.077. Respondents expressed the highest agreement with statement TA1, “*We use automated systems for monitoring feed production*” (mean = 4.27). The respondents agreed least with statement TA2 (mean = 3.12), “*Predictive analytics inform our maintenance decisions*”.

Furthermore, the overall mean score of technology adoption was 3.75 (SD 0.644), indicating that respondents slightly agreed with the items measuring the construct.

The main findings pertaining to the extent of technology adoption in poultry feed manufacturing mills are:

- 11 Respondents agreed the most that they use automated systems for monitoring feed production.
- 12 Respondents agreed the least that predictive analytics inform their maintenance decisions.

4.4.4 Operational efficiency

The objective of the measure was to determine the extent to which respondents perceive the statements measuring operational efficiency. Operational efficiency was measured on a 5-point Likert scale, where 1 was Strongly Disagree, and 5 was Strongly Agree. The scales were adapted from existing literature (Abubakar, 2017; Mitau, 2023; Singh *et al.*, 2023; Susilawati, 2021).

Table 4-10 provides the standard deviation and mean scores of each of the statements that measured operational efficiency in poultry feed manufacturing mills.

Table 4-10: Operational efficiency in poultry feed manufacturing mills

Statement		N	Mean	Standard Deviation (SD)
Operational efficiency			3.82	0.514
OE1	Our feed mill consistently meets production targets.	81	4.06	0.677

OE2	We have minimal unplanned equipment downtime.	81	3.37	0.697
OE3	Production processes are well-optimised to reduce waste	81	3.48	0.910
OE4	We effectively manage input costs (e.g., energy, materials, labour).	81	4.04	0.715
OF5	The cost per tonne of feed produced is competitive.	81	4.15	0.743

Table 4-10 indicates that the mean values for the five statements (OE1 – OE5) ranged from 3.37 to 4.15. The standard deviation values suggested low variability in responses as they ranged from 0.677 to 0.910. Respondents expressed the highest agreement with statement OE1, “*Our feed mill consistently meets production targets.*” (mean = 4.06). The respondents agreed least with statement OE2 (mean = 3.37), “*We have minimal unplanned equipment downtime.*”

Furthermore, the overall mean score of operational efficiency was 3.82 (SD 0.644), indicating that respondents slightly agreed with the items measuring the construct.

The main findings pertaining to the extent of operational efficiency within poultry feed manufacturing mills are:

- | | |
|----|---|
| 13 | Respondents agreed the most that their feed mill consistently meets production targets. |
| 14 | Respondents agreed the least that they have minimal unplanned equipment downtime. |

4.5 RELIABILITY

The reliability of the measurement scales for maintenance strategies, feed formulation accuracy, technology adoption and operational efficiency was tested using Cronbach’s alpha values. If a Cronbach’s alpha value is above 0.70, it is considered to be reliable (Hair *et al.*, 2019). Table 4-11 provides the Cronbach’s alpha values for all the constructs of the study.

Table 4-11: Cronbach’s alpha values

Construct	Cronbach’s alpha value
Maintenance strategies	0.664
Feed formulation accuracy	0.663
Technology adoption	0.778
Operational efficiency	0.714

All the Cronbach’s alpha values of the main constructs of the study are presented in Table 4-11. According to (Hair *et al.*, 2019). Cronbach’s alpha values of 0.70 or higher is generally considered acceptable, while values of between 0.60 and 0.69 may be acceptable where new or adapted

scales are used (Taber, 2018:1278). The reliability of Operational efficiency (0.714) and Technology adoption (0.778) are acceptable according to the Cronbach's alpha values. The Cronbach's alpha values for maintenance strategies (0.664), and feed formulation accuracy (0.663) are just below the recommended threshold of 0.70. These constructs are, however, still acceptable as they indicate moderate internal consistency amongst items, as these were developed from and applied in a new context (George & Mallery, 2024). These results imply that all constructs can be retained for further analysis.

The main finding pertaining to the reliability of the constructs of the study is:

15 The measuring items used to measure the main constructs of the study are considered acceptable for further analysis.

4.6 CONFIRMATORY FACTOR ANALYSIS (CFA)

The validity of the proposed theoretical framework comprising the four main constructs of the study (maintenance strategies, feed formulation accuracy, technology adoption and operational efficiency) was determined by conducting a confirmatory factor analysis (CFA).

4.6.1 Convergent validity

The standardised factor loadings and significance values (p-values) for each statement of the variables are presented in Table 4-12.

Table 4-12: Standardised factor loadings and significance values

Variable	Statement	Std. Loading	SE	p-value
Maintenance strategy	MS1 Our plant follows a structured maintenance plan	0.748	0.0831	<.001
	MS2 Preventive maintenance is carried out on a regular basis	0.790	0.0798	<.001
	MS3 We use condition-monitoring tools or sensors to predict failures	0.593	0.1253	<.001
	MS4 Operators are trained to perform basic maintenance tasks	0.554	0.1195	<.001
	MS5 Equipment failures significantly disrupt production (<i>reversed</i>)	0.105	0.1353	0.440
Feed Formulation Accuracy	FFA1 Feed batches are consistent in composition and quality	0.554	0.0646	<.001
	FFA2 We regularly optimise feed formulations to reduce costs	0.472	0.0855	<.001

FFA3	Ingredient quality variability affects batch consistency	0.351	0.1269	<.001
FFA4	Nutrient levels in formulations are accurately calculated and delivered	0.450	0.0677	<.001
FFA5	Our feed formulation system is automated or digitally supported	0.425	0.1201	<.001

Table 4 12: Standardised factor loadings and significance values (continued)

Variable	Statement	Std. Loading	SE	p-value
Technology Adoption	TA1 We use automated systems for monitoring feed production	0.497	0.0803	<.001
	TA2 Predictive analytics inform our maintenance decisions	0.586	0.1186	<.001
	TA3 Technology adoption has improved our overall efficiency	0.548	0.0892	<.001
	TA4 Our staff are trained to use modern technologies effectively	0.733	0.0893	<.001
	TA5 Investment in technology is a strategic priority in our organisation	0.480	0.0870	<.001
Operational Efficiency	OE1 Our feed mill consistently meets production targets	0.345	0.0775	<.001
	OE2 We have minimal unplanned equipment downtime	0.318	0.0804	<.001
	OE3 Production processes are well-optimised to reduce waste	0.634	0.0945	<.001
	OE4 We effectively manage input costs (e.g., energy, materials, labour)	0.460	0.0757	<.001
	OE5 The cost per tonne of feed produced is competitive	0.360	0.0848	<.001

As presented in Table 4-12, majority of items measuring Maintenance strategies are significant ($p < 0.001$), and load moderately to strongly (0.554 – 0.790). However, MS5 (reversed item) does not contribute meaningfully to the maintenance factor ($p = 0.440$, not significant). This item was, therefore, removed from the maintenance strategies scale.

In terms of feed formulation accuracy, all items, FF1 – FF5 are significant (p -values < 0.001) and loadings indicate a moderate representation (0.351 – 0.554). All items measuring technology adoption (TA1 – TA5) are significant (p -value < 0.001), and the loadings range from 0.480 – 0.733 which indicate a strong representation of the latent variables.

Similarly, the items measuring operational efficiency (OE1 – OE5) are significant with p -values of < 0.001 . These items also load moderately to strongly onto their respective latent factors, ranging between (0.318 – 0.634).

4.7 EVALUATING THE ASSUMPTIONS OF A STANDARD MULTIPLE REGRESSION

Before a standard multiple regression can be conducted, it is important to confirm that the assumptions are met. This study included three independent variables (maintenance strategies, feed formulation accuracy, and technology adoption) and required a sample size of 50

respondents (Pallent, 2010:150). The sample size of the study exceeded the 50-respondent requirement, as 81 usable responses were retained. Furthermore, multicollinearity was not a concern with Variance Inflation Factor (VIF) values ranging from 1.38 and 1.97 and Tolerance values between 0.508 and 0.723 (Field, 2013). Similarly, the Shapiro-Wilk test for normality yielded a non-significant result ($p = 0.594$) that suggests that the residuals were normally distributed. Furthermore, no outliers were detected in the residual plots, confirming the assumption of homoscedasticity was met. Therefore, all of the assumptions of linear regression were sufficiently met. This means that the standard multiple regression could be conducted.

