DURBAN UNIVERSITY OF TECHNOLOGY

UTILISING FMEA TO IMPROVE THE RELIABILITY OF PACKAGING EQUIPMENT: THE CASE OF PACKAGING EQUIPMENT AT PEPSICO DURBAN

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by

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A MINI DISSERTATION SUBMITTED IN PARTIAL REQUIREMENT FOR THE MBA DEGREE AT THE DURBAN UNIVERSITY OF TECHNOLOGY, UNDER THE FACULTY OF MANAGEMENT SCIENCES, DUT BUSINESS SCHOOL

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ABSTRACT

The study aimed to enhance the reliability of packaging equipment at PepsiCo Durban using Failure Mode and Effects Analysis (FMEA). The focus is on mitigating unplanned stoppages in the packaging hall, which has led to significant waste of potato chips due to equipment failures. The research addresses the need for proactive maintenance strategies within the Fast-Moving Consumer Goods (FMCG) industry, emphasising the importance of sustainable practices in manufacturing.

The methodology used a mixed-method approach, including document analysis of maintenance records, thematic analysis to identify patterns and critical failure modes and interviews with the maintenance team. The study evaluated the implementation of audit findings from ISO 9001 and the PepsiCo Europe Maintenance Methodology (PEMM). By integrating FMEA within the existing quality management framework, the research developed a comprehensive strategy to improve equipment reliability and reduce operational inefficiencies. This approach aligns with Sustainable Development Goals, particularly those related to responsible consumption, climate action, and life on land.

Overall, the study provides insights into improving operational sustainability using FMEA in enhancing packaging process reliability, ultimately contributing to the reduction of packaging waste and promoting environmental stewardship.

The study identified critical failure modes in packaging equipment, particularly mechanical wear, lubrication deficiencies, and inadequate preventive maintenance, as primary contributors to unplanned downtime at PepsiCo Durban. Through the application of FMEA, the research uncovered root causes such as ineffective maintenance scheduling, insufficient operator and engineering personnel training, and poor documentation practices. High-risk equipment, including case packers and sealers, was prioritised using Risk Priority Numbers (RPNs). The study further developed targeted strategies to improve equipment reliability, including enhanced preventive maintenance planning, operator and engineering personnel upskilling, and improved spare parts and data management. The integration of FMEA into the existing quality management framework proved effective in reducing equipment failure, minimising waste, and supporting sustainable operational improvements aligned with PepsiCo's environmental and efficiency goals.

Keywords: FMEA (Failure Mode and Effects Analysis), Equipment Reliability, Preventive Maintenance, Corrective Maintenance, Risk Priority Number (RPN), Packaging Equipment, Operational Efficiency, Sustainability, FMCG Industry, Quality Management Framework

DECLARATION

I, Dean Govender, affirm that this mini-dissertation is my own original work, and that all sources have been properly cited and referenced. A complete bibliography is included at the end of this dissertation. The views expressed herein are my own and do not necessarily reflect those of the Durban University of Technology.

I also confirm that this dissertation, in whole or in part, has not been submitted for the completion of a Master of Business Administration (MBA) degree at any other academic institution, either within South Africa or internationally.

Signature:

Dean Govender 20400656 30 June 2025

STUDENT NAME NUMBER DATE

SUPERVISOR: M. Ramchandra 30 JUNE 2025

DEDICATION

This dissertation is dedicated to the four pillars of my strength, my family, my loving wife Suganthree, and my daughter Nanthiya, whose unwavering support and countless sacrifices have given me the strength to push myself beyond my limits. I am profoundly grateful for your dedication, encouragement, and prayers, which have been the driving force behind my journey. Your love and belief in me have played an essential role in helping me to achieve my goals.

I am deeply fortunate to have an amazing family whose steadfast support and moral guidance have played a crucial role in my achievements. I sincerely recognize that reaching this milestone would not have been possible without your continuous encouragement and presence. You have been my rock, and I will always be thankful for the boundless love and strength you have provided me.

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To my brother Kamlyn, thank you for being an integral part of this journey, constantly encouraging me to reach my full potential, even when it felt out of reach, and for being the key that opened the doors I needed to pass through on this challenging path

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Life's journey often presents trials that test our resolve and inner strength. Yet, it is through resilience and grace that we find the courage to rise above them. With deep humility and gratitude, I give thanks to my Lords and Mothers, the givers and sustainers of life and for blessing me with health, wisdom, and divine direction throughout this academic journey.

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To my beloved family, thank you for your enduring encouragement and faith in me. Your love and support have been the foundation of my strength and perseverance, motivating me to pursue and achieve my goals.

I would also like to sincerely thank my dedicated language editor. Your meticulous attention to detail and thoughtful feedback have significantly enhanced the clarity and quality of this work.

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LIST OF ABBREVIATIONS

PEMM	PepsiCo Europe Maintenance Methodology
FMCG	Fast- Moving Consumer Goods
FMEA	Failure Mode and Effects Analysis
LSS	Lean Six Sigma
PPM	Parts Per Million
PFMEA	Process Failure Mode and Effects Analysis
DFMEA	Design Failure Mode and Effects Analysis
SFMEA	System Failure Mode and Effects Analysis
SERV-FMEA	Service Failure Mode and Effects Analysis Concept
FMEA	Concept Failure Mode and Effects Analysis
RCM	Reliability Centred Maintenance
FMMEA	Failure Modes, Mechanisms, and Effects Analysis
FMEDA	Failure Modes Effects and Diagnostic Analysis
MFMEA	Maintenance FMEA
RPN	Risk Priority Number
AP	Action Priority
AIAG	Automotive Industry Action Group
ASQC	American Society for Quality Control
SAE	Society of Automotive Engineers
CAPA	Corrective and Preventive Actions

QMS	Quality Management Systems
RCA	Root Cause Analysis
SPC	Statistical Process Control
DOE	Design of Experiments
QFD	Quality Function Deployment
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
OEE	Overall Equipment Effectiveness
PM	Preventive maintenance
PdM	Predictive maintenance
CM	Corrective maintenance
RCM	Reliability Centred Maintenance
TPM	Total Productive Maintenance
PLCs	Programmable Logic Controllers
HMIs	Human-Machine Interfaces
CMMS	Computerised Maintenance Management Systems
EAM	Enterprise Asset Management
LCC	Life Cycle Cost
KPIs	Key Performance Indicators
SHE	Safety, Health & Environment
ARV	Asset Replacement Value

MIAP	Maintenance Improvement Action Plan
QIP	Quality Improvement Plans
FSSC	Food Safety System Certification
AIB	American Institute of Bakers
LSS	Lean Six Sigma
BOM	Bill of Materials
MCDM	Multi Criteria Decision-Making
BWM	Best Worst Method
SMAA	Stochastic Multi Objective Acceptability Analysis
MARCOS	Measurement of Alternatives and Ranking According to Compromise Solution
M-CRITIC	Intra Criteria Correlation
ABAC	Alternative by Alternative Comparison
QIPs	Document analysis of Quality Improvement Plans
CMMS	Computerised Maintenance Management System
IoT	Internet of Things

Chapter 1: Overview

In this chapter, a brief overview of the study is undertaken to obtain a basic understanding of the expected findings in the forthcoming chapters of this mini-dissertation.

1.1 Introduction

The Fast-Moving Consumer Goods (FMCG) industry is highly dependent on operational efficiency and equipment reliability to ensure product quality, reduce waste, and maintain profitability. At PepsiCo Durban, a significant challenge exists within the packaging department, where frequent equipment stoppages have resulted in substantial waste of sellable potato chips. This chapter provides an overview of the research, which explores the application of Failure Mode and Effects Analysis (FMEA) within a quality management framework to enhance equipment reliability in the packaging section. The chapter outlines the context of the research, the problem statement, the aim and objectives, the research questions, and the rationale behind the study. Additionally, it introduces the research methodology, highlights the delimitations and limitations, and addresses the ethical considerations relevant to the research. Through this structured approach, the chapter sets the foundation for investigating how FMEA can serve as a proactive tool for reducing downtime and improving sustainability in FMCG packaging operations.

1.2 Context of the research

PepsiCo is a global leader in the food and beverage industry, renowned for its diverse product portfolio, including brands like Pepsi, Mountain Dew, Lay's, Doritos, Gatorade, Tropicana, and Quaker Oats (Qian 2023: 1). PepsiCo's strategic initiatives include continuous investment in innovation and sustainability, demonstrating its dedication to not only maintaining its market leadership but also addressing global challenges through sustainable practices and strategic growth (PepsiCo Global 2024: 33). The Prospecton manufacturing site in Durban, which produces popular potato snack foods, faces a significant problem related to packaging waste. According to the Internal PepsiCo TE and KPI (2023: 2), 194,108 tons of sellable potato chips were wasted due to end-of-line packaging inefficiencies, which translates to a loss of 679,378 tons of potatoes. Such a substantial amount of waste highlights critical issues within the FMCG industry's packaging and palletising departments. Addressing these inefficiencies is crucial for reducing waste and improving operational sustainability.

The waste at the PepsiCo manufacturing site is primarily due to unplanned equipment stoppages in the packaging hall caused by reliability issues. When the end-of-line packaging machine fails, the potato chips that are supposed to be packaged are not packed and the organisation is forced to dispose of the otherwise good quality potato chips. The reason for this is that the line is continuous and does not contain any buffering, storage, or holding capacity, thus any overflow is automatically directed to waste. Furthermore, storage of unpacked chips is not a viable option as it leads to rapid product degradation. FMEA has been identified as a suitable theoretical framework for exploration in the current study, as is evident in the literature which indicates that’s FMEA was used in many areas of FMCG. However, there is a gap in the literature because there is no evidence FMEA was used in FMCG, specifically in the packaging department to improve equipment reliability. Additionally. It is also evident in the literature that FMEA is useful due to its predictive methodology, that can be used to improve equipment reliability (Suharjo, Suharyo and Bandono 2019: 2862).

While, PepsiCo has ISO 9001, Food Safety System Certification (FSSC), and the American Institute of Bakers (AIB) certification, aimed to assure product quality, it does not fully address the triple bottom line (PepsiCo 2024). According to Hamidi and Worthington (2023: 396) the 3 P's, Profit, Planet, and People reflect a triple bottom line approach that considers not only financial outcomes but also environmental and social impacts. This framework has become increasingly important as companies aim to integrate sustainability into their core business strategies and operations. According to the PEMM Audit Feedback Deck (2024: 3), PepsiCo has PepsiCo Europe Maintenance Methodology (PEMM) for its maintenance regime which makes a significant contribution in addressing the other 2 Ps (planet and profit). According to PepsiCo's integrated annual report, the Prospecton plant scored 35.16 % and 18.25 % respectively, against a PEMM control target of 40 % (PepsiCo 2024). This is in contrast to the organisation's continuous progress in the ISO 9001, FSSC, and AIB audits. The Simba Sustainability Prospecton (2024: 8) states that fried waste is sent for recycling and PepsiCo receives and income of R0,96 per kg. The cost of the waste can be broken down into potatoes and oil at a cost of R22.02 per kg and R8,30 per kg, respectively. This indicates that while there is some income that is being generated by this waste, the overall loss to the company is R29,36 per kg.

1.3 Problem Statement

The waste at the PepsiCo manufacturing site is primarily due to unplanned equipment stoppages in the packaging hall caused by reliability issues. When the end-of-line packaging machine fails, the potato chips that are supposed to be packaged are not packaged and the organisation is forced to dispose of the otherwise good quality potato chips. PepsiCo defines corrective maintenance as unplanned, and preventative maintenance as planned events, and confirmed that the engineering maintenance standard ratio in the packaging hall is 32,14% corrective maintenance and 67,86% preventative maintenance (SAP IW47 2023: 39). According to Maseola (2022: 4) an imbalance in corrective and preventative maintenance contributes to frequent equipment failures and inefficiencies. He also indicates that an optimal maintenance standard should be 20% corrective maintenance and 80% preventative maintenance for systems to operate effectively and efficiently. Thus, improving the preventative maintenance ratio is crucial for enhancing equipment reliability and reducing waste. Therefore, aligning maintenance practices with the recommended standards can significantly mitigate unplanned stoppages and associated waste.

Studies have been conducted on enhancing equipment reliability in the FMCG industry's packaging department. Jambrak *et al.* (2021: 1) explored the role of IoT in improving equipment reliability and productivity within food packaging departments and advised that IoT implementation can lead to significant improvements in monitoring and maintenance, thereby reducing downtime and increasing efficiency. Sing (2021: 336) demonstrated the application of Lean Six Sigma methodologies in enhancing operational efficiency and reliability and optimising packaging processes.

Lean Six Sigma in manufacturing helps companies achieve significant improvements in productivity, quality, and customer satisfaction by systematically identifying and eliminating inefficiencies and defects in the process (Gomaa 2025: 16). Lean Six Sigma (LSS) focuses on defective Parts Per Million (PPM) as a key metric to measure the level of defects in a process: the goal of LSS is typically to achieve a very low PPM rate, indicating high quality and reliability (Olanrewaju, Uzorh and Nnanna 2019: 42). IoT when integrated in manufacturing facilitates allows for smarter, more connected factories that can operate with greater efficiency and responsiveness to equipment operation by embedding IoT sensors in equipment and machinery to collect real-time data on various parameters such as temperature, vibration, pressure, and energy consumption (Soori, Arezoo and Dastres 2023: 1). Therefore, while IoT and Lean Six Sigma offer significant benefits such as process optimisation and waste reduction, they typically address different aspects of manufacturing efficiency and quality rather than focusing specifically on proactive risk assessment and reliability enhancement.

This research aims to explore the application of FMEA within a quality management framework, specifically in the FMCG packaging department, with the focus of enhancing equipment reliability. By integrating FMEA into a quality management framework, organisations can systematically analyse risks, prioritise preventive actions, and mitigate equipment failures before they occur (Tang, Chen and Lin 2020: 4). Thus, exploring FMEA through a quality management lens offers a new avenue for advancing equipment reliability and operational excellence in FMCG packaging departments.

1.4 Aim and Objectives

1.4.1 Aim of the study

This research explores the application of Failure Mode and Effects Analysis (FMEA) through a quality management framework to enhance equipment reliability in the packaging department of the Fast-Moving Consumer Goods (FMCG) industry.

1.4.2 Objectives of the study

To achieve the aim of this study, the following objectives are tendered:

i. To benchmark the organisation's historical corrective/preventative maintenance ratio against industry standards, through a literature review and internal document analysis;

ii. To identify critical failure modes in the packaging equipment through document analysis by analysing the organisation's maintenance records;

iii. To ascertain the challenges in optimising the corrective/preventative maintenance ratio by conducting interviews with Maintenance Management staff, and Preventative Maintenance Team Members, Line Support Instrument

Technicians, and Line Support Millwrights to determine departmental challenges and external challenges such as behavioural, interdepartmental, or supply chain disruptions;

iv. To ascertain the extent to which PEMM and ISO 9001 audit finding recommendations have been implemented, through document analysis of the Quality Improvement Plan (QIP) and interviews with maintenance management and supervisory staff; and

v. To develop a FMEA Implementation Strategy by integrating Failure Mode and Effects Analysis (FMEA) into the current quality management framework.

1.4.3 Research Questions

The investigation is guided by the following research questions:

i. What are the current maintenance ratios against industry standards?
ii. What are the critical failure modes?
iii. What are the challenges in optimising the maintenance ratio?
iv. To what extent has the implementation of audit findings been executed?
v. What is the most suitable FMEA Implementation Strategy for the quality management framework that can be used in the Durban packaging department at PepsiCo?

1.5 Rationale for the study

Packaging waste is a critical issue that significantly impacts the earth's capacity to sustain human life and addressing this problem is essential for maintaining ecological balance (Ramchandani et al. 2021: 1). Reducing raw material wastage not only conserves resources but also enhances environmental sustainability and minimizes packaging waste that can positively influence Sustainable Development Goals (SDGs) established by the United Nations to tackle global challenges by

2030 (United Nations, 2024). This study addresses, in particular, SDG Goal 12 (responsible consumption and production), goal 13 (climate action), and goal 15 (life on land).

While PepsiCo has implemented robust quality assurance systems such as ISO 9001, FSSC, and AIB, these frameworks primarily emphasize product quality and food safety, with limited focus on proactive equipment reliability. Additionally, despite the existence of PEMM, audit scores have shown a declining trend, signalling gaps in the effectiveness of current maintenance strategies. This reinforces the need for a structured, preventive approach to maintenance that can systematically address potential equipment failures.

Although FMEA has seen successful application in industries such as the automotive sector, its implementation within the FMCG sector, specifically, in packaging operations at PepsiCo, remains largely underexplored (Kök and Yıldız 2023: 1630). This presents a unique research opportunity to evaluate how integrating FMEA within an existing quality management framework can enhance equipment reliability, reduce waste, and improve operational sustainability at PepsiCo Durban.

By reducing packaging waste and optimising maintenance practices, this research not only addresses organisational challenges but also contributes to global efforts toward sustainability and environmental stewardship.

1.6 Research Methodology

According to Melnikovas (2018: 33), Saunders' research onion is a framework that guides researchers through designing a study by systematically addressing layers of research decisions, including philosophy, approach, strategy, and techniques. It helps ensure that each element of the research design aligns with the overall research objectives. Pragmatism is a research philosophy that focuses on practical outcomes and solutions, prioritising the research question over specific methodologies, allowing for the use of flexible approaches, and combining research approaches and techniques to best address the research objectives (Kaushik and Walsh 2019: 3).

This study was cross-sectional and adopted a mixed-method (qualitative and quantitative) approach. The qualitative approach involved archival research through documentary analysis and interviews. Qualitative research is a methodological choice that involves exploring complex phenomena through non-numerical data, using methods like interviews and observations to gain a deep, contextual understanding of human experiences and behaviours, offering in-depth, holistic insights into complex issues, and emphasises flexibility and participant perspectives (Aspers and Corte 2019: 145).

The quantitative approach allowed for the analysis of numerical data and ensured comprehensive and triangulated findings (Meissel and Brown 2023: 1). In this study, the quantitative approach involved the use of FMEA, which provided a numerical foundation for prioritising maintenance tasks and helped determine which failures needed immediate attention. This approach was used to rank failure modes identified from maintenance records according to their severity, frequency, and likelihood of detection. Statistical Trend Analysis was used to analyse patterns and changes in numerical data over time. It was ideal for this study because it helped determine whether maintenance strategies had improved or declined over time and supported data-driven recommendations for optimizing maintenance ratios (corrective vs. preventive) and Pareto Analysis was the technique that highlighted the most significant factors contributing to a problem, following the 80/20 rule; this technique will be used to identify the most significate factors that had resulted in poor audits scores. This study also adopted pragmatist research; the research design was descriptive and exploratory. The approach used in this research was inductive research, which involved collecting data and developing theory/frameworks because of the data analysis rather than starting with a hypothesis to be tested (Kumar and Ujire 2024: 58). This approach was exploratory and aimed to generate new insights and theories/ frameworks based on observed patterns and themes within the data (Corley, Bansal and Yu 2021: 162).

1.6.1 Target population

The target population included all the Maintenance Management Staff, Preventative Maintenance Team Members, Line Support Instrument Technicians, and Line Support Millwrights, which only consisted of 12 people; hence, everyone was interviewed.

1.6.2 Sampling method

Census sampling is commonly applied when dealing with small populations, as it makes it possible to include every individual or unit, ensuring the highest level of accuracy and removing any sampling errors (Nanjundeswaraswamy and Divakar 2021: 328). With smaller groups, the time, cost, and resources needed to survey everyone are reasonable, making a complete census both feasible and beneficial (Fecht *et al.* 2020: 15). Therefore, this study used census sampling, which involved collecting data from all members of a defined population.

1.6.3 Measuring instrument

While the qualitative approach provides in-depth understanding and contextual insights, the quantitative approach allows for the analysis of numerical data, ensuring comprehensive and triangulated findings (Meissel and Brown 2023: 1). The quantitative research methodology in this study involved data collection, analysis, and interpretation that involved numerical data. The quantitative aspect focused on analysing historical maintenance records from the past 10 years, including failure reports (IW28 and IW38) and audit findings from ISO 9001 and

PEMM, to identify patterns, failure frequencies, and the corrective versus preventive maintenance ratio, benchmarked against industry standards. Key metrics such as the Risk Priority Number (RPN), preventive to corrective maintenance ratios, and statistical trends in equipment downtime are calculated using techniques like Pareto Analysis and trend analysis. Statistical tools, such as Excel or SPSS, support these analyses, offering a numerical foundation to identify critical failure modes and evaluate maintenance efficiency. These quantitative insights complement the qualitative findings from interviews and thematic analysis, enabling a robust evaluation of maintenance practices and the development of an optimized strategy for improving packaging equipment reliability (Lanka *et al*. 2021: 1).