4.7.1 Result of the standard multiple regression analysis

The proposed theoretical framework is illustrated in Figure 4-1, indicating the various relationships that will be examined.

Figure 4-1: Proposed theoretical framework

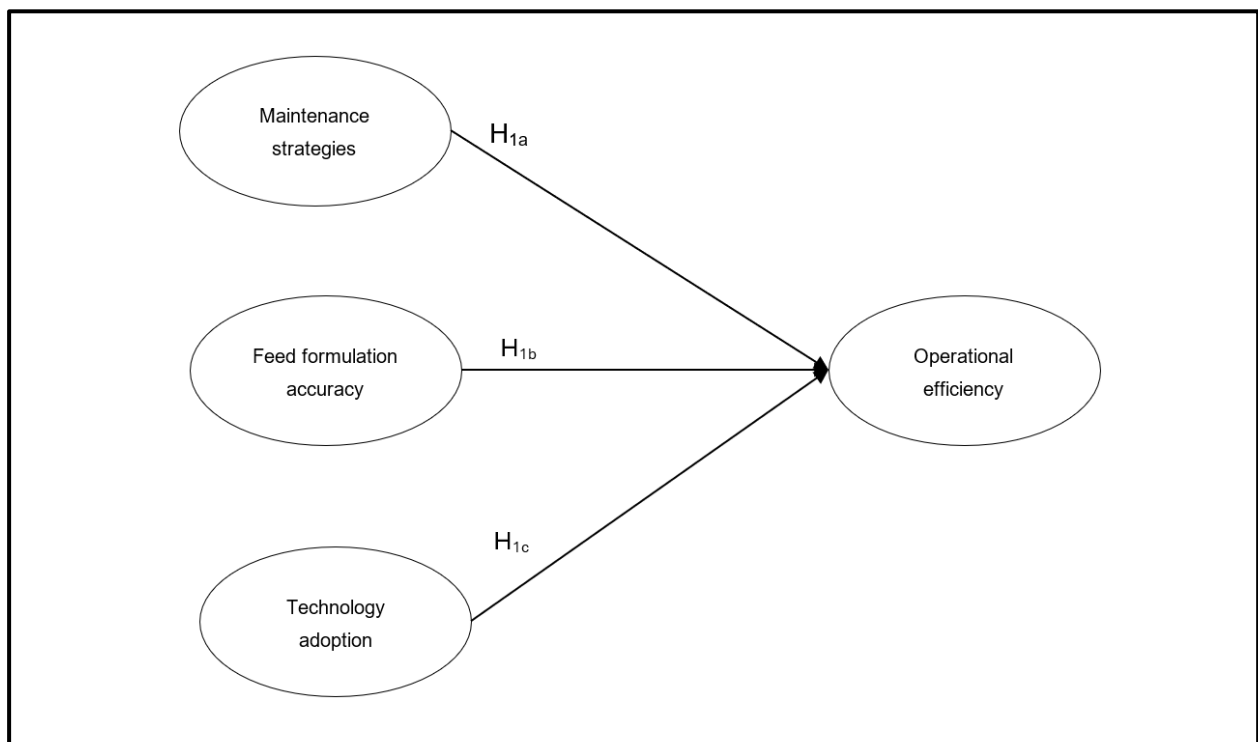


Table 4-13 provides a summary of the linear regression results. The R^2 value of 0.399 indicates that 39.9% of the variability in operational efficiency can be allocated to the 3 predictors (maintenance strategies, feed formulation accuracy, and technology adoption).

Table 4-13: Model summary

Construct	R	R^2	Adjusted R^2
1	0.632	0.399	0.376

Table 4-14 presents the standard regression coefficients.

Table 4-14: Coefficients

	Model	Standard coefficient β -value	t	p-value
1	Maintenance strategies	0.144	1.53	0.130
	Feed formulation accuracy	0.386	3.50	<0.001*
	Technology adoption	0.241	1.87	0.065

The standard regression coefficients were calculated to determine the relative contribution of each predictor (maintenance strategies, feed formation accuracy, and technology adoption) to operational efficiency. The results from Table 4-14 indicate that feed formulation accuracy (FFA) had the strongest positive effect on operational efficiency ($\beta = 0.386$, $p < .001$), followed by Technology adoption ($\beta = 0.241$, $p = 0.056$), which is just above the significant level of 0.05. Maintenance strategies showed a weaker and non-significant effect ($\beta = 0.144$, $p = 0.170$).

The hypotheses formulated for the study with the regression results are summarised and presented in Table 4-15.

Table 4-15: Regression results and hypothesis testing

Hypothesis	Relationship	Std. β	S.E.	p-value	Hypothesis testing
H _{1a}	Maintenance strategies have a positive and significant effect on operational efficiency in poultry feed manufacturing	0.144	1.53	0.130	Non-supported
H _{1b}	Feed formulation accuracy has a positive and significant effect on operational efficiency in poultry feed manufacturing.	0.386	3.50	<0.001*	Supported
H _{1c}	Technology adoption has a positive and significant effect on operational efficiency in poultry feed manufacturing.	0.241	1.87	0.056	Not-supported

The regression results revealed that maintenance strategies do not have a significant positive impact on operational efficiency in poultry feed manufacturing ($\beta = 0.144$, $p = 0.170$; rejecting H_{1a}). Concerning H_{1b}, feed formulation accuracy has a positive and significant effect on operational efficiency in poultry feed manufacturing ($\beta = 0.386$, $p < .001$; accepting H_{1b}). Lastly, technology adoption does not have a positive and significant effect on operational efficiency in poultry feed manufacturing ($\beta = 0.241$, $p = 0.056$; rejecting H_{1c}).

As a result, the main findings relating to the hypotheses formulated are presented below:

- 16 Maintenance strategies do not have a positive and significant effect on operational efficiency in poultry feed manufacturing.
- 17 Feed formulation accuracy has a positive and significant effect on operational efficiency in poultry feed manufacturing.
- 18 Technology adoption does not have a positive and significant effect on operational efficiency in poultry feed manufacturing.

4.8 MODERATION ANALYSIS

A moderation analysis was conducted in order to explore whether regional and organisational contextual factors (e.g. firm size, managerial experience, geographic location) moderate the relationships between the independent variables (maintenance strategies, feed formation accuracy, and technology adoption) and operational efficiency.

4.8.1 Moderation analysis relating to the independent variables and firm size

A moderation analysis was conducted to determine whether the firm size moderates the relationships between the independent variables, including maintenance strategies, feed formation accuracy, and technology adoption, and the dependent variable (operational efficiency). The results of the moderation analysis are presented in Table 4-16.

Table 4-16: Moderation results relating to the independent variables and firm size

	Estimate	SE.β	95% confidence interval		z	p
			Lower	Upper		
MS	0.2787	0.1003	0.0747	0.4683	2.777	0.005
Size	-0.1569	0.0941	-0.3252	0.0453	-1.667	0.095
MS * SIZE	-0.0542	0.1613	-0.4609	0.1871	-0.336	0.737
FFA	0.5045	0.0763	0.352	0.6530	6.608	<.001
SIZE	-0.1301	0.0822	-0.293	0.0306	-1.582	0.114
FFA * SIZE	0.0403	0.1315	-0.203	0.3075	0.306	0.759
TA	0.4599	0.0598	0.3363	0.5706	7.69	<.001
SIZE	-0.2075	0.0754	-0.3569	-0.0535	-2.75	0.006
TA * SIZE	0.0957	0.0884	-0.0619	0.2782	1.08	0.279

Table 4-16 shows no statistically significant interactions were found with size as the moderator (0.737; 0.759, 0.279). This suggests that firm size did not moderate the relationships between

maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.