1.6.4 Data collection method

Archival research involves extracting and analysing evidence from original archives, which are collections of historical documents, records, and other materials, to gain insights into past events, trends, and phenomena (Maier *et al*. 2023: 2). In this study archival research was used to analyse varies archives such as the maintenance records database, PEMM audit databases, to extract meanings from documents through document analyses techniques that provided historical and current issues (Maier *et al*. 2023: 2). Interviews are a qualitative data collection method where researchers ask questions to gather in-depth information about participants' experiences, opinions, and perspectives on a specific topic (Shahzad and Lodhi 2023: 51). In this study, interviews were used to extract both current and historical issues.

1.6.5 Data analysis

The technique and procedure used in this research was thematic analysis, a qualitative method that identifies, analyses, and reports patterns or themes within data, providing a detailed interpretation of the dataset. It is a flexible approach that supports inductive research, allowing themes to emerge naturally from the data (Finlay 2021: 103) and content analysis was also used as a research method to systematically analyse and interpret the content of textual, visual, and audio data to identify patterns, themes, and meanings which involved coding and categorizing data to quantify and analyse the presence of certain phenomena or concepts within the content (Preiser *et al*. 2021: 271).

FMEA frameworks utilise both qualitative and quantitative tools. Qualitative tools comprise Failure Modes Identification, Effects of Failure, Failure Causes, Detection Methods, and Risk Categories. Failure Modes Identification describes how a system or component can fail: example, material fatigue or human error (Wang, Feng and Yang 2019: 1). Effects of Failure describe the potential consequences or impacts of the failure mode on the system, process, or customer: example, reduced performance or safety hazards, These effects are typically categorized in a qualitative way, such as minor, moderate, or severe (Anjalee, Rutter and Samaranayake 2020: 171). Failure Causes identify the underlying reasons for the failure, such as design flaws, manufacturing defects, or external factors that are usually described qualitatively (Qian *et al.* 2023: 1). Risk Categories like high, medium, or low are qualitative judgments based on the combination of severity, occurrence, and detection (Jose *et al*. 2020: 314).

1.6.6 Pretesting

No pretesting was done because the sample was 100 % of the population and the sample size was small, consisting of 12 people.

1.6.7 Validity and reliability

In qualitative research, ensuring the study's quality and reliability involves establishing credibility, dependability, confirmability, and overall trustworthiness

(Ahmed 2024: 1). Trustworthiness, encompasses credibility, dependability, and confirmability, and refers to the overall integrity of the research, convincingly presenting methods and findings to inspire confidence in its validity and reliability (Stahl and King 2020: 1). Credibility refers to the confidence in the truth of the findings, achieved through detailed representation of participants' experiences, prolonged engagement, triangulation, and member checking (Shufutinsky 2020: 56). Dependability pertains to the stability and consistency of the findings over time and conditions, established through an audit trail documenting the research process and decisions (Kakar *et a*l. 2023: 152). Confirmability ensures that findings are shaped by participants rather than researcher bias: achieved through reflexivity and an audit trail of data collection and analysis (Sadık 2019: 147).

In this study, credibility will be ensured by e-mailing each participant a copy of the transcription that was taken during the interview for confirmation, and data source triangulation will also be used to support credibility by collecting data from four different groups of employees, Maintenance Management Staff, Preventative Maintenance Team Members, Line Support Instrument Technicians and Line Support Millwrights to determine departmental challenges. Dependability was ensured by the researcher by recording all steps in the research in a journal. Confirmability was undertaken by sharing the results with the supervisor to ensure confirmability. Audit trails were conducted by filing all field notes and transcripts in one location so that they could be accessed easily for the study to be executed in the same way to yield similar results.

1.7 Delimitation of the study

This research study is limited to the snack food manufacturing operations at PepsiCo Durban. The study evaluated the application of FMEA through a quality management framework to enhance equipment reliability in the packaging department. The boundaries or scope of the research are as follows:

i. The study was limited to the packaging department at PepsiCo Durban and did not extend to other departments or locations.
ii. The research only analysed historical maintenance records from the past 10 years.
iii. Only maintenance management staff, preventative maintenance team members, line support instrument technicians, and line support millwrights were interviewed. Other employees, such as production managers, quality control personnel, and HR managers, were excluded.
iv. The study used a mixed-method approach, including qualitative (archival research, document analysis, and interviews) and quantitative (Pareto analysis, statistical trend analysis, and failure mode categorization) techniques.
v. The study relies on PEMM audit reports, IW28 and IW38 reports, ISO 9001 audit findings, and maintenance records.

1.8 Limitations of the study

The following limitations could affect the generalizability and reliability of the study's findings:

I. The study was limited to 12 employees from specific roles (Maintenance Management Staff, Preventative Maintenance Team Members, Line Support Instrument Technicians, and Line Support Millwrights). This small sample may not fully represent all challenges in packaging equipment reliability.

II. The study was limited to the packaging department at PepsiCo Durban. Findings may not be generalizable to other departments, industries, or geographical locations.

III. The research relies on historical maintenance records from the past 10 years. There might have been inconsistencies or missing data that could have affected the accuracy of the failure trend analysis.

IV. The study primarily used thematic analysis and content analysis, which are subjective and dependent on interpretation. While efforts are made to ensure credibility, bias cannot be fully eliminated.

V. The study followed a cross-sectional approach, meaning it captured data at a single point in time rather than over a prolonged period. This might have limited the insights into long-term trends and reliability improvements.

VI. Employees who are not directly involved in maintenance (e.g., production managers, quality control personnel, and HR managers) were excluded. Their insights might have provided a broader perspective on equipment reliability challenges.

VII. While the study aimed to compare findings with industry standards, access to benchmark data from competitor companies or global best practices may be limited.

1.9 Ethical Considerations

A simple and clear consent form was designed for the questionnaire. The purpose of the study and the reasons for selecting participants were explained to ensure participants understood what to expect, along with any potential benefits. Participants were assured that their responses would remain confidential. They were also informed of their right to withdraw from the study at any time. Additionally, all necessary precautions were taken to prevent any physical harm resulting from the research.

1.9.1 Data Storage

All data gathered during this research was securely stored to ensure participant confidentiality and will be disposed of appropriately in the future. Physical transcripts will be kept in a safe location for five years before being destroyed. Digital data will be saved on encrypted drives, stored in a locked and secure area accessible solely to authorised personnel.

1.9.2 Structure of the study chapters

This mini dissertation is structured into five main chapters, each contributing to the development and fulfilment of the study's aim and objectives:

Chapter 1: Overview

Introduces the background of the study and outlines the research problem, aim, objectives, and research questions. It also explains the rationale, scope, methodology, limitations, and ethical considerations that guided the study.

Chapter 2: Literature Review

Provides a comprehensive review of relevant literature on FMEA, its historical development, integration into quality management systems, application in the FMCG sector, and benchmarking of maintenance practices. It also highlights gaps in existing research and justifies the need for the study.

Chapter 3: Research Methodology

This chapter outlines the research design and methodology employed in the study. It covers the underlying research philosophy, approach, and strategy, as well as the target population, sampling techniques, data collection methods, and procedures for data analysis. Additionally, measures taken to ensure the validity and reliability of the study are discussed.

Chapter 4: Data Analysis and Discussion of Results

This chapter presents and analyses the data collected using qualitative and quantitative methods. It interprets the findings about the research objectives and literature reviewed, highlighting key patterns, trends, and insights.

Chapter 5: Conclusions and Recommendations

This final chapter summarises the key findings of the study, draws conclusions based on the research objectives, and provides practical recommendations for implementing FMEA to improve equipment reliability in the packaging department. Suggestions for future research are also included.

1.10 Conclusion

This chapter established the foundation for the study by contextualising the operational challenges faced by the packaging department at PepsiCo Durban. It highlighted the problem of excessive waste due to unplanned equipment stoppages and underscored the importance of improving preventive maintenance practices to align with industry standards. The chapter presented the aim and specific objectives of the study, described the central research questions, and justified the selection of FMEA as a suitable framework for addressing reliability concerns. It outlined the research methodology and ethical considerations, it also ensured transparency and academic thoroughness.

The next chapter will explore existing research on FMEA, maintenance strategies, and quality management frameworks relevant to the FMCG industry.

Chapter 2: Literature Review

This chapter explores the diverse literature regarding FMEA that is related to the aim and objective and the various aspects of the current research.

2. 1. Introduction to FMEA

This chapter presents an in-depth review of the literature related to FMEA as it applies to improving equipment reliability, particularly in the context of the packaging department in the FMCG industry. It begins by defining FMEA and exploring its historical development, followed by an examination of its various types and integration with quality management systems. The chapter also highlights FMEA's role in the FMCG sector, particularly in packaging operations, and presents real-world case studies from leading companies. Furthermore, the chapter discusses benchmarking of maintenance ratios, types of maintenance strategies, and tools such as the Maintenance Practice Evaluation Matrices. Common failure modes in packaging equipment and challenges in optimising corrective and preventive maintenance ratios are explored, along with the role of ISO 9001 and PepsiCo's PEMM standards. The literature review concludes by identifying best practices and challenges in FMEA implementation and outlines research gaps that this study seeks to address.

2.1.1 Definition and Overview

This section provides an overview of the FMEA methodology, its purpose, and how it is applied in various contexts.

FMEA is a systematic approach used to identify, analyse, and prioritise potential failure modes in systems, processes, and services to enhance reliability and safety (Liu *et al.* 2019: 1). Developed by the U.S. military in the 1940s, it has become an essential tool in industries such as automotive, aerospace, and manufacturing

(Sharma and Srivastava 2018: 1). This method is widely utilised as an important reliability management tool to effectively evaluate and prevent risk problems that occur in all aspects of production (Ying, Peide and L,G 2023: 1). Suharjo, Suharyo and Bandono (2019: 2862) emphasize that early identification and mitigation of risks through FMEA significantly reduces the likelihood of major problems. Consequently, FMEA serves as a critical framework for enhancing reliability and operational efficiency across various applications.

The FMEA process entails identifying potential failure modes, evaluating their effects, and calculating the Risk Priority Number (RPN) to prioritize corrective actions (Wang 2021: 2875). According to Liu *et al*. (2019: 881) , RPN-based prioritization allows organizations to focus their resources on addressing the most critical risks, thereby improving reliability and performance. As a result, FMEA not only supports effective risk identification and mitigation but also promotes continuous improvement and operational excellence.

In the next section, the history of FMEA and its key milestones are discussed.

2.2 Historical Context and Development of FMEA

FMEA has evolved significantly since its inception. This section covers the history of FMEA, including its development, key milestones and quantitative tools. Significant advancements and changes in FMEA methodology are highlighted here, providing context for its current practices.

2.2.1 Origins

Failure Mode and Effects Analysis (FMEA) originated as a method developed for the U.S. military to assess the reliability of technical systems. Initially formalised in 1949 as a military standard, FMEA was designed to identify and evaluate potential failure modes within systems and their effects on mission success and safety

(Barsalou 2026: Page 2). This systematic approach allowed the military to mitigate risks in their operations by anticipating and addressing possible failures before they occurred. The structured nature of FMEA made it an invaluable tool in enhancing the reliability of complex technical systems (Sharma and Srivastava 2018: 1).

2.2.2 Key Milestones

Following its military use, FMEA was quickly adopted by the aerospace and aviation industries. Boeing, one of the first companies to implement FMEA in the 1950s and 1960s, recognised its potential in preventing failures in critical systems. The method gained further prominence when NASA applied it during the Apollo programme in the 1960s, publishing detailed procedures for FMEA in 1966. The success of these implementations demonstrated FMEA's value in preventing catastrophic failures, particularly in high-stakes industries (Mascia *et al.* 2020: 312).

In 1971, Ford introduced an internal standard for FMEA, marking the method's first significant use in automotive manufacturing. By the 1980s, major U.S. automakers like Chrysler, Ford, and General Motors had formally incorporated FMEA into their product development cycles, creating the QS 9 000 standard. This standardisation reflected the industry's commitment to improving product reliability and safety by systematically analysing potential failures (Barsalou 2022: 59).

In 1993, the Automotive Industry Action Group (AIAG) and the American Society for Quality Control (ASQC) published an industry-wide FMEA manual, which was followed by the Society of Automotive Engineers (SAE) releasing guidelines for Design FMEA and Process FMEA in 1994. European automakers also developed their own FMEA standards during this period. The culmination of these efforts was the integration of FMEA into the international standard ISO/TS 16949 in 1999, which unified FMEA practices across U.S., European, and Japanese manufacturers (Atin and Lubis 2020: 1).

The evolution of FMEA methodology has seen significant advancements, especially within the automotive industry. A major milestone was the 2019 introduction of the AIAG & VDA FMEA Handbook, which introduced a structured 7-step approach to Process FMEA. This approach, which includes phases like System Analysis and Risk Mitigation, improves both the precision and transparency of the method. According to Kök and Yıldız (2023: 1630) , the handbook's shift from the traditional Risk Priority Number (RPN) to the Action Priority (AP) metric enhances the prioritization of risks, making it more effective. This evolution has streamlined FMEA practices, leading to improved product reliability and fostering a more proactive approach to risk management.

This section highlighted FMEA's evolution from a military reliability tool into a globally standardised and industry-critical methodology used across sectors to enhance safety, reliability, and performance. FMEA has matured from a military reliability tool into a globally recognised standard applied across multiple industries, from aerospace to automotive manufacturing, and beyond. Over the decades, FMEA methodology has become more systematic, collaborative, and data-driven, with enhanced tools like the 7-step approach and AP metric making it more actionable and effective in modern risk management.

In the next section the quantitative tools used in FMEA are discussed.

2.2.3 Quantitative Tools of FMEA

Quantitative tools of FMEA comprise of the Risk Priority Number (RPN) which is calculated as the product of three numerical ratings: Severity, Occurrence, and Detection. Each is rated on a scale, usually from 1 to 10, making the RPN a quantitative measure of risk. Occurrence Rate is a quantitative estimate of how often a particular failure mode might occur, based on historical data or probability models: this is rated numerically in the FMEA (Essam and Eissa 2019: 1). The Severity Rating assigns a numerical value to the seriousness of the consequences of a failure mode, although based on qualitative judgment: this rating is expressed quantitatively on a scale (e.g., 1-10). Detection Rating is a quantitative measure of the likelihood that the failure will be detected before causing harm: this is also rated on a scale (e.g., 1-10). By combining these qualitative descriptions with the quantitative scoring system (RPN, severity, occurrence, and detection ratings), FMEA provides a structured way to assess and mitigate risk (Wanga *et al*. 2021: 1).

In the next section, the different types of FMEA are examined.

2.3 Types of FMEA

This section briefly describes the types of FMEA and their specific applications in different industries.

Design Failure Mode and Effects Analysis (DFMEA) focuses on identifying potential failures in the design of a product or system with the primary goal of improving performance, reliability, and safety. This process involves identifying potential failure modes, analysing their causes, and evaluating their effects on the system's overall functionality. Techniques such as brainstorming, root cause analysis, fault tree analysis, design of experiments, and control plans are systematically used to assess design risks (Sahayam 2023: 7).

Process Failure Mode and Effects Analysis (PFMEA) focuses on potential failures within manufacturing or assembly processes to ensure that production consistently meets specifications. This method identifies possible failure modes, analyses their causes, and evaluates their effects on the manufacturing process (Wolniak 2019: 13). Pascu, Malciu and Dumitru (2022: 37) highlight how PFMEA plays a critical role in process validation, ensuring that manufacturing processes produce products that meet required standards. By thoroughly evaluating process risks, PFMEA significantly improves the reliability and quality of production.

System Failure Mode and Effects Analysis (SFMEA) focuses on identifying potential failures across an entire system, encompassing both design and manufacturing processes to ensure overall system reliability. This approach aims to examine failure modes, their causes, and the effects on the entire system, ensuring that all subsystems work together seamlessly. It does this by integrating elements from both DFMEA and PFMEA, using techniques such as system-level risk assessments and cross-functional team reviews (Johansson 2022: 30).

Software Failure Mode and Effects Analysis (SW-FMEA) is dedicated to identifying potential failures within software systems, focusing on failure modes, their causes, and the effects on software functionality. To address these issues, techniques such as software architecture evaluation, validation of safety requirements, and comprehensive software specifications are utilised, which ensures that the software operates reliably under all anticipated conditions Sahayam (2023: 1).

Service Failure Mode and Effects Analysis (SERV-FMEA) is a systematic approach used to identify potential failures in service processes, with the goal of improving service quality and enhancing customer satisfaction. By focusing on failure modes, their causes, and effects, service providers can proactively address issues before they impact service delivery. This is done by using techniques such as regular customer feedback analysis to identify areas for improvement and service shortcomings (Hu, Liu and Wang 2019: 49).

Concept Failure Mode and Effects Analysis (Concept FMEA) is employed in the early stages of design to assess potential failures in proposed concepts and support the selection of the most viable design alternatives. This method identifies possible failure modes and their effects, allowing for necessary adjustments before moving forward with detailed design. The process frequently incorporates feasibility studies, which evaluate the practicality and success potential of the concepts being explored (Fakhravar 2020: 5).

Reliability-Centred Maintenance (RCM) focuses on identifying and addressing preventive maintenance needs to ensure safe and cost-effective operations. This approach involves analysing equipment conditions and optimising maintenance schedules to prevent failures. Techniques such as condition monitoring are utilised to continuously assess equipment health, enabling timely maintenance interventions (Enjavimadar and Rastegar 2022: 1).

Hazard Analysis is a critical process that identifies safety-related risks throughout a system's life cycle, ensuring that potential hazards are addressed proactively. This analysis involves a systematic examination of possible hazards and the implementation of risk mitigation strategies. Tools like the risk assessment matrix are often used to evaluate and prioritise risks based on their severity and likelihood (Liangliang, Yan-Fu and Enrico 2022: 12).

Human Factors FMEA addresses potential failures related to the interaction between humans and equipment, focusing on minimising risks associated with human error. This method involves analysing user interactions to identify potential design flaws that could lead to errors. Ergonomic assessments are often included to ensure that equipment and workspaces are user-friendly and reduce the likelihood of mistakes (Xue, Wang and Liu 2021: 71).

Business Process FMEA aims to improve organisational efficiency by identifying and addressing potential failures in business processes. This approach focuses on enhancing workflow, decision-making, and overall process effectiveness.

Techniques like workflow optimisation are employed to streamline tasks and information flow within the organisation (Teplicka *et al.* 2021: 41).

Failure Modes, Mechanisms, and Effects Analysis (FMMEA) examines potential failure mechanisms and prioritises them to prevent system failures. This method involves developing detailed models of failure mechanisms to understand and predict how failures might occur. The systematic evaluation of these mechanisms helps prioritise the most critical failure modes for further analysis (Zhou *et al.* 2023: 1033).

Failure Modes, Effects and Diagnostic Analysis (FMEDA) is an extension of traditional FMEA that includes a more detailed diagnostic analysis of component failure modes. This method evaluates the effects of failure modes and assesses the effectiveness of diagnostic measures in detecting and isolating failures. Diagnostic coverage analysis is a key element in this process, ensuring that failures are identified and addressed promptly Zhang et al. (2019: 15),

Maintenance FMEA (MFMEA) focuses on identifying potential failures in maintenance and repair processes to enhance the reliability and safety of equipment. This method involves evaluating maintenance procedures and developing optimised schedules to prevent failures and extend equipment life (Zeng *et al.* 2020: 1).

The key insights from this section is that FMEA is a versatile and systematic tool used across various industries and functions to identify, evaluate, and mitigate potential failure modes before they impact performance, safety, quality, or reliability. FMEA, in its many forms, is a proactive risk management tool that enhances product quality, process reliability, safety, and customer satisfaction. Each type is tailored to a specific domain, design, production, software, maintenance, service, and business to ensure continuous improvement and operational excellence.

The next section discusses how FMEA integrates with quality management systems.

2.4 FMEA in the FMCG Industry

The FMCG industry, particularly in packaging, benefits significantly from FMEA. This section explores the relevance of FMEA in the FMCG sector.

In the FMCG sector, particularly in packaging, FMEA is highly relevant due to its ability to proactively address risks that could impact product quality and safety (Harianto 2020: 1). This method helps anticipate issues, ensuring that potential failures are addressed early in the design and production stages. It does this by enhancing reliability by systematically evaluating risks, ultimately contributing to more efficient and secure packaging solutions. Therefore, FMEA plays a crucial role in maintaining high standards within the FMCG industry.

FMEA helps identify potential failures in packaging materials, such as risks of leakage or contamination, and proactively addresses these issues before they affect the product. This is essential for meeting stringent regulatory requirements, as FMEA ensures compliance by systematically identifying and mitigating risks associated with non-compliance (Szczyrba and Ingaldi 2024: 364).