4.8.2 Moderation analysis relating to the independent variables and management years of experience

A moderation analysis was conducted to determine whether the years of managers' experience moderate the relationships between the independent variables, including maintenance strategies, feed formation accuracy, and technology adoption, and the dependent variable (operational efficiency). The results of the moderation analysis are presented in Table 4-17.

Table 4-17: Moderation results relating to the independent variables and managers' years of experience

	Estimate	SE.β	95% confidence interval		z	p
			Lower	Upper		
MS	0.2783	0.0889	0.1059	0.460	3.131	0.002
EXPERIENCE	0.0866	0.0537	-0.0150	0.198	1.612	0.107
MS * EXPERIENCE	-0.0356	0.0882	-0.2256	0.132	-0.403	0.687
FFA	0.48838	0.0773	0.3249	0.627	6.3181	<.001
EXPERIENCE	0.06011	0.0469	-0.0217	0.156	1.2830	0.199
FFA * EXPERIENCE	0.00192	0.0772	-0.1476	0.158	0.0248	0.980
TA	0.4041	0.0633	0.28846	0.547	6.383	<.001
EXPERIENCE	0.0813	0.0474	-0.00623	0.177	1.713	0.087
TA * EXPERIENCE	0.0835	0.0921	-0.08969	0.277	0.906	0.365

Table 4-17 shows that no statistically significant interactions were found with the years of experience as the moderator (0.687, 0.980, 0.365). This suggests that the number of years of experience of managers does not moderate the relationships between maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.

4.8.3 Moderation analysis relating to the independent variables and the firm's geographic location

A moderation analysis was conducted to determine whether the firm's geographic location moderates the relationships between the independent variables, including maintenance strategies, feed formation accuracy, and technology adoption, and the dependent variable (operational efficiency). The results of the moderation analysis are presented in Table 4-18.

Table 4-18: Moderation results relating to the independent variables and firm's geographic location

	Estimate	SE.β	95% confidence interval		z	p
			Lower	Upper		
MS	0.2736	0.1021	0.0823	0.4615	2.679	0.007
GEO	-0.0442	0.0464	-0.1178	0.0381	-0.952	0.341
MS * GEO	-0.0753	0.1086	-0.2487	0.1135	-0.694	0.488
FFA	0.5005	0.1009	0.345	0.750	4.958	<.001
GEO	-0.0173	0.0686	-0.119	0.148	-0.252	0.801
FFA * GEO	-0.0536	0.1155	-0.176	0.275	-0.464	0.643
TA	0.4090	0.0799	0.279	0.5817	5.118	<.001
GEO	-0.0425	0.0572	-0.137	0.0922	-0.744	0.457
TA * GEO	-0.0926	0.0857	-0.192	0.0728	-1.081	0.280

Table 4-18 shows that no statistically significant interactions were found with the firm's geographical location as the moderator (0.488, 0.643, 0.280). This suggests that the firm's geographical location does not moderate the relationships between maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.

As a result, the main findings relating to the moderation analysis are presented below:

- 19 Firm size does not moderate the relationships between maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.
- 20 The number of years of experience of managers does not moderate the relationships between maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.
- 21 Geographical location does not moderate the relationships between maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.

4.9 SUMMARY OF THE MAIN FINDINGS RELATING TO THE EMPIRICAL SECONDARY OBJECTIVES

A summary of the main findings linked to each secondary objective of the study is presented in Table 4-19.

Table 4-19: Summary of the main findings

Secondary objective 4: To compile a sample profile of the respondents who participated in the study	
Main finding 1	Majority of the sample were Operations Managers.
Main finding 2	Majority of respondents indicated that they have more than 10 years of experience.
Main finding 3	Majority of the respondents are currently employed at a medium company with 51 to 200 employees.
Main finding 4	Majority of the respondents indicated that their poultry feed mill produces 20,001 – 30,000 tons of feed.
Main finding 5	Majority of the respondents are based in South Africa.
Secondary objective 5: Determine the maintenance strategies of feed mills in Africa	
Main finding 6	Respondents agreed the most that their plant follows a structured maintenance plan.
Main finding 7	Respondents agreed the least that equipment failures significantly disrupt production.
Secondary objective 6: Determine the feed formulation accuracy of feed mills in Africa	
Main finding 8	Respondents agreed the most that their nutrient levels in formulations are accurately calculated and delivered.
Main finding 9	Respondents also agreed that they regularly optimise feed formulations to reduce costs.
Main finding 10	Respondents agreed the least that ingredient quality variability affects batch consistency.
Secondary objective 7: Determine the technology adoption of feed mills in Africa	
Main finding 11	Respondents agreed the most that they use automated systems for monitoring feed production
Main finding 12	Respondents agreed the least that predictive analytics inform their maintenance decisions
Secondary objective 8: Determine the operational efficiency of feed mills in Africa	
Main finding 13	Respondents agreed the most that their feed mill consistently meets production targets.
Main finding 14	Respondents agreed the least that they have minimal unplanned equipment downtime.
Secondary objective 9: Examine the interrelationships among maintenance strategies, feed formulation accuracy, technology adoption and operational efficiency	
Main finding 15	The measuring items used to measure the main constructs of the study are considered acceptable for further analysis
Main finding 16	Maintenance strategies do not have a positive and significant effect on operational efficiency in poultry feed manufacturing
Main finding 17	Feed formulation accuracy has a positive and significant effect on operational efficiency in poultry feed manufacturing
Main finding 18	Technology adoption does not have a positive and significant effect on operational efficiency in poultry feed manufacturing

Table 4 19: Summary of the main findings (continued)

Secondary objective 9: To explore regional and organisational contextual factors (e.g. firm size, managerial experience, geographic location) that may moderate the relationship between these practices and operational efficiency	
Main finding 19	Firm size does not moderate the relationships between maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.
Main finding 20	The number of years of experience of managers does not moderate the relationships between maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.
Main finding 21	Geographical location does not moderate the relationships between maintenance strategies, feed formation accuracy, and technology adoption and operational efficiency.

4.10 CONCLUSION

Chapter 4 presented the sample realisation rate and findings with reference to respondents' perceptions of maintenance strategies, feed formation accuracy, technology adoption, and operational efficiency in their feed mills. In addition, the results of the statistical analysis were reported, including the frequencies and percentages, means and standard deviations, Cronbach's Alpha coefficients, and overall mean scores.

Furthermore, a standard multiple regression analysis was conducted to test the proposed theoretical framework and formulated hypotheses. Lastly, a moderation analysis was conducted to determine if regional and organisational contextual factors, such as firm size, managerial experience and geographic location, moderate the relationships between the independent variables (maintenance strategies, feed formation accuracy, and technology adoption) and operational efficiency.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

Chapter 5 concludes with an overview of the study, a summary of the main findings from the literature review in Chapter 2 and the empirical results presented in Chapter 4. The differences between the theoretical insights and the practical realities observed are integrated in these sections. The study's primary and secondary objectives are subsequently evaluated to assess whether each has been achieved. Finally, the chapter ends with industry recommendations and suggestions for future studies, aimed at improving operational efficiency in African poultry feed manufacturing.

5.2 OVERVIEW OF THE STUDY

Africa's growing population and the increasing preference for cost-effective protein sources have led to a substantial rise in the demand for poultry products (Faye *et al.*, 2025:6; Kleyn & Ciacciariello, 2021:268). To address the growing demand coupled with the high volume of poultry imports, research efforts should be aimed at strengthening local production and narrowing the supply gap (Morgan & Farris, 2024). The feed manufacturing industry is the focal point of local poultry production, considering that feed accounts for approximately 70% of total poultry production costs (Nkukwana, 2018:870; Stark & Fahrenholz, 2017:1). Operational inefficiencies and limited resources within the poultry feed production sector have highlighted the need to assess and improve production performance (Amin & Sobhi, 2023:1; Andam *et al.*, 2017; Nafea *et al.*, 2025:1). The goal of this sector is to reduce feed costs and waste while striving to narrow the demand–supply gap in poultry products across Africa.