Operational efficiency and cost management benefit significantly from FMEA, as early identification and mitigation of potential failures can prevent costly recalls, rework, or product wastage, thereby lowering overall operational costs (Conceição *et al.* 2019: 2023). This proactive approach enhances both the financial performance and reliability of packaging operations, contributing to sustainable and efficient business practices.

Through systematically identifying and mitigating potential failures, FMEA ensures consistent product quality, reinforcing consumer trust and loyalty. This reliability enhances the brand's reputation, positioning it as a trusted and dependable choice in the market (Uzoigwe 2024: 213). Consequently, FMEA contributes to long-term brand success and customer satisfaction.

As the FMCG sector places greater emphasis on sustainability, FMEA helps identify potential environmental impacts of packaging materials and processes, promoting the creation of more eco-friendly solutions (Mohan 2023: 2). This ensures that new packaging innovations are not only effective but also align with sustainability goals, leading to more responsible and sustainable practices in the industry.

FMEA also improves logistic efficiency by identifying potential failures in packaging that could impact transportation, resulting in more robust packaging solutions and optimised supply chain performance (Kilic *et al.* 2023: 93). By proactively mitigating these risks, FMEA contributes to a more resilient and streamlined supply chain, ensuring consistent delivery of high-quality products.

FMEA is a powerful tool in the FMCG packaging sector, contributing to product safety, operational efficiency, innovation, cost management, and brand strength. Its proactive, systematic approach enables companies to anticipate, prevent, and manage risks, making it essential for achieving high-quality, sustainable, and consumer-focused packaging solutions.

The next section reviews case studies where FMEA has been implemented in the FMCG sector and show its practical benefits.

2.4.1 Case Studies of the FMCG Sector where FMEA has been Implemented

In this section, different FMCG companies that have used FMEA to achieve different organisational targets are discussed.

Nestlé implemented FMEA to enhance its packaging processes for a popular beverage line. The analysis identified critical failure modes, such as weak seals that could result in product spoilage. By addressing these issues, Nestlé significantly reduced the number of product recalls, improved consumer safety, and achieved cost savings through reduced waste and rework. This proactive approach not only strengthened regulatory compliance but also enhanced the brand's reputation (Uzoigwe 2024: 221). Through FMEA, Nestlé was able to ensure more reliable and sustainable packaging solutions, reinforcing its commitment to quality and customer satisfaction.

Unilever, recognized for its dedication to sustainability, applied FMEA in the redesign of its packaging for personal care products. The analysis concentrated on environmental impacts, including material degradation and recyclability. By addressing potential issues through FMEA, Unilever successfully introduced more eco-friendly packaging solutions. This not only advanced the company's sustainability goals but also positively influenced consumer perceptions of the brand's commitment to environmental responsibility (Ananda and Wessiani 2023: 54). FMEA played a critical role in aligning Unilever's packaging innovations with its broader sustainability initiatives, fostering trust and loyalty among environmentally conscious consumers.

Procter & Gamble (P&G) applied FMEA to optimize the packaging process for a household cleaning product. The company analysed failure modes related to packaging material defects and process variability. The insights gained from FMEA led to improvements in material handling procedures. As a result, P&G achieved a significant reduction in packaging defects, enhancing operational efficiency and reducing costs. Additionally, the improved process contributed to a more consistent product presentation, ensuring customer satisfaction and brand reliability (Mandal 2024: 565). This proactive approach to risk management helped P&G maintain high standards in product quality.

PepsiCo utilised FMEA to address quality control issues in snack packaging. The analysis focused on potential failure modes such as incorrect sealing, packaging material contamination, and label misalignment. By implementing targeted corrective actions based on FMEA findings, PepsiCo improved packaging integrity and product safety. This led to a significant reduction in product defects, fewer consumer complaints, and lower costs associated with product returns and recalls. As a result, PepsiCo strengthened its brand trust and maintained a higher level of customer satisfaction (Dodin 2015: 41). Through these enhancements, FMEA contributed to the company's overall commitment to quality and operational excellence.

Coca-Cola applied FMEA to its beverage can production line, focusing on can integrity and filling process issues. The analysis identified risks related to can defects like leaks and dents, as well as filling process concerns such as contamination and overfills. The improvements made because of FMEA reduced the frequency of defects and enhanced overall product quality. Coca-Cola benefited from cost savings through decreased wastage and fewer quality control issues, demonstrating FMEA's effectiveness in optimising production processes (Taifa, Makundi and Mwaluko 2022: 536). This proactive approach not only improved product reliability but also reinforced customer satisfaction and brand reputation.

These real-world examples indicate that FMEA is not just a quality tool but a strategic enabler in the FMCG sector, supporting regulatory compliance, cost-efficiency, sustainability, and consumer loyalty through smarter, risk-informed packaging decisions.

The next section focuses on different corrective and preventative maintenance ratios that are used in various industries and how they are calculated in different sectors.

2.5 What are Maintenance Ratios, and How are they Calculated

Maintenance Ratios reflect industry practices based on historical data, equipment criticality, and cost-efficiency analyses. These ratios provide valuable insights into how industries manage the balance between preventive and corrective maintenance, ensuring optimal performance while controlling costs (Cousineau 2023: 1). By continuously monitoring these ratios, organisations can improve maintenance strategies to reduce downtime and extend the lifespan of equipment.

Equation 2.1: Maintenance Ratio

$$Maintenance\ Ratio = \frac{(Corrective\ Maintenance\ (hours\ or\ cost)}{Total\ Maintenance} : \frac{(Preventive\ \ Maintenance\ (hours\ or\ cost))}{Total\ Maintenance}$$

2.5.1 Maintenance Ratios Found in Various Industries and Sectors

In the manufacturing industry, corrective maintenance typically accounts for 30% to 40% of maintenance activities, while preventive maintenance generally comprises 60% to 70%. For example, a common ratio in manufacturing is 35% corrective to 65% preventive, which helps manage costs and maintain high equipment reliability (Gordon 2021: 92). This balance ensures that potential failures are addressed before they impact production, enhancing overall system performance. The typical ratio is 35:65, meaning 35% of maintenance is corrective and 65% is preventive.

In the oil and gas sector, the emphasis is on reducing unplanned downtime due to the high cost and critical nature of equipment. Consequently, corrective maintenance usually makes up 20% to 30% of the total maintenance activities, with preventive maintenance constituting 70% to 80%. A typical ratio in this industry might be 25% corrective to 75% preventive, reflecting a focus on proactive maintenance to ensure safety and equipment reliability (Sigsgaard *et al.* 2021: 2). This approach helps mitigate risks associated with equipment failures and ensures the smooth operation of critical systems, ultimately enhancing overall operational efficiency and safety. The ratio is 25:75, reflecting a strong emphasis on preventive maintenance due to the high-risk nature of this industry.

Utilities, which rely on continuous service, aim for a similar balance but with slight variations. Corrective maintenance in this sector is usually between 25% and 35%, while preventive maintenance ranges from 65% to 75%. A common benchmark for utilities is a ratio of 30% corrective to 70% preventive, which helps achieve operational reliability and control maintenance costs (Chover, Viciano and Sancho 2020: 218). This balance ensures that critical infrastructure operates smoothly, minimizing disruptions and maintaining high standards of service quality. The ratio is 20:80, as utilities heavily rely on preventive maintenance to prevent outages.

In the healthcare industry, where equipment reliability is critical for patient safety, corrective maintenance is generally lower, ranging from 20% to 30%. Preventive maintenance, on the other hand, is higher, between 70% and 80%. Healthcare facilities often target a ratio of 25% corrective to 75% preventive to ensure that medical devices function properly and safely (Schewelov 2022: 35). This focus on preventive maintenance minimizes risks associated with equipment failure, ensuring the highest standards of care are maintained.

In the Fast-Moving Consumer Goods (FMCG) sector, maintaining high equipment uptime is crucial due to the continuous production processes. This reliance on seamless operations ensures a strong focus on preventive maintenance to minimize disruptions. Preventive measures such as routine inspections, planned maintenance schedules, and predictive analytics are used to reduce unplanned downtime. Maintenance activities are preventive, 70 to 80 % in this sector, with corrective maintenance accounting for only 20% to 30%. This emphasis on preventive maintenance ensures that any unexpected breakdowns have minimal impact on production, helping to avoid costly delays and downtime (Elsawaf 2023: 1). Consequently, FMCG companies prioritise proactive maintenance strategies to maintain operational efficiency and product reliability.

A proactive maintenance strategy, heavily weighted toward preventive maintenance, is a common best practice across industries. The exact balance may vary based on the risk level, cost of downtime, and criticality of equipment, but the consistent goal is to enhance reliability, efficiency, and safety while minimising costs and disruptions.

In the next section, a deeper understanding of the different types of maintenance and the different matrices that the researcher used to evaluate maintenance practice performance are discussed.

2.6 Types of Maintenance and Maintenance Practice Evaluation Matrices

An understanding of the various types of maintenance and maintenance matrices used to understand if maintenance practices are successful, are discussed

2.6.1 Maintenance Practice Evaluation Matrices

Benchmarking and performance metrics are essential for evaluating maintenance practices and ensuring continuous improvement. Metrics like Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and Overall Equipment Effectiveness (OEE) are commonly used to assess maintenance performance. Comparing these metrics against industry standards is crucial for identifying areas for improvement. Achieving a 20% improvement in MTBF and a 15% reduction in MTTR are typical benchmarks for effective maintenance strategies (Lukens *et al.* 2019: 8) . These benchmarks help organisations optimise maintenance practices, enhance reliability, and reduce operational costs.

2.6.2 Types of Maintenance

Preventive maintenance (PM) is a critical approach for reducing unplanned downtime and extending equipment lifespan. Successful PM programmes have been shown to decrease maintenance costs by up to 30% and increase equipment uptime by approximately 25%. PM should account for 60% to 80% of total maintenance activities, varying based on the sector (Nedzanani 2021: 10). This focus on preventive measures helps organisations maintain higher levels of equipment reliability and efficiency, ultimately supporting long-term sustainability.

Predictive maintenance (PdM) leverages condition monitoring and data analysis to anticipate equipment failures, making it a highly effective approach for optimizing maintenance practices. Compared to traditional methods, PdM can enhance maintenance efficiency by up to 20%. This method incorporates technologies such as vibration analysis, thermal imaging, and oil analysis, making it particularly valuable in industries with high-value equipment (Achouch *et al.* 2022: 5). By proactively addressing potential issues, PdM helps organizations avoid costly downtime and ensures continuous operational performance.

Corrective maintenance (CM), which is performed after equipment failure, tends to be less cost-effective and time-efficient compared to preventive or predictive methods. CM often results in higher costs and extended downtime, which can disrupt operations and reduce overall productivity. Ideally, CM should constitute no more than 30% to 40% of total maintenance activities. Over-reliance on CM can lead to increased operational expenses and decreased equipment reliability, impacting long-term efficiency (Baiganov 2023: 104).

Reliability-Centred Maintenance (RCM) is a strategic approach that focuses on identifying critical components and implementing maintenance strategies tailored to their importance in ensuring system reliability. By prioritizing resources where they are most needed, RCM can significantly improve maintenance efficiency. It is especially effective in complex systems with diverse equipment and high operational demands, where ensuring reliability is crucial for continuous performance (Kathiresan 2021: 2). This targeted approach helps optimize maintenance activities and minimize the risk of system failures, leading to increased overall operational efficiency.

Total Productive Maintenance (TPM) is a comprehensive approach that involves the active participation of all employees in maintaining equipment and enhancing processes. By fostering a culture of continuous improvement, TPM can significantly boost OEE. Practices such as autonomous maintenance and planned maintenance contribute to improving OEE by up to 15%, while reducing equipment-related losses. TPM leads to substantial improvements in maintenance performance, which highlights its effectiveness in optimising operational efficiency (Moreno 2020: 81). This approach not only enhances reliability but also drives long-term sustainability in maintenance practices.

Organisations can adopt preventive, predictive, and strategic approaches to improve equipment reliability, reduce downtime, enhance safety, and support sustainable operations across sectors and leverage key performance metrics to determine their success.

The next section a discussion of common failure modes in packaging, the causes of these failures and some of the ways to prevent these failures is undertaken.

2.7 Critical Failure Modes in Packaging Equipment

This section discusses common failure modes in packaging and the impact of these failures have on the business, and then explores various preventative measures of these failures.

2.7.1 Common Failure Modes

Mechanical failures are some of the most prevalent issues, including breakdowns of moving parts such as conveyor belts, gears, and motors. These failures often result from wear and tear, misalignment, or insufficient lubrication. Mechanical issues can cause unexpected downtime, and significantly disrupts production schedules. Regular inspections and proper maintenance practices, including routine lubrication and alignment checks, are crucial for addressing these challenges (Dong 2020: 763). By proactively managing these aspects, organisations can minimise disruptions and maintain smooth operations. Tsarouhas (2020: 240) highlights that the costs associated with repairs and product losses during such downtimes further underscores the importance of preventative measures. Regular maintenance and timely repairs are, therefore, critical in minimising disruptions and maintaining smooth operations. Addressing these challenges effectively ensures that packaging systems remain reliable and capable of meeting production demands.

Electrical failures are a common concern in packaging equipment, involving issues such as short circuits, wiring problems, or malfunctions in control systems and sensors. These failures can lead to equipment stoppages or inconsistent performance, impacting overall packaging efficiency. Electrical failures are frequently caused by component degradation, power surges, or improper installation. Preventive measures, such as regular inspections of electrical components, the use of surge protectors, and ensuring proper wiring and connections, are essential for minimizing these issues (Zhou *et al.* 2022: 1). By addressing these factors proactively, organisations can enhance equipment reliability and reduce downtime. Domingues (2021: 6) emphasizes the importance of preventive measures, including regular inspections and the use of surge protectors, in mitigating these risks. By addressing potential electrical issues proactively, organizations can ensure stable equipment performance and maintain safe, efficient packaging operations.

Pneumatic and hydraulic failures are frequent issues in packaging equipment, impacting systems used for actuation and pressure control (Lené and Rajashekarappa 2021: 1). These failures often result from leaks, pressure drops, or component malfunctions, leading to disruptions in the overall system operation. Leaks and pressure drops can cause significant downtime and decreased efficiency. To address these challenges, regular maintenance of hoses, fittings, and pressure regulators, along with the timely replacement of faulty components, is crucial for ensuring smooth operations (Papoutsidakis *et al.* 2019: 33) . Implementing these preventive measures helps reduce the likelihood of system failures, enhancing the reliability and productivity of packaging equipment. Orošnjak (2021: 1) states that pneumatic and hydraulic failures, such as leaks and pressure drops, can greatly hinder equipment functionality; therefore, regular maintenance and prompt replacement of defective parts must be done to address such challenges to ensure that the system pressure is maintained so organisations can enhance operational reliability.

Control system failures, such as issues with programmable logic controllers (PLCs), human-machine interfaces (HMIs), and other automation components, can disrupt the smooth operation of packaging processes. These failures are typically caused by software glitches, incorrect programming, or hardware malfunctions, which can lead to inefficiencies and downtime. To address these challenges, regular software updates, comprehensive testing of control systems, and proper operator training are essential practices. These measures ensure the reliability and seamless functioning of automated systems, helping to minimize disruptions and enhance overall operational efficiency (Obele, Aikhuele and Nwosu 2024: 1). Regular software updates and comprehensive operator training can be done to address these challenges. By maintaining control system integrity, organizations can ensure operational stability and uphold both safety and efficiency in their packaging (Conklin 2020: 1987).

Material handling failures, which occur when equipment used for moving and sorting packaging materials malfunctions, can result in blockages, jams, or misalignment. These issues disrupt the flow of operations, leading to delays and increased downtime. Regular cleaning, inspection, and calibration of material-handling systems are essential for preventing common problems such as blockages and jams. Additionally, ensuring that materials are accurately loaded and aligned helps minimize handling failures. This proactive approach improves overall system reliability and operational efficiency (Cornejo 2019: 259). Falkenberg and Spinler (2022: 1) emphasize that regular cleaning, inspection, and calibration of material-handling systems are essential for preventing such failures. By maintaining these systems proactively, organizations can ensure smooth operations and minimize the risk of production disruptions.

Seal and closure failures, which can lead to leakage, contamination, or compromised product integrity, are frequently caused by defects in sealing equipment or improper sealing processes. These failures can result in serious quality control issues and costly product recalls. Regular inspection and calibration of sealing equipment, along with adherence to proper sealing procedures, are essential for preventing these types of failures. This proactive approach ensures that seals remain reliable, maintaining product safety and quality standards (Ilhan *et al.* 2021: 326). Implementing these practices helps reduce the risk of seal-related issues, improving overall packaging efficiency and customer satisfaction. Regular inspection and calibration of sealing equipment, as well as strict adherence to proper sealing procedures, must be executed to mitigate risks. By prioritising these measures, organizations can maintain high product standards and safeguard their reputation (Gellerich and Majschak 2023: 383).

Labelling and coding failures occur when equipment used to apply labels or print codes on packaging malfunctions. Common issues include misaligned labels, incorrect codes, and printing errors, often caused by equipment misalignment or ink problems. Regular maintenance, calibration, and verification of labelling and coding systems are essential for ensuring accurate and reliable labelling. These practices help minimize errors, maintain product quality, and prevent potential customer dissatisfaction and regulatory issues (Krzysztof 2021: 125). Ensuring the consistent performance of labelling systems enhances the overall integrity of the packaging process. The importance of regular maintenance and calibration of labelling and coding systems cannot be overlooked to prevent such errors. By ensuring accuracy in labelling and coding processes, organizations can maintain regulatory compliance and streamline inventory management (Lindberg and Sohlin 2021: 17).

Packaging equipment faces a variety of mechanical, electrical, and system-related failures that can disrupt production and compromise product quality. These failures often stem from wear and tear, misalignment, software glitches, or component degradation. To maintain smooth operations and uphold product integrity, proactive maintenance practices are essential across all systems. Across all failure types, preventive maintenance—including regular inspections, calibration, cleaning, and staff training is essential for minimizing disruptions, ensuring product quality, and sustaining efficient operations. By implementing proactive strategies, organizations can prevent costly downtime, maintain regulatory compliance, and build consumer trust through consistent packaging performance.

The next section discusses the common challenges faced with optimizing corrective and preventative maintenance ratios.

2.8 Common Challenges of Optimising in Corrective/Preventive Maintenance Ratios

In this section, the different challenges that are faced, attempting to optimize a Corrective/ Preventive Maintenance Ratio and various strategies of maintenance optimisation are explored.

2.8.1 Challenges Associated with Optimising Corrective/Preventive Maintenance Ratios

One key challenge is achieving the right balance between PM and CM. PM involves scheduled tasks to avoid equipment failures, while CM addresses issues after they occur. Overemphasis on PM can lead to unnecessary downtime and higher costs, whereas prioritising CM may result in frequent failures and production disruptions. Stenstrom *et al.* (2016: 603) suggest that organisations can overcome this challenge by thoroughly analysing equipment failure patterns and maintenance history. By doing so, a balanced approach that minimises costs and maximises system reliability could be developed.

Accurate data collection and analysis are essential for developing effective maintenance strategies, yet they present significant challenges for many organisations. Reliable data on equipment performance, failure rates, and maintenance activities are critical for informed decision-making. However, organisations often face difficulties in gathering and analysing this data effectively. Incomplete or inaccurate data can hinder the ability to make sound decisions. Sala *et al.* (2019: 5) highlight that implementing robust data collection systems and leveraging advanced analytics can help address this issue. While these solutions demand substantial resources and effort to establish and maintain, they are vital for optimising maintenance strategies and improving operational efficiency.

Resource allocation is a critical challenge in optimising the balance between PM and CM. The efficient use of personnel, tools, and spare parts is essential to maintaining operational effectiveness. However, many organisations struggle to allocate resources appropriately. Overcommitting to PM can lead to the underutilization of skilled personnel, while inadequate resources for CM can prolong downtime and escalate repair costs. Hamasha *et al.* (2023: 2) emphasize the importance of developing a clear maintenance strategy and regularly reviewing resource allocation to address these issues. By doing so, organisations can optimise resource use and enhance overall maintenance efficiency.

Integrating PdM into existing strategies is a complex endeavour. PdM leverages condition-monitoring technologies and data analytics to anticipate equipment failures, shifting the focus from scheduled preventive maintenance to condition-based interventions. However, the implementation of PdM demands substantial investment in specialized equipment and training, which can pose a significant challenge. Wernera, Zimmermann and Lentes (2019: 1) highlight that integrating PdM data with existing maintenance systems requires substantial adjustments, adding complexity to the process. For the integration to take place, there must be careful planning and adaptation to ensure a seamless transition to a more predictive approach.