Poultry feed manufacturing involves a series of complex and interdependent processes which can be prone to inefficiencies and wastages at different stages of production (Nafea *et al.*, 2025:35; Shrinivasa & Mathur, 2020; You *et al.*, 2024:643). This study addressed these challenges by setting a primary objective of assessing the influence of maintenance strategies, feed formulation accuracy, and technology adoption on operational efficiency within African poultry feed manufacturing. To support the achievement of this primary objective, ten secondary objectives were formulated to guide and focus the research process.

5.3 FINDINGS OF THE LITERATURE REVIEW

The following sections present the key findings from the literature review, empirical results and main conclusions and provide recommendations drawn in relation to the study's objectives.

5.3.1 Market overview

The global feed manufacturing industry continues to grow, with poultry feed accounting for almost half of total feed production worldwide (Alltech, 2025; Feed Additive, 2025). This highlights poultry feed's pivotal role within the agricultural sector and its vital contribution to food security. The rising demand for poultry products is the primary driver of this growth, as these products are gaining popularity among consumers for their relatively affordability, accessibility, and perceived health benefits (Morgan & Farris, 2024; Tabler *et al.*, 2021:2). The preference for poultry as a protein source has been further solidified by urbanisation, higher disposable incomes, and broad cultural and religious acceptance (Ncube *et al.*, 2016:1; Tabler *et al.*, 2021:2). Despite this global momentum, Africa contributes a mere 4% of total feed production, highlighting both the limited contribution and substantial opportunity for growth in this market (Alltech, 2024). Increasing Africa's market share in global feed product will require targeted investment in local feed manufacturing, with a specific focus on improving operational efficiency (Amin & Sobhi, 2023:1).

5.3.2 Poultry value chain

The poultry value chain highlights the vital role feed plays throughout all production stages. Grandparent stock, parent stock, and broilers each have unique nutritional needs that support their specific production goals (Baghli *et al.*, 2024:3). Grandparent and parent stock have longer lifespans and, therefore, require specialised feed formulations that place emphasis on the nutrients that maintain their health, fertility, and productivity over time (Kakon *et al.*, 2024:48). Losses of birds at these levels due to insufficient nutrition can disrupt the entire chain by reducing chick availability and overall production. In contrast, broilers have short lifespans and require high-energy, nutrient-dense feed to achieve rapid growth and reach market weight in an efficient manner (Junghans *et al.*, 2022:1). Feed is a critical input at every stage of production, influencing bird performance, egg and meat output, and the profitability of poultry operations (Ramankevich *et al.*, 2025:1).

5.3.3 Operational efficiency

Operational efficiency is the ability of organisations to maximise outputs while minimising inputs through optimising the use of resources (Dilshani *et al.*, 2019:46). Operational efficiency depends largely on sustaining equipment uptime to ensure uninterrupted production and optimal performance (Magrini, 2024:8). Of equal importance is the reduction of waste across all stages of production which can be achieved through improved process control and resource utilisation (Taher & Bashar, 2024:339). The optimisation of these factors can increase production volumes without proportional cost growth, which will enable an organisation to achieve economies of scale (Healey, 2015:2). Together, extended equipment uptime, reduced waste, and scale efficiencies

enhance productivity, lower unit costs, and strengthen overall operational efficiency within feed manufacturing (Adeyeye *et al.*, 2025:237; Folorunso *et al.*, 2024:33).

5.3.4 Maintenance strategies

Literature categorised maintenance into two main approaches: proactive and reactive (Gackowiec, 2019:132; Hamasha *et al.*, 2023:3). Proactive maintenance, which includes preventive, condition-based, predictive, and TPM practices, aims to extend equipment lifespan, minimise downtime, and improve overall operational efficiency (Habeeb, 2025:2). Conversely, reactive maintenance is implemented only after equipment failure and often results in increased downtime, higher repair costs, and reduced production efficiency (Ewin & Oye, 2025:1). The findings of this literature review confirmed the hypothesis (H_{1a}) that maintenance strategies have a positive and significant effect on operational efficiency in poultry feed manufacturing (Ewin & Oye, 2025:1). This reinforces the importance of structured and proactive maintenance strategies in enhancing reliability, productivity, and cost performance within feed production environments (Ewin & Oye, 2025:19).

5.3.5 Feed formulation accuracy

Breeding programmes across the poultry value chain are complex and require precise feed formulation to meet the different nutritional needs of each bird type (Baghli *et al.*, 2024:3). Resources are often scarce and expensive; therefore, formulation accuracy can be considered as a strategic tool to optimise resource use and reduce waste (Andam *et al.*, 2017:21; Wongnaa *et al.*, 2023:1). Accuracy in formulation techniques also ensures consistent, high-quality feed at lower cost while maintaining bird health and supporting sustainable poultry production (Betangcor *et al.*, 2024:41). In addition, formulation accuracy affects equipment performance (Tillman *et al.*, 2020:163) due to inaccurate ingredient quantities altering feed composition, making it more difficult to process and subsequently increasing production time and costs (Tillman *et al.*, 2020:163). The findings of this literature review confirmed the hypothesis (H_{1b}) that feed formulation accuracy has a positive and significant effect on operational efficiency, highlighting feed formulation's critical role in driving productivity and containing cost (Tillman *et al.*, 2020:169).

5.3.6 Technology adoption

To remain relevant and competitive in today's rapidly evolving environment, organisations must continuously adapt to integrate new technologies into their workflows (Kumar, 2024:1). Literature shows that process automation enhances production speed, product quality, and traceability while reducing errors and defects (Tabaku *et al.*, 2025:2324). Technological tools that support proactive maintenance strategies can assist in minimising equipment downtime and maintenance costs

(Martinez *et al.*, 2024:2). The accuracy and speed of feed formulation can be improved using specialised software, producing more cost-effective feed by optimising resource use and reducing waste (Akintan *et al.*, 2024:2). Despite these proven benefits, high implementation costs and user-adoption challenges limit the rate of technology adoption (Taher & Bashar, 2024:345). The findings of this literature review supported Hypothesis (H_{1c}), indicating that technology adoption positively and significantly influences operational efficiency in poultry feed manufacturing (Akintan *et al.*, 2024:2; You *et al.*, 2024:644). This underscores technology adoption's role as a key driver of productivity and competitiveness within the sector.

5.4 FINDINGS OF THE EMPIRICAL RESULTS

5.4.1 Sample realisation conclusion

The targeted 150 responses across eight African countries were not achieved, with the lower response rate likely attributed to the industry's reluctance to participate in a competitive market. Although anonymity was assured, some potential respondents were uneasy about engaging in a study led by an employee of a rival company, given the competitive nature of this industry. In addition, each feed mill typically has only one maintenance and one operations manager, limiting the number of possible participants and therefore, creating a perceived risk of a confidentiality breach. These structural and competitive factors suggest a broader hesitation within the industry to share information or collaborate, reflecting a limited collective commitment to sector-wide improvement and knowledge development.

5.4.2 Findings of the data analysis for maintenance strategies

The statement "Our plant follows a structured maintenance plan" showed the highest level of agreement within this section, indicating that most respondents apply a systematic approach to maintenance. Conversely, the lowest level of agreement was observed for the statement "Equipment failures significantly disrupt production.", despite literature's confirmation that equipment failures have a major impact on production operations. This contrasting finding may suggest that respondents interpreted the statement within the context of their own facilities. Since many respondents reported that they follow structured maintenance plans, they may not experience frequent failures and, therefore, did not experience many equipment failures and operation disruption. The lower level of agreement with the general statement would be explained by this interpretation bias. The measurement scales for this construct were adapted from existing literature and yielded a Cronbach's alpha coefficient of 0.664, falling slightly below the conventional threshold of 0.7. This Cronbach's alpha value still reflects moderate internal consistency among items, and the construct was, therefore, deemed acceptable for further analysis. The regression analysis revealed that hypothesis H_{1a} : Maintenance strategies have a

positive and significant effect on operational efficiency in African poultry feed manufacturing was not supported. This finding contradicts the literature, which consistently reports a significant positive relationship between structured maintenance strategies and operational efficiency. Further investigation is warranted on the effect of maintenance strategies on operational efficiency within the context of the poultry feed manufacturing industry in Africa.

5.4.3 Findings of the data analysis for feed formulation accuracy

The statement “Nutrient levels in formulations are accurately calculated and delivered”, held the highest level of agreement in this section. This suggests that respondents adjust their formulation practices to align with the quality of available raw materials, with the aim of ensuring accuracy in nutrient composition. This approach may also explain the lower level of agreement with the statement “Ingredient quality variability affects batch consistency.” This shows that because respondents report that they formulate accurately based on the quality of the raw materials they receive, they are less likely to experience variability that affects batch consistency.

The measurement scales for this construct were adapted from existing literature and yielded a Cronbach’s alpha coefficient of 0.663, which is slightly below the conventional threshold of 0.7. This value Cronbach’s alpha indicates moderate internal consistency among the items, and the construct was, therefore, deemed acceptable for further analysis.

Regression analysis supported the hypothesis H_{1b} : Feed formulation accuracy has a positive and significant effect on operational efficiency in African poultry feed manufacturing. This finding aligns with the literature, which identified accurate feed formulation as a critical determinant of operational efficiency due to its impact on resource optimisation, production consistency, waste and cost reduction.

5.4.4 Findings of the data analysis for technology adoption

The measurement scales for technology adoption were adapted from existing literature and yielded a Cronbach’s alpha coefficient of 0.778 which exceeds the conventional threshold of 0.7, and therefore, confirms good internal reliability. There was low variability within the responses, with most participants indicating that they use automated systems to monitor feed production processes. This finding aligns with the literature around automation that reports that automation enhances product quality, process control, and overall operational efficiency. The lowest level of agreement was recorded for the statement assessing the use of predictive analytics to inform maintenance decisions. This suggests that although automation is present, organisations have not yet fully integrated advanced data-driven technologies into their maintenance strategies. Maintenance departments should, therefore, consider investing in predictive analytics tools to

reduce unplanned downtime, enhance decision-making, and further improve operational efficiency.

5.4.5 Findings of the data analysis for operational efficiency

The measurement scales for operational efficiency were adapted from existing literature and yielded a Cronbach's alpha coefficient of 0.714, surpassing the threshold of 0.7 and confirming acceptable internal reliability. There was low variability within the responses, with most participants indicating that their feed mills consistently meet production targets. This outcome may reflect the influence that structured maintenance planning and accurate feed formulation has on supporting consistent production performance. In contrast, the lowest level of agreement was recorded for the statement regarding minimal unplanned equipment downtime, which suggests that respondents do still experience occasional breakdowns. Unplanned downtime cannot be eliminated entirely, however, the participants response to their experienced unplanned equipment downtime represents an opportunity for improvement. These improvements can be implemented by transitioning from structured maintenance planning to a model that includes the use predictive analytics—an area that received low emphasis among respondents—which could enhance equipment reliability and strengthen overall operational efficiency.

However, hypothesis H_{1c} : Technology adoption has a positive and significant effect on operational efficiency in poultry feed manufacturing, was not supported by the regression analysis results. This finding contrasts the literature, which reports technology adoption as a critical enabler of operational efficiency due to its ability to improve accuracy, reduce waste, and enhance process reliability. This discrepancy suggests that technological tools are being implemented at a basic level, however, there is limited integration of these tools into core operational and maintenance processes. This warrants further investigation on the effect of technology adoption on operational efficiency within the poultry feed manufacturing sector.

5.4.6 Findings of the moderation analysis

There were no significant interaction effects between years of employment, company size, and geographic location. This indicates that these organisational and demographic factors did not have a significant moderating influence on the relationships between maintenance strategies, feed formulation accuracy, technology adoption, and operational efficiency. This suggests that the key drivers of operational efficiency operate similarly across feed mills, and are not influenced by mill size, location, or managerial tenure. This finding implies that improving efficiency within the African poultry feed manufacturing sector is more dependent on the effective implementation of operational practices rather than on contextual or demographic differences.

5.5 ACHIEVEMENT OF OBJECTIVES

5.5.1 Achievement of the primary objective

This section presents conclusions that were drawn based on both the theoretical background and the empirical results. The **primary objective** of the study was to determine the influence of maintenance strategies, feed formulation accuracy, and technology adoption on operational efficiency in African poultry feed manufacturing.

Chapter 2's literature review provided a clear report that maintenance strategies, feed formulation accuracy and technology adoption influence operational efficiency in poultry feed manufacturing. However, the results obtained from the multiple regression analysis revealed varying levels of influence among these constructs on operational efficiency. Feed formulation accuracy demonstrated the strongest positive effect on operational efficiency and showed to be a statistically significant relationship. Technology adoption showed a positive yet just non-significant effect, suggesting that while literature reports that technological integration supports efficiency, its full potential is yet to be realised within the studied sector. Maintenance strategies exhibited a weaker and statistically non-significant effect, indicating that current maintenance practices may not yet be sufficiently advanced to drive measurable improvements in efficiency in this sample.

The objective of determining the influence of these constructs on operational efficiency was successfully achieved through the use of regression analysis. The findings provide valuable insight into the relative importance of each factor and highlight the areas that hold potential to improve operational performance within African poultry feed manufacturing.

5.5.2 Achievement of the secondary objectives

Ten secondary objectives have been formulated for this study and are addressed in subsequent sections.

5.5.2.1 Theoretical secondary objectives

The study was guided by the following theoretical objectives, as presented in Table 5-1:

Table 5-1: Theoretical secondary objectives

Secondary objectives:	Description
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Theoretical secondary objectives:

Objective 1	Conduct a literature review on the African poultry feed manufacturing industry.
Objective 2	Conduct a literature review on the Resource-Based-View
Objective 3	Conduct a literature overview about the key constructs of this study, namely operational efficiency, maintenance strategies, feed formulation accuracy and technology adoption.

Chapter 2's literature review provided an overview of the global poultry feed market and then proceeded to narrow focus to Africa's market share and the industry's role in supporting food security across the continent. The poultry value chain was examined and the importance of feed within poultry production was demonstrated along with its direct influence on market supply. The chapter also discussed the theoretical foundation of the study and each of the main constructs, namely operational efficiency, maintenance strategies, feed formulation accuracy, and technology adoption. The following hypotheses were developed using the insights derived from the literature review:

H_{1a}: Maintenance strategies have a positive and significant effect on operational efficiency in poultry feed manufacturing.

H_{1b}: Feed formulation accuracy has a positive and significant effect on operational efficiency in poultry feed manufacturing.

H_{1c}: Technology adoption has a positive and significant effect on operational efficiency in poultry feed manufacturing.

In conclusion, the evidence presented confirms that the first, second and third secondary objective of the study has been achieved.

5.5.2.2 Empirical secondary objectives

The empirical data analysis was guided by the following objectives, as presented in Table 5-2:

Table 5-2: Empirical secondary objectives

Secondary objectives:	Description
Empirical secondary objectives	
Objective 4	To compile a sample profile of the respondents who participated in the study.
Objective 5	Determine the maintenance strategies of feed mills in Africa.
Objective 6	Determine the feed formulation accuracy of feed mills in Africa.
Objective 7	Determine the technology adoption of feed mills in Africa.
Objective 8	Determine the operational efficiency of feed mills in Africa.
Objective 9	Examine the interrelationships among maintenance strategies, feed formulation accuracy, technology adoption and operational efficiency.
Objective 10	To explore regional and organisational contextual factors (e.g. firm size, managerial experience, geographic location) that may moderate the relationship between these practices and operational efficiency.