Changes in operational conditions significantly influence maintenance needs and effectiveness. Fluctuations in production schedules, equipment usage patterns, and environmental factors require constant adjustments in maintenance strategies. According to Dhamodharan (2021: 12) continuous monitoring and flexibility in maintenance planning are essential to effectively respond to these dynamic conditions. This adaptability ensures that maintenance efforts remain aligned with the evolving demands of the operational environment.

Cultural and organizational factors play a significant role in the effectiveness of maintenance strategies. Resistance to change, poor communication between maintenance and production teams, and inadequate training can create barriers to optimising maintenance efforts. Fostering a culture of continuous improvement and collaboration is crucial for overcoming these challenges. By investing in training and promoting a proactive maintenance culture, organisations can better align maintenance activities with overall organizational goals. Ogunbayo *et al.* (2022: 1) states that these efforts contribute to a more effective and integrated maintenance approach, ensuring smoother collaboration and improved outcomes.

Cost management is a significant challenge in maintenance. PM involves costs related to scheduled tasks and resources, while CM often leads to unexpected expenses and downtime. Balancing these costs while ensuring equipment reliability and minimizing production disruptions requires careful financial planning. Implementing cost-effective maintenance practices and consistently reviewing maintenance expenditure can effectively manage these financial challenges (Mohamad *et al.* 2022: 1054). Additionally, leveraging predictive maintenance technologies can further optimize costs by anticipating and mitigating potential issues before they escalate, ensuring a more efficient use of resources.

Organisations must adopt a strategic, flexible, and data-driven approach to overcome maintenance challenges. A balanced mix of PM, CM, and PdM—

supported by strong data systems, efficient resource use, and a collaborative culture can significantly enhance equipment reliability, reduce costs, and ensure smooth operations.

2.8.2 Strategies on Maintenance Optimisation

RCM is a strategy used to assess the importance of equipment and tailor maintenance efforts accordingly. By allocating resources to high-risk areas and optimising preventive tasks for less critical equipment, organisations can achieve a more balanced and effective maintenance approach (Jongea and Scarf 2020: 805). This targeted approach ensures that maintenance efforts are aligned with both operational needs and risk management objectives.

Computerised Maintenance Management Systems (CMMS) and Enterprise Asset Management (EAM) systems can be used to improve data accuracy and accessibility. These systems enable real-time data collection, trend analysis, and predictive analytics, which are crucial for informed decision-making. Advanced data analytics and machine learning algorithms further enhance maintenance strategies by identifying patterns and predicting potential failures. This not only streamlines maintenance activities but also improves overall maintenance planning and resource allocation (Sveinsvoll 2024: 57).

The TPM approach can be used to maximise the use of resources. The TPM's emphasis is on involving all employees in maintenance activities to ensure the effective utilisation of tools and personnel. Moreover, employing performance metrics such as MTBF and MTTR allows organisations to allocate resources more efficiently, leading to enhanced maintenance outcomes (Mohad *et al.* 2024: 1) . This strategic approach ensures that maintenance efforts are aligned with operational needs, reducing downtime and optimising resource use.

Integrating PdM into existing strategies significantly improves maintenance effectiveness. The use of condition-monitoring technologies, such as vibration analysis, infrared thermography, and oil analysis, can be implemented. PdM enables the anticipation of equipment failures, thereby reducing unplanned downtime and maintenance costs. Successful integration requires aligning PdM data with existing maintenance processes and investing in staff training to effectively interpret and act on predictive insights (Goriparthi 2023: 479) . This proactive approach ensures that maintenance efforts are optimised, enhancing overall equipment reliability and operational efficiency.

Implementing dynamic maintenance scheduling systems that adjust based on real-time production data and equipment performance is crucial. This adaptability ensures that maintenance activities are aligned with operational changes, such as increased production demands or fluctuations in equipment usage, helping to maintain optimal equipment performance and minimize disruptions (Introna and Santolamazza 2024: 1405). By staying agile, organisations can better manage the complexities of modern manufacturing environments, ensuring efficiency and reliability.

Fostering a maintenance culture that prioritises continuous improvement and collaboration is essential. Leadership plays a key role in promoting a proactive maintenance culture by providing the necessary training and resources. Engaging employees in maintenance activities and ensuring open communication between maintenance and production teams can significantly enhance maintenance effectiveness and align with organisational goals (Dixon 2021: 35). This holistic approach ensures that both technical and cultural aspects are integrated, driving sustainable improvements in maintenance performance.

Informed decisions can be made by adopting a life-cycle cost (LCC) approach to evaluate the total cost of ownership for equipment, including maintenance expenses. LCC analysis also helps organisations make informed decisions about maintenance investments, ensuring cost-efficiency over the long term (Dui, Zhang and Guanghan Bai 2024: 1) . This proactive approach ensures that resources are allocated efficiently, minimising unnecessary expenditures and enhancing overall maintenance sustainability.

Integrating advanced tools, collaborative culture, and data-driven strategies can create an efficient, flexible, and cost-effective maintenance framework. These proactive approaches not only enhance equipment reliability and reduce downtime but they also ensure that maintenance practices evolve alongside operational needs and technological advancements.

The next section discusses the limitations of using the traditional FMEA system.

2.9 Limitations of the Traditional FMEA

Traditional FMEA has been criticised for several limitations. Traditional FMEA treat the three key risk factors, occurrence, severity, and detection, as equally important. This uniform weighting can result in inaccurate risk prioritisation, as it fails to consider the varying relevance of each factor depending on the specific context (Shahri, Jahromi and Houshmand 2021: 13).

The conventional FMEA approach struggles with imprecise and uncertain data. It relies on crisp numerical values for risk factors, which may not accurately capture the subjective judgments of experts. This shortcoming has prompted the development of advanced methods, such as those incorporating fuzzy logic, to better handle uncertainty and ambiguity in risk assessments (Jing, Fang and Song 2019: 195).

The RPN calculation is based on the simple multiplication of occurrence, severity, and detection scores, has also faced criticism. This method is overly simplistic and does not adequately reflect the complex interdependencies among system components. It also overlooks the relative importance, or weight, of each risk factor (Liu, Shen and Geng 2023: 2).

Conventional FMEA has demonstrated inconsistencies in risk assessment outcomes, this is due to variability in RPN values when different teams evaluate the same scenarios, underscoring the need for more robust and consistent evaluation methodologies (Zhen and Luyuan 2019: 145).

2.9.1 Section Summary

This section underscores the need for improved FMEA methodologies, such as those using fuzzy logic or weighted scoring, that better handle uncertainty, emphasise contextual relevance, and provide more consistent and accurate risk evaluations.

2.10 Hybrid Frameworks

This section shall look at how FMEA was integrated into different frameworks to enhance its effectiveness and address limitations.

2.10.1 Integrating FMEA and Creating Hybrid Frameworks

Several studies have proposed integrating FMEA with decision-making frameworks to improve risk assessment. For instance, a hybrid FMEA framework combines the TODIM approach (an acronym in Portuguese of Interactive and Multi-criteria Decision Making) and Choquet integral method to account for psychological behaviours and interactions among risk indicators, using generalised trapezoidal fuzzy numbers to handle uncertainty *(Weizhong Wanga et al.* 2019: 516).

The integration of Multi-Criteria Decision-Making (MCDM) methods with FMEA has been explored to enhance risk prioritisation. This framework combines the best-worst method (BWM) and stochastic multi-objective acceptability analysis (SMAA), and measurement of alternatives and ranking according to compromise solution (MARCOS) to determine optimal risk factor weights and prioritise failure modes (Yanbing *et al*. 2024: 18).

A data-driven FMEA framework has been developed to provide objective risk assessments by utilising data-driven risk factors such as failure frequency and cost implications. This approach uses the Intra-criteria Correlation (M-CRITIC) method to assign weights to risk factors and the Alternative Comparison (ABAC) method for risk prioritisation (Ervural and Halil 2023: 1).

FMEA methods have been improved by using language-based and group decision-making approaches. One such method involves using a special type of fuzzy logic that allows people to express hesitation and uncertainty in their opinions. This helps a group agree more easily when ranking failure modes by risk levels (Hengjie Zhang 2019: 580).

Improved FMEA frameworks have demonstrated higher consistency in risk assessments compared to traditional methods. An improved FMEA framework showed near-perfect correlation in risk assessments, highlighting its consistency over traditional FMEA (Subriadi and Najwa 2020: 11). Many hybrid FMEA frameworks aim to reduce subjectivity and better handle uncertainty in risk evaluations. Techniques such as fuzzy logic, hesitant fuzzy sets, and linguistic variables are commonly used to address these challenges *(Weizhong Wanga et al.* 2019: 525).

2.10.1.1 Section Summary

FMEA frameworks have evolved significantly through the integration of advanced decision-making methods and data-driven approaches. By combining techniques like fuzzy logic, MCDM methods (TODIM, BWM, MARCOS), and objective data analysis (M-CRITIC, ABAC), these hybrid models aim to improve the accuracy, consistency, and reliability of risk assessments. They help reduce subjectivity, better manage uncertainty, and encourage group consensus.

ISO 9001 and the PepsiCo's Maintenance Methodology will be discussed next.

2.10.2 FMEA Integrated with Various Manufacturing Tools

FMEA can be used with other manufacturing tools and benefits could be obtained by combining the different tools with FMEA. By integrating FMEA with Root Cause Analysis (RCA), organisations can address existing problems and prevent future ones, creating a more comprehensive quality management system. RCA identifies the root causes of current issues, and FMEA anticipates potential failures during the design and planning stages. This combination not only resolves present challenges but also strengthens overall system reliability (Chi, Sigmund and Astardi 2020: 1).

While Statistical Process Control (SPC) monitors and controls processes through statistical methods, FMEA identifies critical parameters that could lead to failures if they deviate from set limits. It highlights areas where SPC needs to focus more closely, thereby improving process control precision. This integration ensures that potential issues are addressed before they escalate, contributing to a more stable production process (Hanum 2022: 11).

Design of Experiments (DOE) investigates the effects of various variables on outcomes, but FMEA can identify which factors are most likely to cause failures.

This allows DOE to focus on the most significant risks first, making the experimentation process more efficient. Thus, FMEA guides DOE to produce more effective process optimisation, ultimately leading to better product quality (Kurniaa, Jaqinb and Hardi Purbac 2022: 4).

Quality Function Deployment (QFD) translates customer needs into specific product features, and FMEA ensures these features are robust by identifying and addressing potential failure modes early in the design phase. This proactive approach helps to ensure that the final product consistently meets customer expectations. Therefore, integrating FMEA with QFD contributes to higher customer satisfaction and more reliable products (Burak and Omer 2021: 10159).

FMEA can predict issues such as waste using RPN methodology, which will further enable Six Sigma and Lean (LSS) methodologies to address issues more effectively. This integration not only supports the reduction of defects and inefficiencies but also ensures that improvements are sustained over time. Therefore, FMEA plays a crucial role in enhancing the overall effectiveness of continuous improvement efforts (Hii, Muhammada and Muhammad 2024: 185).

2.10.2.1 Section Summary

FMEA complements various quality management tools by proactively identifying risks and failure modes. When integrated with tools like RCA, SPC, DOE, QFD, Six Sigma, and Lean, it enhances their effectiveness and contributes to more reliable processes, better product quality, and higher customer satisfaction.

In the next section, we will unpack ISO 9001 and PEMM.

2.11 ISO 9001 Standards and PEMM

The next section unpacks ISO 9001 and PEMM.

2.11.1 ISO 9001 Standards in relation to Maintenance Practices or Processes

ISO 9001 is an internationally recognised standard that specifies the requirements for a QMS. ISO 9001 requires that equipment used for monitoring and measurement be regularly calibrated and verified to maintain accuracy (Hui, Daud and Nadi 2025: 313). Organisations must maintain detailed records of all maintenance activities, including calibrations and repairs, to provide evidence of adherence to effective maintenance practices. This ensures transparency and accountability in maintaining high-quality operational standards (Mami *et al.* 2019: 97).

In quality management, ISO 9001 requires organisations to establish, implement, maintain, and continually improve a QMS. This includes defining quality objectives, policies, and procedures to ensure all processes, including maintenance, align with these objectives. The standard emphasises a risk-based approach, which requires organisations to identify and address risks and opportunities that could impact the QMS, including those related to equipment maintenance. This proactive approach helps prevent potential issues and enhances the maintenance processes (Mustapha, Ashfaq and Qureshi 2019: 4519).

The standard highlights the importance of aligning processes with customer requirements and satisfaction. Effective maintenance plays a crucial role in achieving this by ensuring that products are consistently produced and meet established quality standards, thereby meeting and exceeding customer expectations. This holistic approach fosters a culture of continuous improvement, ensuring that maintenance practices support both operational excellence and customer satisfaction (Sfreddo *et al.* 2019: 337).

Internal audits are a vital component of ISO 9001, as organisations must conduct regular assessments to evaluate the effectiveness of their Quality Management

System (QMS), including maintenance processes. These audits help identify areas for improvement and ensure that maintenance procedures are consistently followed. ISO 9001 states that top management should periodically review the QMS to ensure its ongoing suitability, adequacy, and effectiveness. This review should encompass an evaluation of maintenance activities and their impact on the overall quality management system (Crispim Camango and Candido 2023: 1766). Therefore, by integrating maintenance into the continuous review process, organisations can maintain high-quality standards and ensure that their processes are aligned with evolving business and customer needs (Crispim Camango and Candido 2023: 1766).

2.11.2 Section Summary

ISO 9001 provides a structured and strategic foundation for embedding maintenance within a broader quality management framework. It reinforces that maintenance is not just about fixing equipment but about ensuring reliability, compliance, and quality outcomes across the entire value chain. By adhering to ISO 9001, organisations can ensure sustained operational excellence and continuous improvement.

In the next section an evaluation of PEMM is undertaken.

2.11.3 PepsiCo Maintenance Methodology

According to the PEMM Training Guide (2014: 9), effective maintenance is a critical component of operational success in the manufacturing industry. At PepsiCo, maintaining high standards in equipment reliability, cost efficiency, and production performance is essential for sustaining business competitiveness. To achieve this, PepsiCo has developed PepsiCo Europe's Maintenance Methodology (PEMM), which is a structured framework that enhances maintenance operations through standardisation, data-driven decision-making, and industry benchmarking. PEMM provides a roadmap for sites to transition from reactive maintenance to a world-class maintenance environment, ultimately optimising costs and improving overall reliability.

The PEMM model is a standardised framework designed to assess and improve maintenance practices across its sites, with the goal of shifting from reactive to proactive, world-class maintenance. It is built on three core axes: the Value of Maintenance, which uses key performance indicators (KPIs) to measure safety, efficiency, and cost-effectiveness; Finding the Detail, which categorises sites into maturity levels (Reactive, Control, Innovative, World-Class) to identify gaps and guide improvements; and Identifying Opportunities, which focuses on using assessment insights to develop structured Maintenance Improvement Action Plans (MIAPs) targeting areas like reliability, planning, execution, and cost control. The model supports continuous improvement and alignment with global best practices through certified assessors who conduct evaluations periodically (Europe Maintenance Academy 2013: 1).

2.11.3.1 Section Summary

PEMM is PepsiCo’s strategic tool for transforming its maintenance operations by combining standardisation, data analytics, benchmarking, and employee involvement. It provides a clear roadmap for achieving excellence in maintenance through continuous assessment and targeted action that ultimately improves the organisation's reliability, safety, efficiency, and profitability.

The following section will discuss how the audit's findings can be utilised to improve maintenance practices.

2.12 Audit Findings and Recommendations

The discussion below focuses on an understanding of how audit findings from ISO 9001 and PEMM add value to the enhancement of current maintenance practices.

2.12.1 Benefits of Audit Findings to Maintenance Practices

Audit findings provide significant benefits to maintenance practices by identifying non-conformities and highlight areas that require improvement, ensuring alignment with the overall Quality Management System (QMS). Through systematic audits, deviations such as inadequate maintenance schedules, incomplete documentation, or improper equipment calibration are detected, allowing organisations to implement corrective actions. This process not only enhances compliance with established standards but also promotes continuous improvement in maintenance activities, leading to increased equipment reliability, better record-keeping, and overall operational efficiency (Felipe and Nunez 2020: 1).

Following the identification of non-conformities, a root cause analysis is conducted to uncover the underlying reasons behind maintenance issues. If an audit reveals inconsistent calibration records, the root cause analysis may reveal factors such as insufficient training, inadequate documentation practices, or equipment malfunctions. Understanding these root causes is crucial for effectively addressing the issues and implementing preventive measures to avoid recurrence. Therefore, this approach ensures that maintenance practices are continuously improved, enhancing overall system effectiveness and reliability (Calderón, Caleb and Collao 2024: 1067).

Moso (2021: 53) states that audit findings and root cause analysis are used by organisations to develop action plans to address identified issues. These plans outline specific corrective and preventive measures designed to rectify non-conformities and improve maintenance practices. An action plan may involve revising maintenance procedures, enhancing training programmes for maintenance personnel, or upgrading equipment to meet calibration standards. Hence, this structured approach supports continuous improvement and maintains the integrity of the QMS.

The implementation of these improvements follows the development of action plans. This phase may involve updating existing procedures, providing additional training for staff, or upgrading equipment and technology to ensure compliance with standards. Effective implementation ensures that both corrective and preventive measures are executed, and maintenance activities are adjusted accordingly. Ongoing monitoring throughout this phase is crucial to confirm that the changes are not only effective but also sustainable over the long term (Balon, Dziadkowiec and Dobrowolska 2024: 479).

After implementing improvements, organisations must engage in continuous monitoring and review to ensure that the changes lead to sustained enhancements in maintenance practices. Tracking the effectiveness of implemented measures and verifying that audit issues have been resolved are critical. Regular internal audits and performance reviews help assess the impact of these changes and identify any new issues. This ongoing monitoring ensures that maintenance practices remain aligned with standards and support overall quality management (Vosloo 2019: 13).

Documentation and reporting are essential for maintaining compliance and demonstrating continuous improvement. These documents serve as evidence of adherence to standards and provide a clear track of progress over time. Regular reporting of outcomes to relevant stakeholders promotes transparency and accountability in maintenance practices, ensuring that all activities are aligned with quality management objectives (Peik 2019: 22).

The principle of continuous improvement, as emphasised by standards, plays a crucial role in the ongoing refinement of maintenance practices. Insights gained from audits provide valuable opportunities to enhance processes and performance. By fostering a culture of continuous improvement, organisations ensure that their maintenance practices are regularly reviewed and updated, resulting in improved efficiency, reliability, and overall quality. This commitment to continuous enhancement ensures that maintenance activities remain aligned with evolving standards and business needs, driving sustained success (Mahabir and Pun 2022: 64).

2.12.2 Section Summary

Audits provide a structured process for identifying weaknesses, implementing corrective actions, and driving long-term improvements that align maintenance with the broader QMS. Audit findings serve as a foundation for enhancing maintenance quality. By identifying non-conformities, analysing root causes, implementing strategic actions, and monitoring progress, organisations can embed a cycle of continuous improvement. This ensures that maintenance practices are not only compliant but also proactive, efficient, and fully integrated into the overall quality management strategy.

The following sections discuss various practices and strategies that can be used to ensure the successful integration of FMEA in a company's existing quality management framework.

2.13 Development of FMEA Implementation Strategies

The various practices and strategies that can be used to integrate FMEA successfully are as follows.

2.13.1 Best Practices for FMEA Implementation

To ensure successful implementation, it is essential to begin by establishing clear objectives for the FMEA (Quigley 2024: 2). Organisations should define specific goals, whether to improve product reliability, minimise defects, or increase process efficiency. Setting clear, measurable objectives aligns FMEA efforts with broader quality management objectives and ensures that the analysis focuses on the most relevant risks and opportunities (Cero and Hasičević 2024: 1).

A key best practice in implementing FMEA is involving cross-functional teams. Engaging members from various departments, such as design, engineering, manufacturing, and quality assurance ensures a holistic approach to identifying potential failure modes and their impacts. Each team member contributes unique expertise, which significantly enhances the effectiveness of the analysis. This collaborative effort fosters a shared understanding of risks and promotes collective responsibility for mitigating them (Majka 2024: 2).

Using a structured approach is essential for consistency and effectiveness in FMEA. The process should begin by defining the scope of the analysis, specifying the process or product being assessed. A systematic method should be employed to identify failure modes, their effects, and causes. Typically, this involves ranking failure modes based on severity, occurrence, and detection to prioritise them. Utilising standardised FMEA templates and tools helps streamline the process and ensures that all critical aspects are thoroughly addressed (Wolniak and Grebski 2023: 633) .

Integrating FMEA with existing quality management processes maximises its impact (Hii, Muhammada and Muhammad 2024: 185). Aligning FMEA activities with other quality management tools, such as root cause analysis and risk management practices, ensures that insights gained from FMEA inform both corrective and preventive actions. Effective integration means that FMEA results are communicated and acted upon within the broader quality framework, addressing identified risks comprehensively (Andrade de Lima *et al.* 2021: 1).