Objective 4 was addressed by collecting demographic and organisational data from the survey responses. This data was used to compile descriptive statistics to develop a comprehensive profile of the respondents. The analysis included variables such as current job role, years of experience within the poultry feed manufacturing industry, organisational size (measured by number of employees and annual production volume in tons), and the geographic location of each organisation.

The results showed that majority respondents held the position of Operations Manager (39.5%), followed by Senior Executives (17%) and Maintenance Managers (16%). Most participants reported having more than ten years of experience in the poultry feed manufacturing industry, followed by those with seven to ten years (19.8%) and four to six years (13.6%) of experience. Majority of respondents were employed at medium-sized companies (51–200 employees), closely followed by those in large feed mills (more than 201 employees). In terms of production capacity, most respondents indicated that their feed mills produce 20,001–30,000 tons per year (28.4%), followed by 5,001–10,000 tons (27.2%) and 10,001–20,000 tons (19.8%). Geographically, majority of respondents (86.4%) were based in South Africa, with the remainder representing other African countries. Objective 4 was successfully achieved through these findings.

To address **Objective 5**, descriptive statistics from the questionnaire indicated that most participants agreed that their organisations follow a structured maintenance plan, which suggests

the presence of formalised maintenance practices across several feed mills. Interestingly, respondents agreed least with the statement that unplanned equipment failures significantly disrupt production time. This response could either imply that structured maintenance plans have assisted in reducing the frequency and impact of equipment failures, or alternatively, that respondents simply perceive breakdowns as part of routine operations. Considering these insights, Objective 5 was achieved.

With regard to **Objective 6**, the results showed strong agreement with the statement “Nutrient levels in formulations are accurately calculated and delivered.” This finding suggests that respondents’ feed formulation processes within their organisations is perceived as both accurate and quality-driven, confirming that Objective 6 was achieved.

The results pertaining to **Objective 7** indicated that most respondents agreed that they use automated systems to monitor feed production processes, but few respondents reported using predictive analytics to inform maintenance decisions. This suggests that while automation is in place, the adoption of advanced data-driven technologies remains limited, achieving Objective 7.

For **Objective 8**, majority of respondents agreed that production targets are consistently met, yet there was lower agreement with the statement regarding minimal unplanned equipment downtime. This aligns with findings under maintenance strategies, where respondents downplayed the disruption caused by equipment failures. Together, these responses suggest that although feed mills generally perform well, they do still face unplanned downtime that could be mitigated through more predictive and technology-supported maintenance practices. Hence, Objective 8 was achieved, and highlights areas for future studies.

To address **Objective 9**, the relationships among maintenance strategies, feed formulation accuracy, technology adoption, and operational efficiency were examined using a standard multiple regression analysis. The results of this analysis indicated that feed formulation accuracy had the strongest positive and significant effect on operational efficiency ($\beta = 0.386$, $p < 0.001$), followed by technology adoption, which showed a positive but just non-significant effect ($\beta = 0.241$, $p = 0.056$). Maintenance strategies exhibited a weaker and statistically non-significant effect ($\beta = 0.144$, $p = 0.170$) on operational efficiency. These findings suggest that formulation accuracy plays a critical role in improving efficiency, while technology adoption contributes moderately and maintenance strategies exert a limited influence on operational efficiency. Hence, Objective 9 was achieved.

Finally, to address **Objective 10**, contextual factors such as firm size, number of employees, or geographic location were assessed as to whether they influenced the relationships between maintenance strategies, feed formulation accuracy, technology adoption, and operational

efficiency. This assessment was completed using a moderation analysis. The results revealed no significant moderating effects existed between the variables, indicating that these relationships remain consistent regardless of organisational or regional differences. Therefore, Objective 10 was achieved.

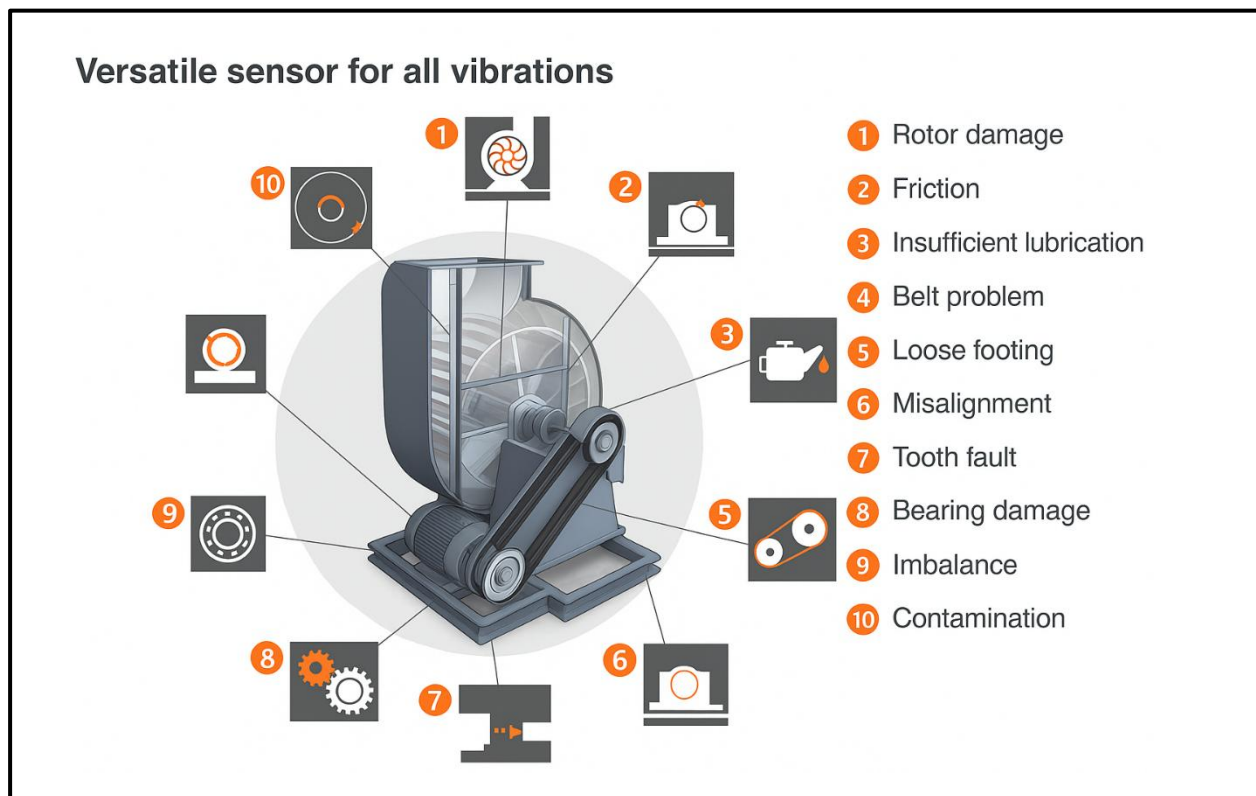
In summary, all research objectives were achieved. The contrasting results between theory and practice underscore the complexity of achieving operational efficiency in African poultry feed manufacturing and highlight areas requiring further investigation.

5.6 RECOMMENDATIONS

This section presents recommendations based on the study's key constructs and empirical results. The recommendations focus on enhancing operational efficiency within African poultry feed manufacturing by addressing their maintenance strategies, feed formulation accuracy, and technology adoption. The recommendations will place emphasis on strengthening maintenance practices to reduce unplanned downtime, improving formulation accuracy to minimise waste and production costs while upholding quality, and advancing technological adoption to support data-driven decision-making and overall process optimisation.