Documentation and tracking of FMEA findings are essential for maintaining transparency and accountability. Comprehensive records of identified failure modes, risk assessments, and the corresponding actions taken are crucial. Maintaining these records allows organizations to monitor progress and assess the effectiveness of risk mitigation efforts over time. This practice ensures that the FMEA process remains effective and adaptable to emerging risks, fostering continuous improvement and maintaining a proactive approach to risk management (Lopez 2023: 15).

Regular review and updates of FMEA are essential to keep it relevant (Gisslen and Gastrin 2021: 63). Periodically revisiting the analysis ensures that it incorporates changes in processes, products, or external factors that may introduce new risks. This approach helps maintain the effectiveness of the FMEA process and ensures it adapts to the organization's evolving needs (Wout 2023: 10).

Training and educating staff on FMEA principles and techniques are crucial for successful implementation (Abrishami *et al.* 2024: 8). Comprehensive training ensures that team members understand their roles and responsibilities within the FMEA process. This fosters expertise and enhances the quality of the analysis, leading to more effective risk identification and mitigation (Gisslen and Gastrin 2021: 62). Well-trained staff contribute to a more accurate and thorough analysis, ultimately improving the organization's ability to manage risks and maintain quality standards.

Leveraging technology can greatly enhance the FMEA process. Specialized FMEA software enables the management and analysis of large data volumes, facilitates team collaboration, and automates various aspects of the analysis. By utilising such tools, organizations can improve the efficiency and effectiveness of the FMEA process, making it easier to track and manage risk mitigation actions (Banduka 2024: 133).

Fostering a culture of continuous improvement supports the long-term success of FMEA. Strong leadership and support are also crucial for the successful implementation of FMEA. Leadership helps overcome resistance to change, secure necessary resources, and emphasise the importance of FMEA within the organisation. Managers play a key role in setting the direction, providing the necessary resources, and endorsing the FMEA process (Zulfiqar *et al.* 2024: 13).

Encouraging a proactive approach to risk identification and promoting a mindset of ongoing enhancement helps integrate FMEA into everyday practices. This culture ensures that FMEA remains a valuable tool for maintaining high-quality standards and achieving operational excellence (Dipak, Kamble and Wankhade 2022: 442).

2.13.1.1 Section Summary

Successful FMEA implementation requires a structured, team-based, and technology-supported approach that can be integrated into the broader quality management system and is driven by strong leadership and a continuous improvement in culture.

In the next section a discussion of the challenges and ways to overcome these challenges is undertaken.

2.13.2 Challenges in Implementing FMEA and Success Factors

Organisations often face resistance from staff who are accustomed to existing processes and view FMEA as an additional burden. This resistance can hinder the adoption of FMEA practices and impact the quality of the analysis. To overcome this challenge, it is crucial to clearly communicate the benefits of FMEA and involve key stakeholders early in the process to secure their support and commitment. By fostering a collaborative approach, organisations can ensure that FMEA is seamlessly integrated into their quality management framework (Zulfiqar *et al.* 2024: 10).

Another challenge in implementing FMEA is ensuring comprehensive participation from cross-functional teams. FMEA requires input from various departments, including design, engineering, and manufacturing. Co-ordinating these diverse teams can be challenging, especially when there are conflicting priorities or communication barriers. Effective co-ordination and fostering a collaborative environment are essential for gathering diverse perspectives and ensuring a thorough analysis: this can be overcome by promoting open communication and establishing clear roles and responsibilities to enhance collaboration and improve the quality of the FMEA process (Marcin 2024: 7).

Data quality and availability are significant challenges in the implementation of FMEA. Accurate and complete data are essential for effectively identifying and assessing failure modes and their associated effects. However, organisations may encounter difficulties with inadequate or unreliable data, which can compromise the effectiveness of the analysis. To address this challenge, it is crucial to implement robust data management practices and ensure the accuracy and reliability of data (Filz *et al.* 2021: 1).

Maintaining consistency across different FMEA analyses is another challenge. Variations on how FMEA is conducted can lead to inconsistent results and reduced reliability. Standardising FMEA procedures, using consistent templates, and employing reliable tools are essential for maintaining uniformity and ensuring consistent, reliable results across various analyses (Oldenhof *et al.* 2010: 592).

In summary, effective communication, collaboration, data quality, and standardisation are key to overcoming common FMEA implementation challenges. Addressing these areas ensures smoother adoption and more accurate, consistent, and valuable risk analysis outcomes.

Focus in the next section is on drawing conclusions from the literature review on the benefits of integrating PEMM with FMEA

2.13.3

2.13.4 Section Summary

Previous discussion unpacked PEMM and FMEA and it was evident that there are various disadvantages of using FMEA in its traditional format. The benefits of combining FMEA with other systems to address its flaws to create hybrid systems was also discussed. The current focus will be on the potential benefits of combining FMEA and PEMM.

Integrating FMEA with Quality Management Systems (QMS) is crucial for enhancing equipment reliability, improving product quality, and ensuring compliance with industry standards (Lee *et al.* 2021: 2). Therefore, the integration of FMEA with PEMM presents a synergistic approach that can potentially enhance the effectiveness of maintenance strategies and operational reliability. Each framework brings unique strengths; however, when combined, they have the potential to address gaps in each system.

Enhancement of PEMM

FMEA serves as an essential tool for identifying potential risks during the design, manufacturing, and process stages which allows for proactive mitigation strategies to be implemented (Plinta, Golinska and Dulina 2021: 325). Thus, FMEA contributes value to PEMM by introducing a structured and analytical framework for risk assessment and prioritisation. It does this through the quantification of failure modes using the RPN and FMEA enables maintenance teams to identify and prioritise potential failures based on severity, occurrence, and detection. This prioritisation informs PEMM by focusing maintenance planning and execution on the most critical risks, thereby improving resource allocation and equipment uptime.

When failures are detected, FMEA can help in analysing their root causes, and the insights gained can lead to refinements in processes, design, and manufacturing practices. This approach directly informs the Corrective and Preventive Actions (CAPA) process, preventing future failures (Al-Hassan and Al-Mahmoud 2024: 10). Therefore, FMEA can facilitate the proactive identification of weaknesses within equipment and systems before failures occur. This predictive capability aligns with PEMM's preventive maintenance goals, thereby strengthening the methodology's effectiveness.

Enhancement of FMEA

FMEA plays a critical role in optimising design and manufacturing processes in reducing defects, additionally identifying critical process steps that require stringent control, which reduces variability and enhances consistency (Introna and Santolamazza 2024: 2). Early application of FMEA can also prevent costly redesign or rework (Ćatić *et al*. 2011: 1). However, FMEA itself does not link directly to PepsiCo's sustainability and compliance initiatives, such as ISO 9001, FSSC, and the triple bottom line (profit, planet, and people). Therefore, it is important to integrate FMEA into PEMM because PEMM audit findings and performance metrics serve as critical inputs for validating and refining FMEA assessments to achieve targets that are in line with company objectives. These audits offer real-time feedback that can highlight emerging risks or the effectiveness of previously implemented FMEA driven actions, thus supporting the dynamic updating of risk registers while continuously enabling the integration of FMEA outcomes that contribute not only to operational reliability but also to strategic corporate goals.

PEMM can also commit to best practices derived from FMEA by embedding them into standard operating procedures, training programs, and knowledge management systems. This could ensure that the insights generated through FMEA are retained, distributed, and consistently applied across maintenance teams. Additionally, PEMM's robust budgeting and resource planning capabilities can ensure that FMEA recommendations are supported with the necessary investment and operational capacity for execution.

In summary, integrating FMEA with PEMM creates a powerful, complementary system that enhances maintenance effectiveness, operational reliability, and continuous improvement. FMEA strengthens PEMM by providing structured risk assessment, prioritisation, and root cause analysis tools, enabling proactive and data-driven maintenance decisions. In turn, PEMM enhances FMEA by embedding it into a broader operational and strategic framework, ensuring its systematic application, alignment with corporate goals (like sustainability and compliance), and long-term impact through training, audits, and resource allocation. Together, they form a more holistic and resilient approach to reliability engineering and maintenance management.

In the next section provides a summary of key findings and some insight on the research gaps.

2.14 Summary and Research Gaps

2.14.1 Summary of Findings

The historical context and development of FMEA are traced from its origins in the U.S. military in 1949 to its adoption in industries such as aerospace, automotive, and manufacturing. Key milestones include its formalisation by Boeing in the 1960s and its integration into the automotive industry's quality standards in the 1980s. The global standardisation of FMEA practices, particularly in the automotive sector, underscores its vital role in ensuring product reliability and safety. FMEA can be categorised into different types, such as DFMEA, PFMEA, SFMEA, and SW-FMEA, each tailored to different aspects of product and process design, manufacturing, and system reliability. The literature emphasises the importance of applying the appropriate type of FMEA based on the specific context and objectives.

FMEA can be integrated with a quality QMS to enhance risk management and continuous improvement efforts. The literature explores how FMEA aligns with other quality tools like RCA and SPC to create a comprehensive approach to quality management. Additionally, it identifies common failure modes in packaging equipment, including mechanical, electrical, pneumatic, hydraulic, control system, material handling, seal and closure, and labelling failures. Addressing these failure modes through regular maintenance and adherence to best practices is deemed crucial for improving equipment reliability and operational efficiency.

Challenges in balancing CM and PM activities are also discussed. Accurate data collection, resource allocation, and adaptation to changing operational conditions are identified as key obstacles that organisations must overcome to optimise their maintenance strategies effectively. The literature further emphasises the importance of implementing PEMM and ISO 9001 standards to improve maintenance management practices. Audit findings play a significant role in identifying areas for improvement and ensuring compliance with quality management requirements.

The application of FMEA in the FMCG packaging industry is shown to enhance product quality, operational efficiency, and consumer safety. Case studies from companies like Nestlé, Unilever, Procter & Gamble, PepsiCo, and Coca-Cola illustrate the practical benefits of FMEA in reducing defects, improving packaging integrity, and supporting sustainability efforts.

The review concludes by discussing best practices for integrating FMEA into existing quality management frameworks, including the importance of clear objectives, cross-functional team involvement, structured methods, and leveraging technology. Continuous review and improvement are crucial for maintaining the effectiveness of FMEA processes. Overall, the literature review underscores FMEA's importance as a vital tool in enhancing equipment reliability, particularly in the FMCG packaging industry. The findings support the need for ongoing research and the development of tailored FMEA strategies to address the specific challenges and dynamics of this sector.

The gaps in the literature, where further research is needed follows in the next section.

2.14.2 Identified Research Gaps

While FMEA has been extensively studied and applied across various industries, there are notable gaps in the literature regarding its application in the FMCG packaging sector, particularly within a quality management framework. One significant gap is the lack of focused studies that benchmark PM and CM ratios, specifically within the FMCG packaging industry. Although industry standards exist, there is a need for research that compares these benchmarks against historical data from FMCG organisations, particularly PepsiCo Prospecton. This study aims to fill this gap by providing insights through a detailed analysis of the organisation's historical maintenance ratios.

Another gap lies in the identification of critical failure modes specific to packaging equipment in the FMCG sector. While failure modes in various industries are documented, the literature does not sufficiently explore the unique failure modes associated with PepsiCo's packaging equipment. This research will address this deficiency by analysing site maintenance records to identify and understand the critical failure modes within the organisation's packaging operations.

Additionally, the challenges in optimising the PM/CM maintenance ratio within the FMCG packaging of PepsiCo South Africa remain underexplored. General challenges in maintenance management are well-documented, but there is a lack of research focused on the unique difficulties faced by this organisation located in South Africa. Through interviews with maintenance management and supervisory staff, this study investigates these specific challenges, offering new insights into the optimisation of maintenance practices in this industry.

Furthermore, there is limited research on the implementation of recommendations from PEMM and ISO 9001 audits within the FMCG sector, especially in this organisation, in the context of packaging. Specifically, the extent to which these recommendations have been incorporated into Quality Improvement Plans (QIP) and overall maintenance practices is not well understood. This research attempts to bridge this gap by analysing these implementations through document reviews and interviews, thereby providing a clearer picture of how industry standards are being adopted by organisations such as PepsiCo in the context of packaging.

Lastly, while FMEA is widely recognised as a valuable tool in quality management, there is a gap in the research concerning its strategic integration into existing quality management frameworks within the FMCG packaging industry. The current study attempts to address this issue by developing an FMEA implementation strategy tailored for the specific needs of the Prospecton plant. The strategy offered is a structured approach to enhancing equipment reliability.

The research objectives of this study are carefully designed to address these identified gaps. By benchmarking maintenance ratios, identifying critical failure modes, understanding the challenges in optimising maintenance, evaluating the implementation of PEMM and ISO 9001 recommendations, and developing an FMEA implementation strategy, this study could contribute significantly to enhancing equipment reliability within the FMCG packaging industry at the Prospecton manufacturing site.

2.15 Chapter Summary

This chapter has provided a comprehensive overview of the theoretical and practical foundations of FMEA within the context of quality and maintenance management. It traced the evolution of FMEA from its military origins to its modern application across various industries, with particular focus on the FMCG sector. The review illustrated how FMEA can be integrated into quality frameworks, such as ISO 9001 and PEMM, and how it complements other manufacturing tools to drive process improvements and equipment reliability. Case studies from prominent FMCG companies demonstrated the benefits of FMEA in reducing waste, enhancing operational efficiency, and improving customer satisfaction. The chapter also examined benchmarking practices, failure modes, and maintenance strategies relevant to packaging operations. It also highlighted the research gaps in the application of FMEA, specifically within packaging departments of FMCG firms. This gap sets the foundation for the current study, which aims to develop an FMEA implementation strategy tailored to the operational needs of PepsiCo Durban’s packaging department.

The upcoming chapter outlines the methodology used to conduct this research.

Chapter 3: Research Methodology

3.1 Introduction

The preceding two chapters provided an overview of the study's objectives and a comprehensive review of relevant literature. This chapter focuses on the research methodology, detailing the type of study conducted, the research design, target population, sample size, sampling strategy, data collection instruments, and analysis techniques. It also discusses the steps taken to ensure the validity and reliability of the findings. The primary aim of this study is to examine the application of Failure Mode and Effects Analysis (FMEA) within a quality management framework to improve equipment reliability in the packaging division of the FMCG sector.

3.2 Research Design

The research onion, developed by Saunders (2009), was used as a conceptual framework that guided the research design and methodology. This framework is used widely across different disciplines for its structured approach to research planning. The research onion serves as a step-by-step guide, helping researchers navigate from broad philosophical foundations to specific data collection and analysis techniques. The layered structure ensures a systematic and organised approach, making it a versatile tool for structuring research across various fields (Haydam and Steenkamp 2020: 304). Hence, the researcher selected Saunders' (2009) research onion as the most suitable framework for this study.

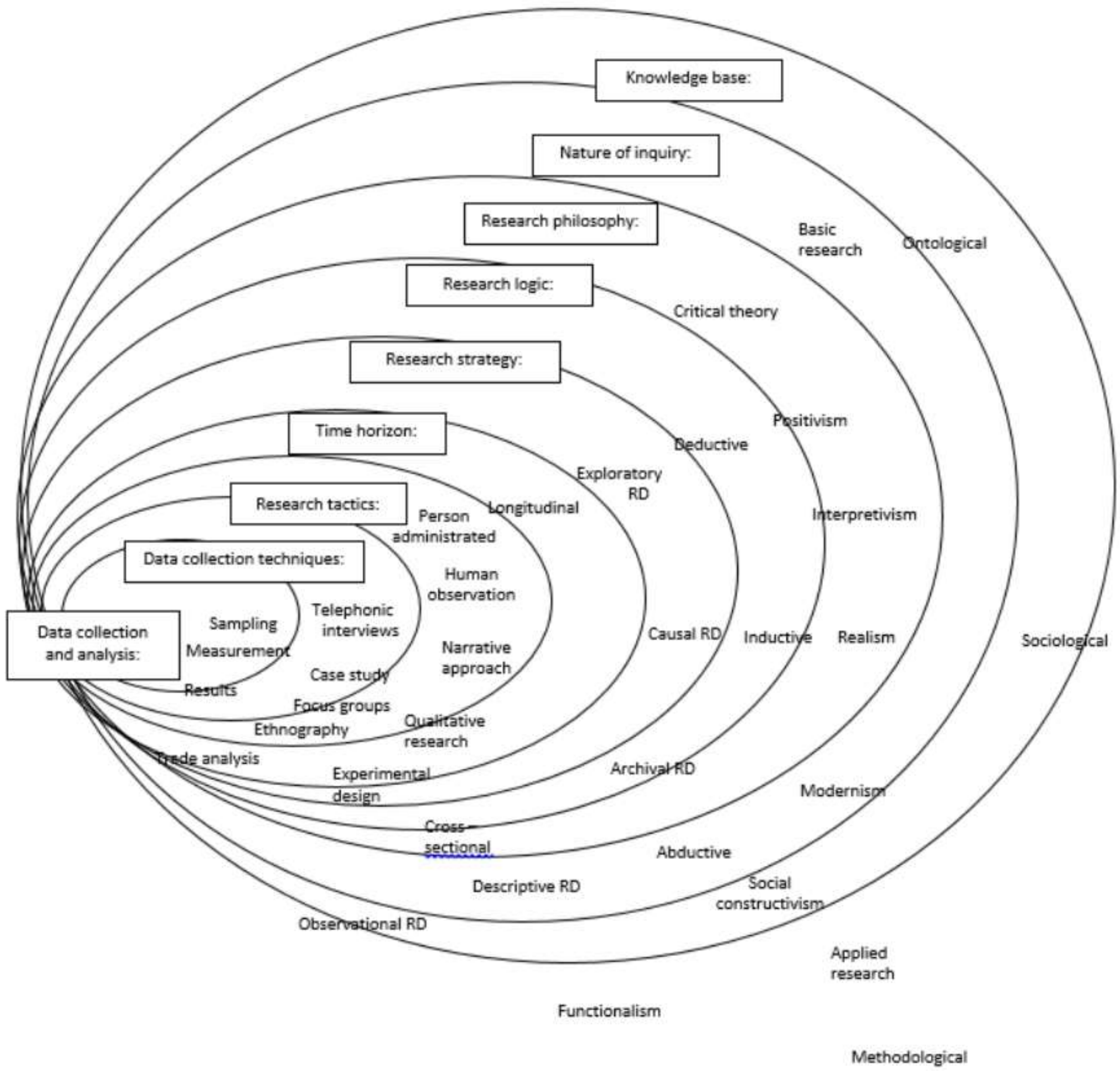

Figure 3. 1 The Research 'Onion' Revisited, Based on: Saunders et al. (2009:106-109)

3.2.1 Onion Layer 1: Research Philosophy

Pragmatism is a philosophical perspective that prioritises practical outcomes and real-world applications over rigid principles or abstract theories. It assesses ideas, beliefs, and actions based on their usefulness and effectiveness in addressing problems (Kaushik and Walsh 2019: 1). In research, pragmatism is commonly linked to mixed-method approaches, as it allows for the integration of both qualitative and quantitative methods, depending on what best suits the research questions. This philosophy emphasises flexibility, practicality, and real-world relevance, rather than strictly adhering to a single theoretical framework (Kelly and Cordeiro 2020: 3).

This study adopted a pragmatic approach that enabled the combination of both quantitative methods (such as statistical failure rates and equipment downtime analysis) and qualitative methods (like expert opinions and employee feedback) to gain a comprehensive understanding of equipment reliability challenges. This flexibility ensured the use of the most suitable tools to address real-world problems. A pragmatic approach allowed for the adjustment of data collection techniques based on their effectiveness. By focusing on practical applications, pragmatism ensured that the research findings were not only academically sound but also relevant to the FMCG industry. With an emphasis on contextual understanding, the study incorporated insights from maintenance teams and engineers, ensuring the FMEA framework was tailored to the PepsiCo environment. By adopting this approach, the research design remains adaptable, problem-oriented, and outcome-driven, ensuring that the FMEA framework leads to tangible improvements in equipment reliability within the packaging department.

3.2.2 Onion Layer 2: Research Approach

Inductive approaches involve developing theories based on research findings rather than starting with an existing theory as a basis. An inductive approach would be suitable for studying an unfamiliar, isolated community. Since there is limited knowledge about the community, research would be necessary to gather information, which would then lead to the creation of theories (Soung 2021: 151).

The inductive approach was ideal for this study because it facilitated the creation of theories and frameworks based on data analysis rather than testing an established hypothesis. This method aligned perfectly with the study's objective of using FMEA to enhance the reliability of packaging equipment at PepsiCo Durban. The study gathered both qualitative and quantitative data through interviews, document analysis, and thematic analysis to identify patterns, failure modes, and maintenance issues. By adopting an inductive approach, the researcher has uncovered new insights and strategies to improve equipment reliability without being constrained by a predefined theoretical framework.

3.2.3 Onion Layer 3: Research Strategy

This layer of the research onion outlines how research can be conducted in alignment with the study's objectives. Outside of the onion, these methods are known as research designs. An archival research strategy involves using pre-existing materials, from which meaning is derived through an analysis of the data. This approach is especially effective for historical research and often involves examining resources like manuscripts and records (Das, Jain and Mishra 2018: 135).

The research strategy adopted for this study was a mixed-methods strategy. An archival research strategy was a suitable approach for this study as it involved examining existing maintenance records, audit reports, and historical data to identify trends, patterns, and failure modes in the packaging equipment at PepsiCo Durban. This method was ideal because it offered valuable, real-world data on past maintenance practices, facilitated trend analysis, ensured objectivity, and complemented the study's inductive methodology aimed at improving equipment reliability by using FMEA.

Given the complexity of improving equipment reliability within the packaging department at PepsiCo Durban, a case study strategy was also selected to allow for an in-depth, contextual analysis of the real-world issues affecting maintenance practices, equipment failure modes, and the implementation of FMEA within a quality management framework. The case study approach was ideal for examining the unique environment, maintenance processes, and organisational dynamics at PepsiCo Durban, which cannot be easily separated from their operational context.

The case study strategy enabled the researcher to collect comprehensive data from multiple sources, including internal documentation, maintenance records, audit findings (ISO 9001, PEMM, and QIPs), and interviews with relevant stakeholders such as Maintenance Management Staff, Preventative Maintenance Team Members, Line Support Instrument Technicians, and Line Support Millwrights. This triangulation of data sources strengthened the validity of the findings.

In addition to the qualitative case study design, the research also employed quantitative strategies, which included the application of FMEA, RPN calculations, Pareto Analysis, and Statistical Trend Analysis to quantitatively assess equipment failure trends, prioritise critical failure modes, and evaluate the corrective vs. preventive maintenance ratios. The integration of these quantitative techniques complemented the qualitative insights gained from interviews and content analysis, offering a holistic understanding of the problem.

3.2.4 Onion Layer 4: Choices

A mixed-method approach integrates both qualitative and quantitative research methods in a single study to offer a thorough and balanced analysis of the research problem. This approach enables researchers to cross-verify findings, enhancing the validity and depth of understanding complex issues (Dawadi 2021: 27).

This study, which aimed to improve the reliability of packaging equipment at PepsiCo Durban using FMEA, used a mixed-method approach. This approach provided a thorough, data-driven understanding of equipment reliability, validated findings through multiple data sources, and ensured that the implementation of FMEA was practical and evidence-based. By offering a holistic view of equipment reliability and using triangulation, the mixed-method approach enhanced the validity of the findings.

3.2.5 Onion Layer 5: Time horizon

A cross-sectional time horizon refers to a research design where data is collected at a single point in time or over a short period, rather than being tracked over an extended duration, as in longitudinal studies; it offers a snapshot of a phenomenon, enabling researchers to examine current trends, relationships, and patterns without the need for continuous data collection (Spector 2019: 125). The Cross-sectional time horizon approach allowed for a swift analysis of current maintenance challenges.

3.2.6 Onion Layer 6: Techniques and Procedures

Techniques are the specific methods or tools employed to gather, analyse, and interpret data in a research study. They are the strategies or approaches used to achieve the research objectives. Procedures, on the other hand, refer to the step-by-step process followed during the research. They involve the structured and systematic actions taken to ensure the research is reliable, valid, and can be replicated (Mazhar *et al.* 2021: 6).

The following section focuses on the different techniques and procedures discussed under qualitative and quantitative research.

3.2.6.1 Qualitative Techniques of Analysis

This section explores the different techniques used in this study's qualitative component.

3.2.6.1.1 Thematic Analysis

According Lochmiller (2021: 2031), Thematic Analysis is widely utilised in qualitative research methods and it enables researchers to identify, analyse, and interpret patterns or themes within data. Thematic analysis focuses on the meanings and experiences conveyed through text, such as interview transcripts, survey responses, or social media content. Lochmiller (2021:2031) highlights the method's flexibility, allowing researchers to approach data either inductively or deductively. He further explains that parent themes serve as broad, overarching categories capturing the most significant patterns related to the research question. These parent themes offer a high-level perspective, while child themes, or sub-themes, provide more specific, detailed insights. He adds that one of the major strengths of Thematic Analysis, is its capacity to organise findings in a clear manner using parent and child themes.

It was ideal for this study because it uncovered the underlying causes of equipment failures beyond numerical data, provided insights into maintenance personnel's views on reliability issues, and allowed patterns to emerge inductively, which aligns with the study's exploratory approach. In this study, interviews with maintenance management staff, technicians, and millwrights were analysed to identify shared challenges, failure modes, and maintenance inefficiencies.

3.2.6.1.2 Content Analysis

Kleinheksel *et al.* (2020: 127) states that content analysis is a systematic research method employed to examine textual, visual, or audio material to identify patterns, themes, biases, and meanings. Kleinheksel *et al*. (2020:127) adds that unlike thematic analysis, which primarily focuses on interpreting underlying themes in qualitative data, content analysis can adopt both qualitative and quantitative approaches. This versatility makes it a valuable tool across various disciplines, including media studies, marketing, political science, psychology, and sociology. Kleinheksel *et al. (2020:17)* explain that content analysis bridges numerical data and narrative interpretation, enabling researchers to uncover trends, biases, and cultural shifts. By counting keywords or analysing metaphors, it offers a structured framework to transform raw content into meaningful insights.

It was well-suited for this study because it helped categorise recurring maintenance failures and connected them to their root causes while also supporting benchmarking against industry standards through the analysis of audit recommendations. In this study, content analysis was applied to PEMM and ISO 9001 audit findings, as well as historical maintenance reports, to identify common issues and compliance gaps.

3.2.6.2 Quantitative Techniques of Analysis

In this section, the different techniques used in this study's qualitative component are discussed.

3.2.6.2.1 Risk Priority Number Calculation

RPN was ideal for this study because it provided a numerical foundation for prioritising maintenance tasks and helped determine which failures need immediate attention. This approach was used to rank failure modes identified from maintenance records according to their severity, frequency, and the likelihood of detection.

3.2.6.2.2 Document Analysis

Document Analysis is a qualitative research technique that involves systematically reviewing and interpreting documents to extract meaning, identify patterns, and answer research questions. Unlike surveys or interviews, it relies on existing materials (e.g., reports, policies, letters, diaries, newspapers, or websites) as primary data sources (Morgan 2021: 64).

It was ideal for this study because it eliminated the need for expensive, time-consuming experiments, provided objective real-world data rather than relying solely on opinions, and allowed for the comparison of historical trends with industry benchmarks. The study used this method to analyse 10 years of maintenance reports, PEMM audits, and ISO 9001 findings to track past maintenance performance and identify trends in CM versus PM.

3.2.6.2.3 Statistical Trend Analysis

JXu *et al.* (2020: 2558) defines statistical trend analysis as a method used to analyse data over time to find patterns, such as rising, falling, or repeating trends. This approach helps turn time-based data into useful insights for decision-making in fields such as business, policy, and research.

This method was used to analyse patterns and changes in numerical data over time. It was ideal for this study because it helped determine whether maintenance strategies have improved or declined over time and supported data-driven recommendations for optimising maintenance ratios (corrective vs. preventive). It was applied to failure reports and maintenance KPIs to track trends in equipment failures and maintenance effectiveness.

3.2.6.2.4 Pareto Analysis

As described by Radson and Boyd (1997: 223), Pareto Analysis involves identifying the small proportion of factors, typically 20%, that are responsible for the majority, approximately 80% of the outcomes. This technique is instrumental in guiding decision-makers to concentrate their efforts on issues or opportunities that will yield the greatest overall impact

It was well-suited for this study because it helped prioritise the most critical failure modes, enabling focused improvements in maintenance strategies and ensuring that FMEA recommendations addressed the most impactful issues. This method was applied to historical maintenance records (IW28, IW38 reports) to identify the most frequent and severe failure modes affecting packaging equipment.

3.3 Validity

Validity refers to the extent to which a research study, measurement tool, or conclusion accurately reflects what it claims to measure or represent. It ensures that the results are truthful, credible, and free from systematic errors (Winter 2000: 1).

Validity was achieved through triangulation, a method that utilises multiple data sources (maintenance records, audit reports, and interviews) to cross-verify findings, thereby ensuring accuracy. In addition, participants also reviewed their interview transcripts to confirm that their responses were accurately captured. The study used an established framework, such as FMEA. Maintenance ratios and equipment reliability were compared against industry standards to validate results in line with best practices. Documentation of all research steps, decisions, and methodologies ensured transparency and traceability.

3.4 Reliability

Reliability refers to the consistency and stability of a measurement tool or research method. It indicates whether an instrument produces similar results under consistent conditions over time, across different observers, or through parallel forms of the test (Bruton, Conway and Holgate 2000: 94).

All field notes, transcripts, and records were stored systematically for easy verification, which ensured dependability through record-keeping. Thematic analysis and content analysis ensured that data interpretation remained consistent across different sources. Structured interviews and pre-defined document analysis criteria ensured uniformity in data gathering. Quantitative measures such as Risk Priority Number and Pareto Analysis reduced subjectivity and improved consistency in failure mode assessments.

3.5 Chapter Summary

This chapter outlined a robust and structured research methodology aimed at exploring the application of FMEA within a quality management framework to enhance packaging equipment reliability at PepsiCo Durban. By adopting Saunders' research onion, the study ensured a methodologically sound approach, starting from a pragmatic philosophical stance that supports mixed methods to the use of an inductive reasoning path that allows theory to emerge from real-world data.

An archival research strategy, underpinned by both qualitative and quantitative techniques, enabled a comprehensive analysis of historical maintenance records and stakeholder insights. The integration of tools such as thematic and content analysis, RPN calculations, statistical trend and Pareto analysis provided an understanding of equipment failures and maintenance inefficiencies. Validity was reinforced through triangulation and benchmark comparisons, while reliability was maintained through systematic documentation, consistent procedures, and replicable techniques.

The next chapter analyses and discusses the findings.

Chapter 4: Data Analysis and Discussion of Results

4.1 Introduction

This chapter presents the analysis and interpretation of data collected through both qualitative and quantitative methods. The purpose of the analysis is to evaluate the effectiveness of applying FMEA within the packaging department at PepsiCo Durban, to improve equipment reliability and reduce unplanned downtime. The chapter begins with a discussion of the response rate, followed by an in-depth thematic analysis derived from interviews conducted with maintenance personnel. This is complemented by content analysis of historical maintenance records and audit documents.

Subsequently, the chapter outlines quantitative findings, including RPN calculations, trend analysis, and Pareto analysis, to identify and prioritise critical failure modes. These results are triangulated to validate findings across data sources and provide a robust foundation for developing an FMEA-based implementation strategy. The insights gained here directly address the study's research objectives and questions, ultimately informing recommendations in Chapter 5.

4.2 Response rate

The response rate was 82 % of the population; 2 employees, a Millwright and an Instrument Technician declined to participate in the interviews, as reflected in Table 4.1. Table 4.1 shows the response rate of participants in percentage and the number of participants who participated in the interviews.

Table 4.1: Response Rate

Respondent	Response Rate	Total Number of Participants	Total Number of Participants Interviewed
Maintenance Manager	100%	1	1
Utilities Engineer	100%	1	1
Electrical Engineer/ Electrical Manager	100%	1	1
Instrument Technician	67%	3	2
Millwright	67 %	3	2
Preventive Maintenance Artisan	100%	2	2
Storeman	100%	1	1
Total	83.33%	12	10

4.3 Qualitative Analysis

This section will unpack all the qualitative data and results.

4.3.1 Introduction

The qualitative phase of this study sought to uncover the lived experiences and perspectives of maintenance personnel at PepsiCo Durban, offering a ground-level view of the challenges and practices shaping equipment reliability in the packaging department. Through interviews, 10 out of 12 targeted participants, spanning roles from Maintenance Managers to frontline Technicians, shared their insights, yielding 181 distinct ideas or insights that painted a picture of the department's operational dynamics.

These insights/references merged into five dominant themes, each with its own sub-themes, revealing where attention was concentrated, and where gaps persisted. Notably, discussions around benchmarking maintenance ratios (30.94%) and identifying critical failure modes (28.18%) dominated the conversations, underscoring the team's acute awareness of inefficiencies and recurring equipment issues. In contrast, fewer references touched on FMEA knowledge (7.73%) or audit implementation (8.29%), hinting at untapped opportunities for proactive risk management and systemic improvement.

The participants' voices also revealed a clear divide in priorities across roles. The Corrective Maintenance Team, burdened by unplanned breakdowns, emphasised time constraints and firefighting. The Preventative Maintenance Team, though smaller in representation, highlighted logistical hurdles like spare parts shortages. Meanwhile, Engineering Management provided challenges in strategic terms, encouraging the need for better training and data-driven planning.

Together, these perspectives created a narrative of a department caught between reactive demands and the aspiration for more reliable and preventative approaches.

Table 4.2 shows the 5 main themes generated and the percentage of references for each theme.

Table 4. 2: Percentage of References

Theme	Percentage of Reference
Benchmarking Maintenance Ratios	30,94
Challenges in Optimising the Maintenance Ratio	24,86
Current FMEA Knowledge Base	7,73
Identifying Critical Failure Modes	28,18
Implementation of Audit Findings	8,29

The thematic distribution of references highlights a mature awareness of maintenance challenges, with emphasis placed on benchmarking performance and diagnosing failures. However, the limited references to FMEA and audit implementation point to missed opportunities in preventative maintenance and strategic follow-throughs.

4.4 Content Analysis

Content analysis was performed on the interview transcripts and the PEMM audit reports. This section provides a brief overview of how the content analysis was conducted. It also includes samples of quotations used in the grouping, which were needed as building blocks for the different groups.

The process of content analysis starts with the statistician reading the transcripts and allowing issues to come through inductively. As the statistician read the transcripts, he/she highlighted a sentence and created a folder/node for this issue. This process was done for the entire transcript and across multiple transcripts. Once all transcripts were complete, similar issues were grouped until no further grouping could occur. This process led to different issues or parent themes/child themes/sister themes.

Figure 4.1 shows that a group of quotations were combined into benchmarking ratios. It indicates the two quotations given by participant 1 and the percentage of coverage.

Aggregate	Classification	Coverage	Number Of Coding References	Reference Number	Coded By Initials	Modified On
Node						
Nodes\\Benchmarking Maintenance Ratios						
Document						
Internals\\Participant 1						
Yes	Corrective Maintenance	0,0439	4			
				1	DG	2025/05/12 09:18 pm
To be honest, as I said now, we were in the transition because we were more based reactive maintenance.						
				2	DG	2025/05/12 09:23 pm
To be honest, I don't really have such.						

Figure 4. 1: Coding Summary Report

4.4.1 Content Analysis of Interview Transcripts

The themes that emerged from the transcripts were grouped into nodes, groups and subgroups; the content of these nodes, groups and subgroups were tabulated and analysed. The content of nodes for this section will be referred to as references. Sample references were extracted and displayed after each table to give the reader an idea of the type of references that were grouped to form a node, group and sub-theme. The reference for all participants was broken down into 3 teams i.e. Corrective Maintenance Team, Engineering Management Team and the Preventive Maintenance Team and displayed in percentage format for the total contribution of the references given regarding a specific theme.

4.4.1.1: Benchmarking Maintenance Ratios

Benchmarking Maintenance Ratios was the largest theme and was generated from 8 participants, who contributed 56 references and 3 sub-themes.

Three themes developed around benchmarking maintenance ratios as shown in Table 4.3 i.e.: Current Maintenance ratio, Ideal Maintenance ratio, and Solutions to Optimise the maintenance ratio.

Table 4. 3: Benchmarking Maintenance Ratios

	A: Current Maintenance ratio	B: Ideal Maintenance ratio	C: Solutions to Optimize the maintenance ratio
1 : Corrective Maintenance	57,38%	0%	29,08%
2 : Engineering Management	24,59%	100%	55,03%
3 : Preventive Maintenance	18,03%	0%	15,88%

The organisation is still heavily reliant on corrective (reactive) maintenance, with engineering management leading the strategic vision for optimisation. However, preventative maintenance voices are underrepresented, and frontline corrective teams are not actively involved in shaping future improvements.

Below are some of the responses from the participants:

Participant 2 states, "*Preventative is about, say 40 and corrective is about 60.*" Participant 5 believes, "*We should be around 15% corrective and 85% preventive.*" To support this shift, Participant 4 explains, "*The line walks plays a major role so we are able to pick up issues before they cause a breakdown.*"

4.4.1.2: Solutions to Optimise the maintenance ratio

The Solutions to Optimise the maintenance ratio theme were large, which allowed the theme to be further subdivided into 12 sub-themes that indicated the percentage of references that were given by the three groups of maintenance personnel, as shown in Table 4.4.

Table 4.4: Solutions to Optimise the Maintenance Ratio

	A : 5 S	B : Communication	C : Condition Monitoring	D : Culture Change	E : Environmental Management	F : Improved spare part management	G : Information Technology System Management	H : Production in relation to maintenance planning	I : Resource Management	J : Strategies to reduce planned maintenance duration	K : Supplier Management	L : Upskilling Employees
1 : Corrective Maintenance	7,8%	0%	35,46%	0%	3,31%	0%	0%	48,46%	0%	0%	4,96%	0%
2 : Engineering Management	0%	34,29%	12,23%	2,04%	0%	0%	3,12%	10,67%	6,35%	16,31%	11,63%	3,36%
3 : Preventative Maintenance	0%	0%	0%	0%	0%	20,16%	0%	39,92%	0%	33,74%	0%	6,17%

Solutions to Optimise the Maintenance Ratio had 8 sources and 38 references, and 12 sub-themes. This table reveals a segmented and role-specific focus on various improvement strategies, suggesting strong silos within the organization's maintenance structure. Each group contributes to different areas, but few strategies show shared or unified focus across all roles. Corrective Maintenance focused on immediate tactical concerns; they are stuck in the short-term loop of fixing breakdowns and adjusting to production demands, without strong involvement in longer-term process improvements. Engineering Management: Broadest and most strategic focus Engineering Management acts as the strategic hub, offering a balanced view of both technical and human factors necessary for optimising maintenance practices. Preventative teams are highly relevant but narrowly focused. Their emphasis is on resource logistics and planning, but they appear disconnected from organisational culture or broader systems thinking.

4.4.1.3: Challenges in Optimising the Maintenance Ratio

The theme of challenges in optimising the maintenance ratio was generated by 8 participants, who submitted a total of 45 references; this main theme was further broken into 4 sub-themes.

Table 4.5: indicates the percentage of references given and was further subdivided into 2 sub-themes, i.e.: Employee Skills and Resource Availability, and Time for task execution.

Table 4. 5: Challenges in Optimising the Maintenance Ratio

	A: Employee Skills and Resource Availability	B: Time for task execution
1. Corrective Maintenance	10,39%	89,61%
2. Engineering Management	62,82%	37,18%
3. Preventive Maintenance	72,73%	27,27%

This table reveals a distinct role-based divergence in perceived challenges, underscoring the operational pressures versus strategic limitations within the organisation's maintenance system. Corrective Maintenance: Overwhelmed by Time Pressure, this team operates in a firefighting mode, with little breathing room to improve practices or upskill. Engineering Management: Concerned with Workforce Capability. Engineering sees the bigger picture and understands that without building capabilities, long-term improvements are not sustainable. This group has the right mission but lacks the tools and talent to fulfil it effectively.

Below are some of the responses from the participants:

Participant 1 notes, "*I would say resources and I would say the skills, metrics.*" Similarly, Participant 4 highlights, "*Time and availability of the machine.*"

4.4.1.4: Employee Skills and Resource Availability

The theme of Employee Skills and Resource Availability was generated by 6 participants who submitted 18 references that further developed into 2 sub-themes.

Table 4.6 indicates that Employee skills and resource availability were further broken down into 2 sub-themes: Employee Skills and Resource Availability.

Table 4. 6: Employee Skills and Resource Availability

	A : Employee Skills	B : Resource Availability
1. Corrective Maintenance	83,33%	16,67%
2. Engineering Management	74,05%	25,95%
3. Preventive Maintenance	100%	0%

This table clearly shows that across all maintenance roles, the dominant concern is a shortage of employee skills, not a lack of physical resources or materials. The maintenance system is fundamentally undermined by insufficient training, knowledge, or experience across teams. Simply investing in new technology or systems will not solve the core problem unless skills gaps are addressed first. The table signals a critical need for skills development across all levels of the maintenance hierarchy and cross-functional teams, especially in preventative teams, who are expected to perform proactive tasks but feel undertrained or ill-equipped.