5.6.1 Recommendations for maintenance strategies

Although results revealed that most feed mills have structured maintenance plans, these strategies should be expanded to include proactive, predictive, and TPM measures. Predictive maintenance allows early detection of faults through real-time monitoring and data analysis (Habeeb, 2025:6; Lee *et al.*, 2019:507). Feed mills should use predictive tools such as vibration monitors and temperature sensors that is linked to programmable logic controllers (automated processors) to identify when equipment performance deviates from normal conditions (Habeeb, 2025:6). Automated alerts can then notify maintenance teams to act before failures occur. Condition-monitoring (predictive) devices are available from industry suppliers such as IFM Electronic. Figure 5-1 illustrates the range of operational parameters and diagnostic features that these devices can measure and display.

Figure 5-1: IFM condition monitoring elements

Source: IFM Electronic (2025).

These measures will assist in reducing unplanned downtime, extend equipment lifespan, and lower maintenance and replacement costs (Ahuja & Gupta, 2024:290). In conjunction to this, TPM should be implemented by training operators to perform simple daily checks such as cleaning, greasing, and inspecting equipment (Habeeb, 2025:6). This approach creates a shared responsibility and encourage continuous improvement for both machines and employees (Habeeb, 2025:6).

By combining predictive systems with TPM, feed mills can build a proactive maintenance culture that improves reliability, stability, and overall operational efficiency (Karim, 2025:176).

5.6.2 Recommendations for feed formulation accuracy

Most respondents indicated that nutrient levels are accurately calculated and delivered, reflecting a solid foundation in feed formulation practices. To strengthen this further, it is recommended that feed manufacturers integrate artificial intelligence (AI) systems into their formulation processes (Martinez *et al.*, 2024:2). These AI-driven technologies enable real-time optimisation by analysing extensive data around ingredient quality, bird performance, environmental conditions, and production parameters (Martinez *et al.*, 2024:2). Using this real-time data, these technologies are

able to continuously adjust nutrient compositions in response to changing conditions, ensuring consistency, precision, and improved feed efficiency (Martinez *et al.*, 2024:2).

The application of AI-based formulation can contribute to the improved operational efficiency and sustainability of feed manufacturers by reducing over-formulation, minimising ingredient waste, enhancing batch uniformity, and lowering production costs (Arteaga-Cabrera *et al.*, 2025:16). Implementation should start with pilot testing of AI modules and formulation, and technical teams should be trained to interpret and apply AI-generated recommendations. Key performance indicators such as feed cost per ton, nutrient accuracy, and batch variability, should be monitored to evaluate the model's impact on the formulation process (Klenam *et al.*, 2025:8). Once proven effective, AI-driven formulation systems can be scaled across facilities to promote precision manufacturing and strengthen competitiveness in the poultry feed industry.

AI-driven formulation software is offered by companies such as BESTMIX®, highlighting how artificial intelligence is transforming the feed industry through improved precision, efficiency, and cost optimisation (Verstrepen, 2025).

5.7 LIMITATIONS OF THIS STUDY

Apart from the limitations discussed in Chapter 3, additional limitations were identified during the execution of this research.

- The study included participants from several African countries, but most responses came from South Africa. This uneven distribution limits how widely the findings can be applied to the general population. Operating environments, infrastructure, and resource availability differ greatly across regions, which may influence how the results translate to other African contexts.
- There is a limited number of suitably qualified respondents within feed mills. Most facilities employ only one maintenance or operational manager, which can significantly restrict the pool of participants with the necessary technical knowledge. As a result, there is an inherently lower population size from which a sample size can be drawn of individuals directly responsible for maintenance activities. This can lead to a potential imbalance between operational, production, and maintenance perspectives. This constraint may have reduced the diversity and depth of insights regarding the influence of maintenance strategies on operational efficiency.
- Differences in respondents' professional backgrounds may have introduced bias. Maintenance personnel tend to focus on equipment reliability, while nutritionists and formulators placed greater emphasis on feed composition and accuracy. As a result,

participants often prioritised aspects most relevant to their field of expertise. This may have influenced the balance of responses across the study's constructs.

- No validated instrument existed to measure maintenance strategies, feed formulation accuracy, technology adoption, and operational efficiency within the context of African poultry feed manufacturing. To accommodate for this, the questionnaire was adapted from literature and scales used in broader operations studies. The instrument showed acceptable internal reliability, however, the absence of a fully standardised and validated scale may have affected the validity and comparability of the findings. Adjustments made for contextual relevance might also have led to different interpretations among respondents, especially between those with technical (maintenance) and nutritional (formulation) backgrounds. Future research should focus on developing and validating a measurement scale that is specific to the poultry feed manufacturing industry to improve reliability and replicability.

5.8 RECOMMENDATIONS FOR FUTURE RESEARCH

Future research should focus on developing a validated measurement scale that accurately captures the influence of maintenance strategies, feed formulation accuracy, and technology adoption on operational efficiency within the poultry feed manufacturing industry. A reliable, industry-specific tool is needed to strengthen construct validity and ensure consistent interpretation across different technical roles and organisations.

This study found no statistical significance between maintenance strategies or technology adoption and operational efficiency. This contradicts the literature, which strongly supports the positive impact both maintenance strategies and technology adoption has on operational efficiency. Further studies should, therefore, re-examine these relationships using larger, more diverse samples and participants that possess direct expertise in the fields of maintenance and engineering. Increasing the number of respondents and the number of African regions will also enhance representativeness and comparability.

Finally, future research should deepen the understanding of how maintenance and technology practices contribute to feed production stability and expand into the ultimate goal of food security. By adding to the knowledge base that bridges the gap between theory and practice, such studies can help the African poultry feed industry evolve toward more efficient, sustainable, and resilient operations.

5.9 CONCLUSION

The primary purpose of this chapter was to present the conclusions drawn from the literature review and the empirical investigation. The discussion summarised the key constructs analysed in Chapter 4 and compared the results with existing research in the literature review. This chapter assessed whether or not the study's primary and secondary objectives were achieved and provided practical recommendations to the poultry feed manufacturing sector that will guide them in enhancing operational efficiency. Finally, this chapter identified areas for future research to be conducted to address the limitations encountered in this study and to further strengthen understanding of the relationships between maintenance strategies, feed formulation accuracy, technology adoption, and operational efficiency in Africa.

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ANNEXURE A: SURVEY INSTRUMENT

Demographic and Organisational Information

2.1 What is your current job role?

- ☐ Operations Manager
- ☐ Maintenance Manager
- ☐ Technical Advisor
- ☐ Senior Executive
- ☐ Other (please specify): _____

2.2 How many years of experience do you have in the poultry feed manufacturing industry?

- ☐ Less than 1 year
- ☐ 1–3 years
- ☐ 4–6 years
- ☐ 7–10 years
- ☐ More than 10 years

2.3 What is the size of your poultry feed mill (by number of employees)?

- ☐ Small (1–50 employees)
- ☐ Medium (51–200 employees)
- ☐ Large (201+ employees)

2.4 Approximately how many tons of feed does your facility produce per month?

- ☐ Less than 1,000 tons
- ☐ 1 001 – 5,000 tons
- ☐ 5,001 – 10,000 tons
- ☐ 10,001 – 20,000 tons
- ☐ 20,001 – 30,000 tons
- ☐ More than 30,000 tons

2.5 In which country is your company primarily based?

- ☐ South Africa
- ☐ Nigeria
- ☐ Kenya
- ☐ Ghana
- ☐ Other (please specify): _____

ANNEXURE A: SURVEY INSTRUMENT (CONTINUED)

Operational Efficiency (Dependent Variable)

Definition: Operational efficiency refers to the ability of a feed mill to maximise output while minimising input costs and waste, measured through performance indicators such as downtime, throughput, and cost per tonne.