4.4.1.5: Current FMEA Knowledge Base

In Table 4.7, the theme was generated by 6 participants who submitted 14 references relating to the current FMEA Knowledge Base. The total references were then compared to the total number of references given by all participants. This was done to determine the strength of the knowledge base of FMEA, while considering the theme as displayed in sample 4.3

Table 4. 7: Current FMEA Knowledge Base

	A: Current FMEA Knowledge Base	Percentage of References
1. Corrective Maintenance	2	1,10
2. Engineering Management	11	6,08
3. Preventive Maintenance	1	0,55

Out of 181 total references, only 14 (about 7.7%) focused on the Current FMEA Knowledge Base. Engineering Management dominates with 11 references (6.08% of the total references), showing that it is the main area with documented FMEA knowledge. Corrective Maintenance has 2 references (1.10%), indicating limited but some involvement with FMEA. Preventative Maintenance has only 1 reference (0.55%), showing very minimal FMEA knowledge documented. FMEA knowledge is not widely documented across the total references, and it is mostly concentrated within the Engineering Management area. Corrective and Preventive Maintenance shows very limited FMEA knowledge, suggesting there's an opportunity to better integrate and expand FMEA practices in these maintenance areas to improve failure analysis and prevention.

Below is a response from one participant:

Participant 1 admits, "*To be honest, I don't have FMEA knowledge. I have never had that experience.*"

4.4.1.6: Identifying Critical Failure Modes

The theme of Identifying Critical Failure Modes was generated by 8 participants and generated a total of 51 references, 6 child themes, as shown in Table 4.8. Table 4.8 shows the percentage of three main themes, i.e., Common failure modes, Failure mode trend detection strategy and Root Cause Identification, and Frequency of Failures.

Table 4. 8: Identifying Critical Failure Modes

	A: Common failure modes	B: Failure mode trend detection strategy and Root Cause Identification	C: Frequency of Failures
1. Corrective Maintenance	31,45%	57,25%	11,3%
2. Engineering Management	3,23%	96,37%	0,4%
3. Preventive Maintenance	0%	94,1%	5,9%

The data shows that maintenance activities are distinctly divided by responsibility areas, each playing a different role in failure management: Corrective Maintenance is primarily focused on responding to failures and is heavily referenced in failure analyses, indicating a reactive approach to fixing problems after they occur. Engineering Management is key in detecting failure trends and identifying root causes, highlighting its strategic and proactive role in managing maintenance systems, despite being less directly linked to failure occurrences. Preventive Maintenance emphasises early detection and prevention of failures, with strong involvement in trend analysis but fewer direct failure references, reflecting its focus on reducing failure frequency before problems arise.

Below are some of the responses from the participants:

Participant 1 explains, "*So normally it's gonna be bearing, it's gonna be a shaft, it's gonna be belts. So, all the things like your motors*." Regarding detection and root cause identification, Participant 4 states, "*Equipment monitoring, so your equipment monitoring can be, you do your condition monitoring, so can be overheating of your equipment.*" Highlighting the frequency of failures, Participant 8 notes, "*Sometimes you can say it can happen three times in one day.*"

4.4.1.7: Common Failure Modes

The theme of common failure modes as displayed in Table 4.9 was generated by 5 participants who gave 10 references and then the theme was broken down into 2 child themes, i.e., Electrical Failures and Mechanical Failures.

Table 4.9: Common Failure Modes

	A : Electrical Failures	B : Mechanical Failures
1. Corrective Maintenance	69,42%	30,58%
2. Engineering Management	37,5%	62,5%
3. Preventive Maintenance	0%	0%

Within the Corrective Maintenance category, the majority of references (69.42%) relate to Electrical Failures, with fewer references (30.58%) related to Mechanical Failures. This indicates that corrective maintenance efforts focus more heavily on fixing electrical problems after they occur. For Engineering Management, a larger proportion of references (62.5%) are associated with Mechanical Failures, while 37.5% relate to Electrical Failures. This suggests that engineering management activities, such as planning, trend analysis, and strategic interventions, are more focused on mechanical issues. Preventative Maintenance has no references tied directly to either electrical or mechanical failures in this dataset, possibly reflecting either a lack of documented preventative strategies categorised this way or that preventative efforts are applied more broadly and not failure-type specific in the sources reviewed.

Below are some of the responses from the participants:

Participant 6 notes, "*It would be more your weighers and bag makers*," when referring to electrical failures. For mechanical issues, Participant 5 states, "*Bearing failures and conveyor belt failures.*"

4.4.1.8 Failure Mode Trend Detection Strategy and Root Cause Identification

The theme of Failure Mode Trend Detection Strategy and Root Cause Identification was generated by 8 participants as shown in Table 4.10, who gave a total of 30 references; this main theme branched out into 2 child themes, i.e., Failure Mode Trend Detection Strategy and Root Cause Identification.

Table 4. 10: Failure Mode Trend Detection Strategy and Root Cause Identification

	A: Failure mode trend detection strategy	B: Root Cause Identification
1. Corrective Maintenance	100%	0%
2. Engineering Management	72,49%	27,51%
3. Preventive Maintenance	100%	0%

Corrective Maintenance and Preventative Maintenance are fully focused on Failure Mode Trend Detection (100%) with no references in Root Cause Identification. This suggests that within these responsibilities, efforts are concentrated on monitoring and detecting failure trends rather than investigating underlying causes. Engineering Management, while still heavily involved in Failure Mode Trend Detection (72.49%), also contributes significantly to Root Cause Identification (27.51%). This indicates that engineering management plays a more balanced role by not only detecting trends but also actively identifying the fundamental causes of failures.

Below are some of the responses from the participants:

Participant 5 stated, "*One is job cards, and we'll look at mean time between failures and the mean time to repair.*" For identifying root causes, Participant 7 explains, "*We're using the method is fishbone and RCA 5Y, and fishbone, most of the time.*"

4.4.1.9: Implementation of Audit Findings

The theme of Implementation of Audit Findings, as displayed in Table 4.11, was generated by 7 participants, of whom 15 submitted references. These references were then displayed in percentage format, considering all references submitted to assert the strength of the theme.

Table 4. 11: Implementation of Audit Findings

	A.: PEMM Knowledge Base	Percentage of References
1. Corrective Maintenance	2	1,10
2. Engineering Management	6	3,31
3. Preventive Maintenance	2	1,10

Implementation of Audit Findings had 7 sources and 15 references out of a large total of 181 references; only 10 references (about 5.5% of the total) relate to PEMM. PEMM is not widely covered or documented across the overall reference pool. Engineering Management holds the majority of the PEMM knowledge, while corrective and preventative maintenance have very little focus or documented knowledge on PEMM.

This could suggest that PEMM is a specialised or an emerging area mostly associated with engineering management, and there's an opportunity to expand PEMM knowledge and integration, especially in corrective and preventative maintenance functions.

Below are some of the responses from the participants:

Participant 4 stated, "*I would say PEMM audits, I am not familiar with those tasks.*"

4.4.1.10: Section Summary

The content analysis of nodes, branches and sub-branches of maintenance practices across corrective, preventative, and engineering management roles reveals key findings that highlight a strong focus on benchmarking maintenance ratios and identifying critical failure modes, indicating a mature awareness of operational challenges. However, significant gaps exist in the integration of FMEA knowledge and the implementation of audit findings, particularly in corrective and preventative maintenance teams.

The data underscores a reactive dominance in corrective maintenance, where teams are heavily burdened by immediate breakdowns and lack of involvement in long-term strategic improvements. Engineering management emerges as the strategic hub, driving initiatives for optimisation but facing challenges in workforce capability and resource allocation. Preventative maintenance, while critical, remains narrowly focused and disconnected from broader organisational systems.

A recurring theme across all roles is the pressing need for employee upskilling, as skills shortages outweigh resource limitations. Additionally, the limited documentation and application of FMEA and PEMM knowledge suggest missed opportunities for proactive failure prevention and systemic improvements.

4.4.2: Content Analysis of PEMM Audits

Content analysis was used to systematically organise and interpret textual data in PEMM audits over the past 10 years. Each audit was broken down into the 10 maintenance business processes, and the content from each business process was analysed., The worst out of the 10 categories was analysed.

The content of the PEMM audit questionnaire and transcripts was analysed based on the worst-performing maintenance business process. Through statistical analysis, it was discovered that planning, and preparation was the worst scoring; seven sub categories scored zero out of 5 and through content analysis it was discovered that the audits are the same, which indicates that the audits for 2017 was not done and possibly the same score was given due to the current situation at the time within the business.

4.4.2.1: Lowest Scoring PEMM Maintenance Business Process 2015 & 2017

Effective maintenance management is crucial for ensuring the reliability and efficiency of industrial operations. This assessment was conducted to evaluate the implementation of action plans resulting from the maintenance strategy review. It was determined that the first MIAP must be developed because of this assessment. Consequently, no actions from MIAP or PEMM have been implemented to date. The findings highlight several critical gaps in maintenance processes, including backlog management, statutory work compliance, and data standardisation, all of which require immediate attention.

One of the key areas identified for improvement is the availability of spare parts and material lists. A well-organised and easily accessible inventory of spare parts is essential for minimising downtime and ensuring efficient maintenance operations. Ideally, these lists should be readily available in the EAM system for all equipment. However, the assessment revealed that the site does not have a Bill of Materials (BOM), and the lack of an integrated and standardised spare parts list poses challenges in inventory control and can lead to delays in maintenance activities.

Another critical issue is the absence of an effective backlog work management system. Proper backlog management is vital to ensure that maintenance tasks are planned, prioritised, and executed efficiently. At the Prospecton site, there is no structured backlog management system in place. As a result, approximately 150-180 work orders are generated each week but remain unresolved or unplanned. This lack of oversight leads to inefficiencies and increases the risk of equipment failures, ultimately impacting operational performance. Implementing a formal backlog management system would help in tracking pending tasks, prioritising urgent work, and improving overall maintenance effectiveness.

Statutory work order compliance is another area of concern. All statutory (legal) work orders must be clearly defined and properly tracked within the EAM system to ensure regulatory compliance and operational safety. However, the assessment found that there is no follow-up process for statutory work at the site. Most statutory maintenance activities are included as part of routine maintenance tasks in Pragma, based on estimations rather than being distinctly managed. Additionally, the absence of a priority-based system within Pragma means that critical statutory tasks are not given the necessary urgency, further increasing compliance risks. A well-defined process for managing statutory work orders would enhance regulatory adherence and ensure that essential maintenance activities are not overlooked.

Furthermore, standardisation of static data within the maintenance system is lacking. The static data tables for equipment, tasks, work instructions, and employee assignments should align with the established data standards of EAM systems such as SAP. However, the assessment revealed that there is no standardised approach for managing this data in Pragma at the site. The absence of data standardisation can lead to inconsistencies, errors, and inefficiencies in maintenance planning and execution. Establishing clear data governance policies and ensuring alignment with industry standards would help streamline maintenance operations and improve data accuracy.

In addition to data standardisation, the review process for planned job time estimates is another area that requires improvement. In an optimised maintenance system, estimated times for all planned jobs should be reviewed and updated regularly to ensure accurate scheduling and resource allocation. However, at the site, there are no estimated times included in the planned work, and no formal review process exists. This lack of time estimation hinders effective work planning and can result in inefficient use of resources. Implementing a structured review process for planned job times would enable better workforce management and improve maintenance efficiency.

Lastly, maintenance tasks and their associated instructions should be periodically reviewed to ensure they remain relevant, effective, and appropriately detailed. Regular reviews help in optimising task frequency and ensuring that instructions are comprehensive enough to guide maintenance personnel effectively. However, the assessment found that there is no structured review process in place for existing maintenance tasks at the site. Without regular reviews, maintenance procedures may become outdated or ineffective, leading to suboptimal performance. Establishing a formal review process would enhance the accuracy and reliability of maintenance tasks, ultimately contributing to improved equipment performance and longevity.

The PEMM assessment highlights several deficiencies in the current maintenance strategy, including backlog management, statutory compliance, data standardisation, and review processes. Addressing these gaps through structured action plans and improved maintenance practices will be essential for enhancing operational efficiency and reliability. Implementing a backlog management system, standardising data processes, ensuring compliance with statutory requirements, and regularly reviewing maintenance tasks are key steps toward achieving a more effective and streamlined maintenance strategy. By taking proactive measures, the site can significantly improve its maintenance performance and reduce the risk of unplanned downtime.

4.5: Thematic Analysis of Interview Transcripts

The interview transcripts inductively generated themes, which stemmed from key quotations (refer to Annexure 9).

4.5.1: Benchmarking Maintenance Ratios

The analysis indicates that the current state of FMEA knowledge and application is fragmented and immature across the site. While some engineering managers recognise its strategic value, the broader workforce, especially frontline technicians and operators, lacks basic awareness, training, and exposure to the methodology. For example, participant 6 states, *"There is a lack of knowledge and understanding of FMEA and how to apply it. Most of the team does not know where to start or how to complete it properly."*

FMEA is acknowledged by a few advanced users as a powerful tool for developing inspection routines and guiding root cause analysis, yet its implementation remains limited. Most participants either had no experience with FMEA or had only seen early efforts to introduce it. This underuse stems from perceived complexity, insufficient training, and a lack of formal rollout across departments. For example, participant 1 stated, "*To be honest, I don't have FMEA knowledge. I have never had that experience.*"

Furthermore, even where interest exists, FMEA is often viewed as a time-consuming exercise, impractical to implement across large volumes of equipment without structural support. Several participants emphasised that effective adoption would require structured training and cross-functional collaboration, rather than siloed or top-down efforts. For example, participant 5 stated, *"I wouldn't say* *resistance as such, but because it's a big effort to take hundreds of pieces of equipment and start to do this and expect it to be done in a short space of time."*

In essence, PepsiCo Durban is aware of the potential of FMEA but has yet to institutionalise it as a core tool in its reliability and maintenance strategy. Moving forward, success will depend on demystifying FMEA, embedding it into routine engineering practices, and empowering multidisciplinary teams through practical training and inclusive implementation frameworks.

4.5.2: Identifying Critical Failure Modes

The approach to identifying critical failure modes at PepsiCo Durban is currently informal, reactive, and fragmented, despite the availability of structured tools like SAP, 5 Whys, and Fishbone Diagrams. While teams do make efforts to trace issues, especially when breakdowns recur, these actions are typically triggered by immediate failures rather than embedded within a proactive, standardised process. For example, participant 1 stated, *"To be honest, as I said now, we were in the transition because we were more based on reactive maintenance."*

Recurring failure types, such as mechanical wear (bearings, belts), electrical faults (sensors, wire breakage), and environmental impacts (overheating, lubrication issues), are well known among staff, particularly in high-usage machines like bag makers, slicers, and conveyors. These predictable patterns indicate missed opportunities for systematic prevention. For example, participant 8 stated, *"Sometimes you can say failures can happen three times in one day, and sometimes it can happen."*

Although some data is tracked through SAP and discussed during shift meetings, the current practice relies heavily on informal team conversations and ad-hoc analysis. This limits the ability to build a site-wide failure knowledge base, prevent issues holistically, and prioritise risks based on impact. For example, participant 9 states, *“So if you start seeing a common occurrence with these on the shift reports, we flag it and then we sit as a team and discuss this in our meetings in length; what should be done, these meetings are informal.”*

Additionally, learning often occurs retrospectively, such as realising that deviations from OEM specifications, like switching belt types, led to increased failures. While these insights are valuable, they highlight a reactive learning culture rather than a preventive one. For example, participant 9 stated *“Someone had an idea to put a sip lock belt, so we put a sip lock belt so, you can easily replace the belt, by using a pin through, right? But for maintenance-wise it is easy to install, but then we started to see the frequency of breakdowns increasing.”*

To strengthen failure mode identification, PepsiCo Durban must shift toward a structured, cross-functional reliability strategy that formalises trend detection, leverages historical data systematically, and close the loop from insight to design improvement. Embedding these practices will elevate maintenance from reactive problem-solving to strategic risk mitigation.

4.5.3: Common Failure Modes

The recurring nature of equipment failures at PepsiCo Durban points to systemic reliability issues that are well-known but not yet strategically mitigated. The most common failure modes, mechanical (bearings, belts, shafts), electrical (sensors, wiring), and environmental (overheating, poor lubrication, vibration), are not isolated incidents but predictable patterns, particularly concentrated in high-usage equipment like bag makers, slicers, conveyors, and weighers. For example, participant 3 stated *“We have I think our biggest machine failure on the ACP, Bag makers, Rev Gates. Also, it is usually the sensors and wire breakage.”*

These failures often repeat daily or every few days, especially during production start-ups, suggesting that root causes are not being fully addressed. While staff are aware of the problem areas, the lack of robust condition monitoring and predictive maintenance strategies means issues are typically dealt with after the fact, rather than prevented in advance. For example, participant 5 stated, *“Failures occur daily”*

Additionally, many of these failures are attributed to basic maintenance lapses, such as improper lubrication, poor quality of maintenance execution, and inadequate temperature or vibration checks, tasks that could be systematically monitored and planned. For example, participant 5 stated, *“quality of work could be one thing where we execute the task, but it's not executed at the right quality, and that can result in equipment failures.”*

The key takeaway is that targeted investment in proactive maintenance practices, such as predictive analytics, component standardisation, and improved operator training, could significantly reduce unplanned downtime. By focusing on the most failure-prone machines and components, PepsiCo Durban can make measurable progress in reliability without a full overhaul, just by doing the basics more consistently and strategically.

4.5.4: Failure Mode Trend Detection Strategy and Root Cause Identification

The analysis reveals that failure trend detection and root cause identification at PepsiCo Durban are inconsistently practiced, blending both structured tools and informal, experience-based routines. While methodologies like 5 Whys, Fishbone diagrams, and FMEA are available and used by some engineering personnel, they are often applied after problems have already escalated, rather than as part of a proactive reliability strategy. For example, participant 7 stated, *“The team thinking in a mindset prevents rather than corrects, so using the correct tool, using the tools that are needed to identify maintenance that we can actually execute in a preventative fashion rather than corrective.”*

In practice, informal discussions during shift meetings and reliance on daily logs are the primary ways to address trends that surfaced. However, these efforts lack standardisation, which makes it difficult to capture trends systematically across teams and departments. Although SAP is used to log failures and track history, many staff find the system too complex or poorly integrated into their daily work, resulting in inconsistent data entry and limited analysis. For example, participant 9 stated, *“The challenge was with the use of a program called SAP, right. The SAP is very detailed.”*

A significant concern is the gap in technical training and role clarity, especially at the operational level. While senior engineers may be comfortable with RCA tools, frontline workers often fall back on intuition and experience, lacking the process discipline and training needed to consistently identify root causes. Example, participant 2 stated, *“At the moment we have a bit of both time constraints and skills constraints.”*

Notably, learning is also occurring through experimentation and feedback, where teams identify ineffective modifications only after repeated failures and revert to OEM specifications, highlighting a reactive rather than preventive culture. Example participant 9 stated, *“Someone had an idea to put a sip lock belt, so we put a sip lock belt so you can easily replace the belt, by using a pin through, right? But for maintenance-wise, it's easy to install, but then we started to see the frequency of breakdowns increasing.”*

To move forward, PepsiCo Durban must formalise its failure analysis processes, invest in cross-level training, and promote structured, data-driven diagnostics. Making trend detection a proactive, routine part of maintenance operations, rather than an afterthought, will strengthen equipment reliability, reduce repeat failures, and build a culture of continuous improvement.

4.5.5: Implementation of Audit Findings

The thematic analysis reveals that the implementation of audit findings, particularly those from the PEMM audits, is still in its developmental stage, marked by a disconnect between strategic intent and operational reality.

At the leadership level, there is a clear awareness of audit objectives and a willingness to integrate findings into broader planning and performance management systems. Some departments are already aligning audit outcomes with PEMM pillars like asset utilisation, planning discipline, and EHS compliance, indicating progress in embedding audits into strategic routines.

However, for most teams, particularly at the technician and shop-floor level, the implementation process is hindered by unclear communication, limited visibility of expectations, and insufficient training. Many participants reported being unfamiliar with audit tasks or unsure how to apply the findings, suggesting that the insights from audits are not being cascaded effectively through the organisation.

Where progress is being made, with audit recommendations slowly feeding into planning discussions rather than being actioned as a co-ordinated improvement strategy. Engineering leaders emphasised the need for systemic discipline, including accurate data tracking (e.g. MTBF, MTTR) and a standardised RCA process. There is also a consensus that deeper use of tools like FMEA and RCA would greatly enhance the value and impact of audit findings.

The audits are producing valuable insights, but the translation of those insights into sustained action remains inconsistent. To bridge the gap between audit and action, PepsiCo Durban must institutionalise audit implementation as a structured, accountable process, supported by system-wide communication, continuous training, and inclusive team engagement. This will ensure audit outcomes, do not just inform reports, but actively shape and improve maintenance performance on the ground.