Instruction: Please rate your agreement with the following statements on a scale from 1 (Strongly Disagree) to 5 (Strongly Agree).

Statement	1	2	3	4	5
3.1 Our feed mill consistently meets production targets.	☐	☐	☐	☐	☐
3.2 We have minimal unplanned equipment downtime.	☐	☐	☐	☐	☐
3.3 Production processes are well-optimised to reduce waste.	☐	☐	☐	☐	☐
3.4 We effectively manage input costs (e.g., energy, materials, labour).	☐	☐	☐	☐	☐
3.5 The cost per tonne of feed produced is competitive.	☐	☐	☐	☐	☐

Maintenance Strategies (Independent Variable 1)

Definition: Maintenance strategy refers to the approach used to ensure the reliability and performance of machinery, including preventive, predictive, and autonomous maintenance practices.

Statement	1	2	3	4	5
4.1 Our plant follows a structured maintenance plan.	☐	☐	☐	☐	☐
4.2 Preventive maintenance is carried out on a regular basis.	☐	☐	☐	☐	☐
4.3 We use condition-monitoring tools or sensors to predict failures.	☐	☐	☐	☐	☐
4.4 Operators are trained to perform basic maintenance tasks.	☐	☐	☐	☐	☐
4.5 Equipment failures significantly disrupt production.	☐	☐	☐	☐	☐

ANNEXURE A: SURVEY INSTRUMENT (CONTINUED)

Feed Formulation Accuracy (Independent Variable 2)

Definition: Feed formulation accuracy refers to the consistency, precision, and cost-effectiveness of feed composition as per nutritional and production requirements.

Statement	1	2	3	4	5
5.1 Feed batches are consistent in composition and quality.	☐	☐	☐	☐	☐
5.2 We regularly optimise feed formulations to reduce costs.	☐	☐	☐	☐	☐
5.3 Ingredient quality variability affects batch consistency.	☐	☐	☐	☐	☐
5.4 Nutrient levels in formulations are accurately calculated and delivered.	☐	☐	☐	☐	☐
5.5 Our feed formulation system is automated or digitally supported.	☐	☐	☐	☐	☐

Technology Adoption (Independent Variable 3)

Definition: Technology adoption in this context includes the use of digital tools, automation, IoT, AI, and data analytics in feed mill operations.

Statement	1	2	3	4	5
6.1 We use automated systems for monitoring feed production.	☐	☐	☐	☐	☐
6.2 Predictive analytics inform our maintenance decisions.	☐	☐	☐	☐	☐
6.3 Technology adoption has improved our overall efficiency.	☐	☐	☐	☐	☐
6.4 Our staff are trained to use modern technologies effectively.	☐	☐	☐	☐	☐
6.5 Investment in technology is a strategic priority in our organisation.	☐	☐	☐	☐	☐

Organisational Practices and Culture

Statement	1	2	3	4	5
7.1 Continuous improvement is encouraged by leadership.	☐	☐	☐	☐	☐
7.2 Staff are empowered to suggest efficiency improvements.	☐	☐	☐	☐	☐
7.3 Maintenance is viewed as a strategic function, not just operational.	☐	☐	☐	☐	☐

ANNEXURE B: CONSENT FORM

Dear Participant,

You are invited to participate in a research study conducted in fulfilment of the requirements for a Master of Business Administration (MBA) degree at the North-West University (NWU) Business School. The study investigates key factors influencing operational efficiency in the African poultry feed manufacturing sector, with a specific focus on maintenance strategies, feed formulation accuracy, and technology adoption.

Please read the information below carefully before deciding whether to participate. Should you have any questions, you are encouraged to contact the researcher.

Participation in this study is entirely voluntary. You may decline to participate or withdraw at any time without penalty or explanation.

This study has received ethical clearance from the NWU Economic and Management Sciences Research Ethics Committee (EMS-REC) and complies with both the NWU's research ethics policy and international ethical standards for social science research.

Project Information

Title of the study: **Evaluating the Influence of Maintenance Strategies and Feed Formulation Practices on Operational Efficiency in African Poultry Feed Manufacturing**

Institution: North-West University (NWU) Business School

Ethics Reference Number: NWU-00670-25-S4

Principal Investigator: Prof Leenta Grobler – leenta.grobler@nwu.ac.za | +27 82 878 5894

Researcher: Ms Carien Orton – corton@cbh.africa | +27 71 881 2930

Purpose of the Study

This study aims to examine how maintenance strategies (including Total Productive Maintenance and predictive maintenance), feed formulation accuracy, and technology adoption affect operational efficiency in poultry feed mills. The research intends to offer practical insights for feed mill managers, technical personnel, and policymakers across Africa.

ANNEXURE B: CONSENT FORM (COTNINUED)

What is Expected from You

If you agree to participate, you will be asked to:

- Complete a structured online survey lasting approximately 10–15 minutes.
- Provide honest and accurate responses based on your professional experience and knowledge.
- Respond to both closed-ended (multiple choice, Likert scale) and a few open-ended questions.

Confidentiality and Data Protection

- This study is completely anonymous. No personally identifiable information will be collected.
- Your responses will be aggregated and analysed statistically. Individual responses cannot and will not be traced.
- All data will be securely stored on password-protected systems and used solely for academic research purposes.
- The research team will manage data in compliance with the Protection of Personal Information Act (POPIA), Act No. 4 of 2013, and the NWU Research Ethics Policy.
- The anonymous data may be accessed by designated NWU personnel for monitoring and auditing purposes.

Voluntary Participation and Right to Withdraw

Participation is voluntary and refusal to take part will not result in any penalty or disadvantage. Because the survey is anonymous, once submitted, data cannot be withdrawn or linked back to the participant.

Declaration and Consent

By selecting “Yes” below, you confirm the following:

- I have read and understood the information provided regarding this study.
- I understand what is expected of me and voluntarily agree to participate.
- I understand that the study is anonymous and that my data, once submitted, cannot be withdrawn.
- I understand that authorised personnel may access the anonymised data for quality assurance and ethical oversight.

Do you consent to participate in this study?

Yes, I agree to participate.

No, I do not agree to participate.

ANNEXURE C: CONFIRMATION OF TECHNICAL EDITING

LEON DU PREEZ
TECHNICAL EDITING

Dr Leon du Preez
Senior Lecturer
North-West University
Potchefstroom
2531

19 November 2025

To whom it may concern:

DECLARATION OF TECHNICAL EDITING

This letter verifies that I, Dr Leon du Preez, did the technical editing of Mrs C Orton's mini-dissertation entitled: *"Assessing the influence of maintenance strategies and feed formulation practices on operational efficiency in African poultry feed manufacturing"* for the degree Master of Business Administration at the North-West University. The document has been edited (formatted) in accordance with the technical requirements of the North-West University as set out in the Manual for Higher Degrees Studies and Referencing Guide (NWU Harvard 2020). Notwithstanding, the editor's revisions are recommendations, and as such the implementation thereof remains the responsibility of the author. In addition, the editor will not be responsible for any changes made after the date of issue.

Furthermore, the editor shall not be held responsible for the grammatical correctness of the document, nor for the accuracy of its content. Responsibility for these aspects remains solely with the author.

Sincerely,



Dr Leon du Preez

ANNEXURE D: CONFIRMATION OF LANGUAGE EDITING



PikBioStat

Statistical Solutions

18 November 2025

Certificate of Proofreading and Editing

**This is to Certify That
Carlen Orton (student number 20252749)**

has received Proofreading and Editing Services from PikBioStat

This certifies that the dissertation titled

**“Assessing the influence of maintenance strategies and feed formulation
practices on operational
efficiency in African poultry feed manufacturing.”**

submitted in partial fulfilment of the requirements for the
Master of Business Administration (MBA)
degree has been professionally proofread and edited for
grammar, spelling, punctuation, structure, and overall readability.

Date of Completion: 18 November 2025

Kelsi Greenwood, MSc

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