4.5.6: Benchmarking Maintenance Ratios

The thematic analysis of benchmarking practices at PepsiCo Durban reveals a strong awareness of ideal maintenance standards and a clear aspiration to move towards world-class benchmarks, typically described as an 80/20 or 85/15 preventative-to-corrective maintenance ratio. Participants consistently referenced these targets and acknowledged their current state as predominantly reactive, often closer to a 70% corrective / 30% preventative mix.

Benchmarking is viewed not only as a metric-tracking exercise but as a strategic tool to guide operational improvement. Tools like SAP, RCA, and PEMM audits form the technical backbone of their benchmarking framework, enabling teams to compare performance both internally and against other sites or OEM standards. Key metrics such as MTBF and MTTR are in use, helping to identify trends and justify targeted interventions.

However, the primary barriers are deeply embedded reactive habits, time constraints from production demands, and inconsistent follow-through on improvement plans. Participants frequently cited a need for cultural transformation, better planning discipline, and more rigorous systems to turn benchmarking insights into concrete results.

PepsiCo understands where it is and where it needs to be; the benchmarking process provides both a mirror of current performance and a map for improvement. What’s missing is a cohesive, site-wide commitment to act on these insights through sustained cultural, procedural, and leadership alignment.

4.5.7 Section Summary

The thematic analyses conducted across the various areas of maintenance practice at PepsiCo Durban paint a picture of a site that is consciously working towards improvement but remains stuck in a transitional phase. While there is widespread recognition of the importance of proactive maintenance strategies, such as preventative maintenance, root cause analysis, and the use of tools like FMEA and SAP, the actual implementation across the site is inconsistent.

Many of the participants demonstrated a strong understanding of what "world-class maintenance" should look like. There is broad awareness of the ideal benchmark, an 80/20 split between preventative and corrective maintenance, and a genuine desire to move in that direction. However, the reality is that most departments are still operating in a predominantly reactive state, with current ratios often skewed around 70% corrective and 30% preventative. This misalignment is primarily due to resource constraints, time pressures from production demands, and a reactive culture that has been deeply embedded over time.

Encouragingly, efforts to strengthen collaboration between production and maintenance teams are evident. Participants described recent improvements in planning discussions and scheduling cooperation. Daily shift reports and planning meetings are increasingly used as tools to flag recurring problems and scheduled work more effectively. Yet, the integration of these discussions into formal long-term strategies remains limited, and preventative maintenance is often deprioritised in favour of keeping lines running.

A recurring issue across the interviews was the lack of technical skills and training, especially, among contractors and less experienced artisans. While engineers and managers often use tools like SAP, RCA, and occasionally FMEA, frontline staff are frequently excluded from these systems, either due to complexity, limited access, or a lack of training. This creates a disconnect between the strategic intent of reliability programmes and the daily execution on the ground.

In terms of failure trends, the same problems appear repeatedly; failures of bearings, belts, sensors, and bag makers are among the most common. These issues are predictable and often detectable through basic condition monitoring. However, due to time constraints, inconsistent documentation, and insufficient follow-ups, these failures are allowed to persist, impacting productivity and equipment reliability.

Another significant gap lies in the implementation of audit findings and structured analysis tools. PEMM audits, RCA, and FMEA are all referenced by engineering leads, yet these tools are not consistently applied or understood by operational staff. In several cases, participants admitted they had never encountered or used FMEA at all. This lack of awareness severely limits the organisation's ability to proactively identify and prioritise high-risk failure modes before they impact performance.

Overall, PepsiCo Durban is aware of what needs to change and has many of the necessary tools at its disposal, but it has not yet fully embedded these practices across all levels of the operation. The current state reflects a gap between intention and execution, a gap that can only be closed by addressing both technical and cultural barriers. To achieve sustainable, optimised maintenance performance, the organisation must invest in targeted training, stronger communication across teams, structured follow-through on audit recommendations, and a cultural shift that embraces proactive maintenance as a core value.

4.6: Quantitative

In this section, all the quantitative data obtained from the relevant sources will be unpacked.

4.6.1 Risk Priority Number (RPN) Calculation

In this section, we will discuss the contents of Table 4.12

In Table 4.12 the RPN calculation is shown as a multiple of Severity, Rate of Occurrence, and Detection.

Table 4.12: RPN Calculation

Failure Mode	Severity (S)	Rate Occurrence (O)	Detection (D)	RPN
Network error	6	10	3	180
Belt snapping	10	4	6	240
Sensor damaged	8	6	8	384
Back-seal unit faults	6	5	6	180
Damaged cables	4	5	7	140
Date code print error	3	6	3	54
Vacuum pump damaged	8	6	4	192
Weigher vibration	2	8	6	96
Weight hopper tripping	7	5	3	105
Front and rear jaw malfunction	8	3	6	144

4.6.1.1: Top-Priority Risks (Requiring Urgent Action)

Sensor Damage (RPN = 384) stands out as the most critical failure due to its high severity, moderate likelihood, and very poor detectability. If sensors fail undetected, they could lead to incorrect process controls, product defects, or even equipment damage. Immediate improvements in sensor reliability and detection methods are needed. Belt Snapping (RPN = 240) is less frequent but extremely severe; a snapped belt could stop production, damage machinery, or create safety hazards. Since detection is only moderately effective, preventive maintenance and stronger belt materials should be considered. Vacuum Pump Damage (RPN = 192) also poses a high risk due to its severe impact and moderate occurrence, though it is somewhat easier to detect than other high-RPN failures. Predictive maintenance could help catch issues early.

4.6.1.2: Moderate Risks (Needing Planned Mitigation)

Network Errors (RPN = 180) occur very frequently (O=10), but their severity is moderate, and they are relatively easy to detect. Still, frequent disruptions could impact productivity, suggesting a need for more robust network infrastructure or redundancy. Back-seal Unit Faults (RPN = 180) and Front/Rear Jaw Malfunctions (RPN = 144) have moderate-to-high severity but lower occurrence, meaning they do not happen often but could cause significant issues when they do. Preventive inspections and component strengthening would help reduce risks.

4.6.1.3: Lower-Priority Risks (Manage with Routine Controls

Damaged Cables (RPN = 140) and Weigh Hopper Tripping (RPN = 105) are less severe but still notable due to detection challenges or operational challenges. Regular inspections and minor design tweaks could minimise their impact.

Weigher Vibration (RPN = 96) occurs often but has low severity, mostly causing minor inefficiencies. Balancing and stabilising the machinery should control this issue. Date Code Print Errors (RPN = 54) are the least critical, mainly affecting traceability rather than functionality. Basic printer maintenance and quality checks can keep this issue under control.

4.7: Document Analysis

Figure 4.2 represents in percentage format the best-in-class corrective maintenance vs the corrective maintenance and preventative maintenance level at PepsiCo Durban.

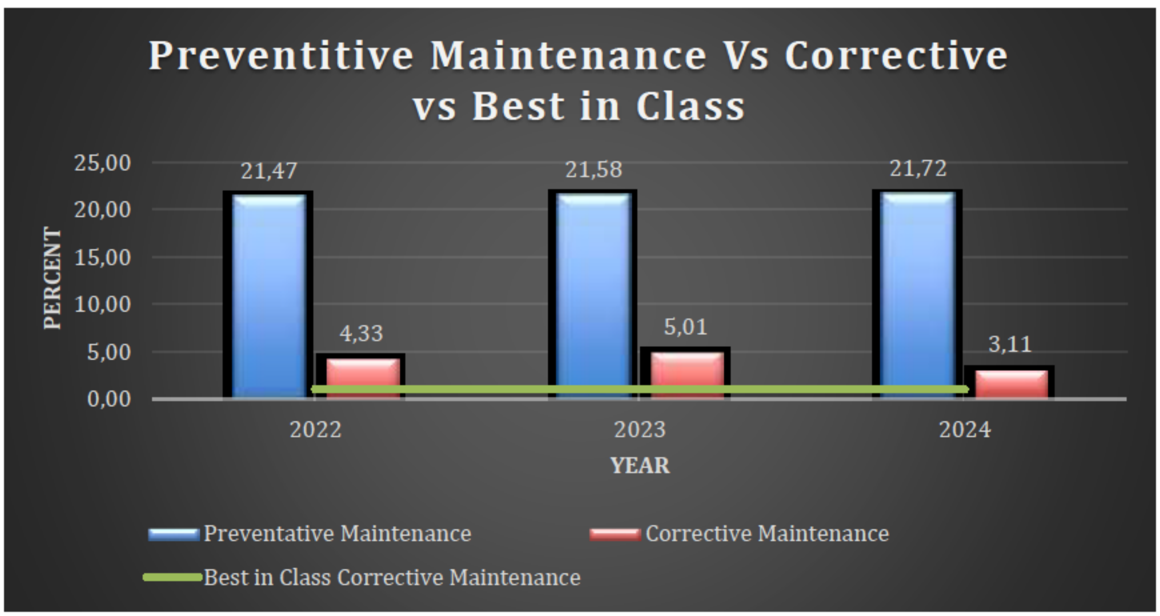

Figure 4. 2: Preventive maintenance vs corrective maintenance vs best in class

This technique involves systematically reviewing existing records to extract valuable insights, as displayed in Figure 4.2. True efficiency sheets for the past 10 years were analysed, and it was discovered that pre-2022 dark hours were not captured on the sheet and pre-2017 packaging failures related to equipment reliability were not considered downtime because the layout of packaging equipment is in parallel, indicating that if one machine stops it will not shut down the snack food manufacturing. Post-2017 is was discovered that packaging equipment stoppages effects the snack food manufacturing throughput and multiple equipment stoppages in packaging can shut down the entire production system. Therefore, the introduction of the slow running calculator was implemented, to quantify the packaging downtime and convert the downtime into equipment downtime. Information from 2022 indicates preventative maintenance is averaging 20 %, (assuming all dark hours are used for maintenance), which is below the industry standard of 80 %. The corrective maintenance is averaging 4 times above the best in class.

4.8: Statistical Trend Analysis

In this section, the statistical data collected from the relevant sources will be explained.

4.8.1 Maintenance Business Process Trends and Packaging Down Time Trend

Maintenance business process trends, as indicated in Figure 4.3, show the 4-year PEMM audit score for each area of control. Example: The cost control score for the 2020 PEMM audit was 58%.

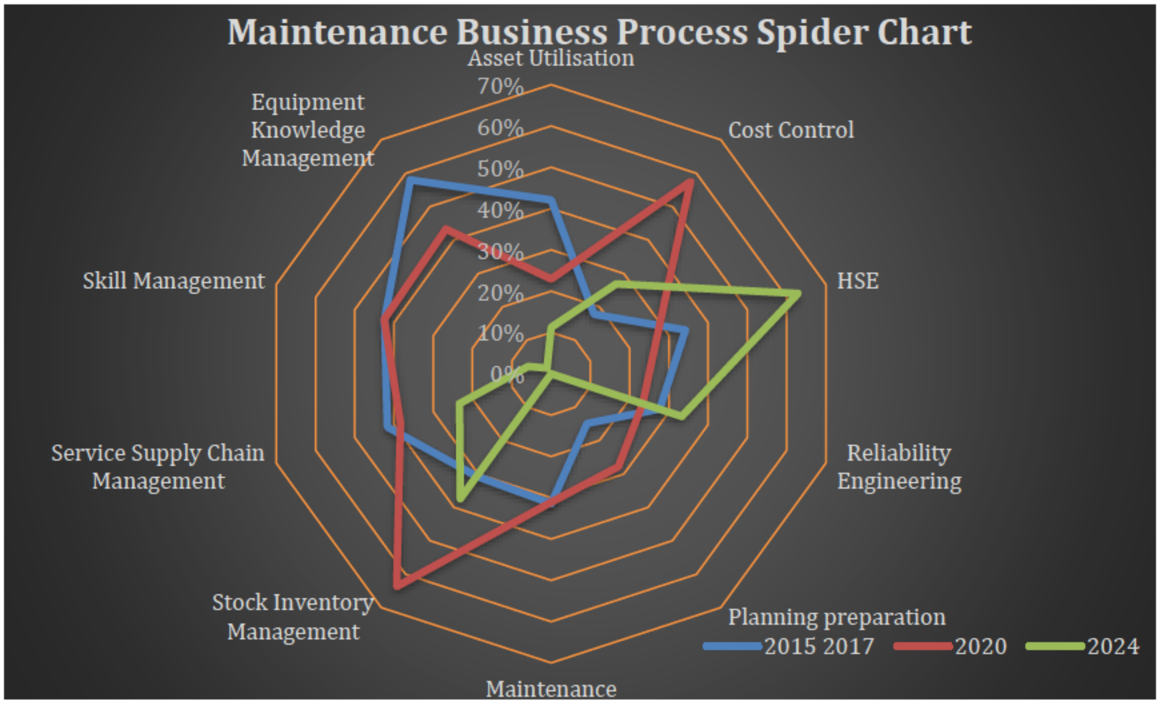

Figure 4. 3: Maintenance Business Process Trends

One of the most notable observations from the data is the consistent improvement in Cost Control and Health, Safety, and Environment (HSE) practices, which peaked around 2020 and 2024. These trends suggest that there was a strong emphasis on financial efficiency and workplace safety during these years, potentially driven by strategic corporate initiatives and regulatory compliance efforts. However, in 2024, there was a decline in Stock Inventory Management and Service Supply Chain Management, indicating possible inefficiencies in spare part availability and procurement processes. These challenges could lead to increased equipment downtime and maintenance delays, affecting overall operational efficiency.

Figure 4.4 shows the packaging trends in PepsiCo Durban from 2018 to 2024.

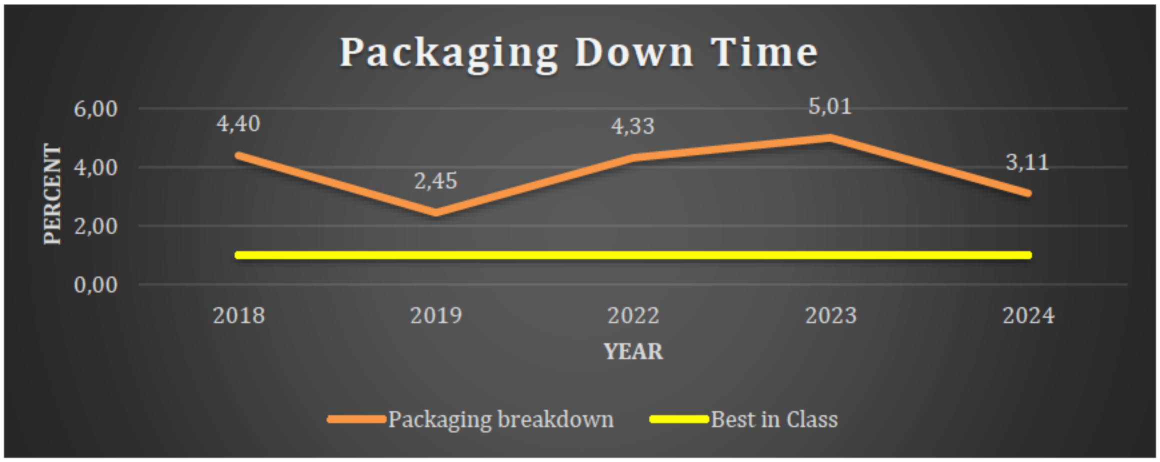

Figure 4. 4: Packaging Down Time Trend

The trends in packaging downtime provide further insights into the relationship between maintenance execution and operational performance. The data shows that 2019 recorded the lowest downtime at 2.45%, a period that coincided with an increase in maintenance efficiency observed in previous years. This suggests that preventive maintenance efforts during this period were effective in reducing equipment failures and minimising production disruptions. In contrast, 2023 experienced the highest downtime at 5.01%, aligning with the decline in maintenance execution and stock inventory management. The lack of spare parts and inefficient supply chain operations during this period likely contributed to increased equipment failures and unplanned maintenance events.

The analysis of maintenance business process trends and Packaging Down Time Trends highlight the evolving dynamics of maintenance execution, cost control, health and safety, and supply chain management over different years. The line graph and spider chart illustrate significant trends in maintenance processes from 2015 to 2024, revealing critical insights into cost efficiency, safety improvements, and operational effectiveness.

A notable improvement was observed in 2024, where downtime decreased to 3.11%. This reduction aligns with improvements in cost control and HSE measures, suggesting that a better focus on financial and safety strategies contributed to increased operational reliability. The correlation between maintenance execution variability and packaging downtime further emphasises the need for consistent and well-planned maintenance strategies to ensure stable equipment performance.

Figure 4.5 shows the trend of the PEMM Score from 2015 to 2024.

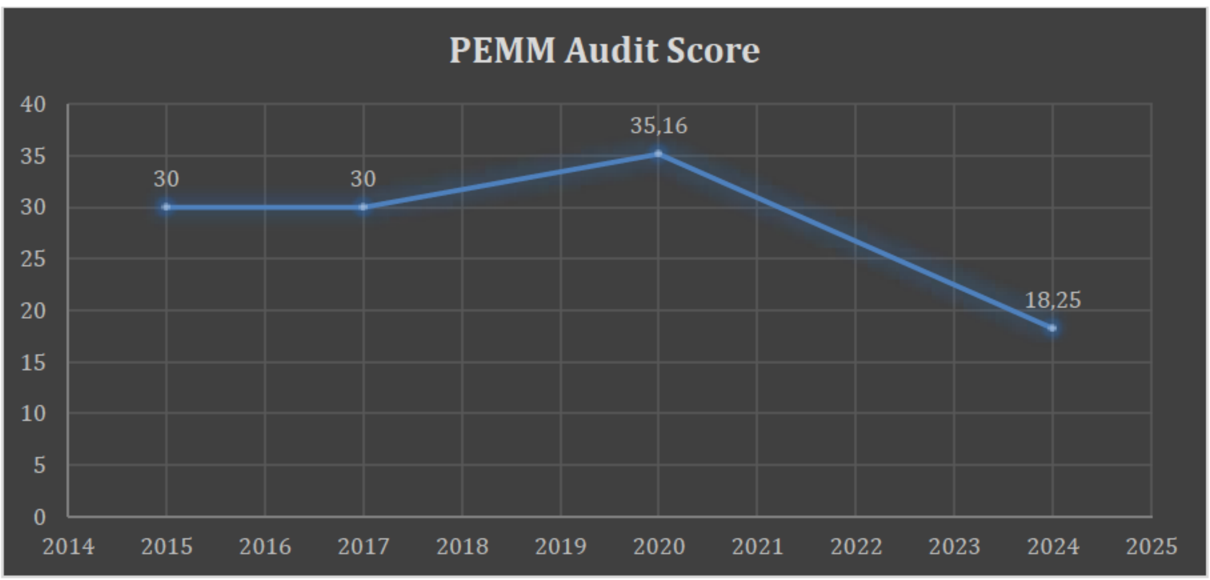

Figure 4. 5: PEMM Score Trend

The PEMM score is consistently well below the target of 60 %, which could be due to fluctuations in maintenance execution over the years, further suggesting variations in the implementation of maintenance strategies. These inconsistencies could be due to shifting priorities, workforce changes, or evolving maintenance methodologies due to the 5 different maintenance managers that were used in the past 10 years. In contrast, Equipment Knowledge Management has remained stable, reflecting continuous efforts in preserving and improving knowledge-sharing practices within maintenance teams. The stability in this area ensures that expertise and technical know-how are consistently maintained, minimising the impact of workforce turnover on maintenance operations.

In conclusion, the analysis of maintenance trends and packaging downtime reveals critical areas of improvement and potential risks in maintenance operations. While cost control and safety measures have shown positive progress, inefficiencies in stock inventory management and maintenance execution remain challenges that need to be addressed.

4.8.2 Pareto Analysis

Pareto analysis is a statistical technique that highlights the most significant factors contributing to a problem, following the 80/20 rule. This graph (Figure 4.5) represents a Pareto Analysis comparing Average PEMM Score vs. the Audit Scoring Matrix across various maintenance business processes. Planning Preparation (147 Max Points) is the highest-scoring category but has a low average PEMM score (12.48). Reliability Engineering (105 Max Points) and Maintenance Execution (105 Max Points) follow, with moderate PEMM scores. The cumulative percentage line shows that the first few categories (Planning Preparation, Reliability Engineering, and Maintenance Execution) contribute to more than 50% of the total issues. The last few categories (e.g., Equipment Knowledge Management and Skill Management) have the least impact on overall performance. This follows the Pareto principle; a few key processes contribute to overall performance gaps. The focus should be on improving Planning Preparation, Reliability Engineering, and Maintenance Execution since these categories contribute significantly to the cumulative percentage. Lower-scoring categories (like Equipment Knowledge Management and Skill Management) still require attention but have a lesser impact on overall performance.

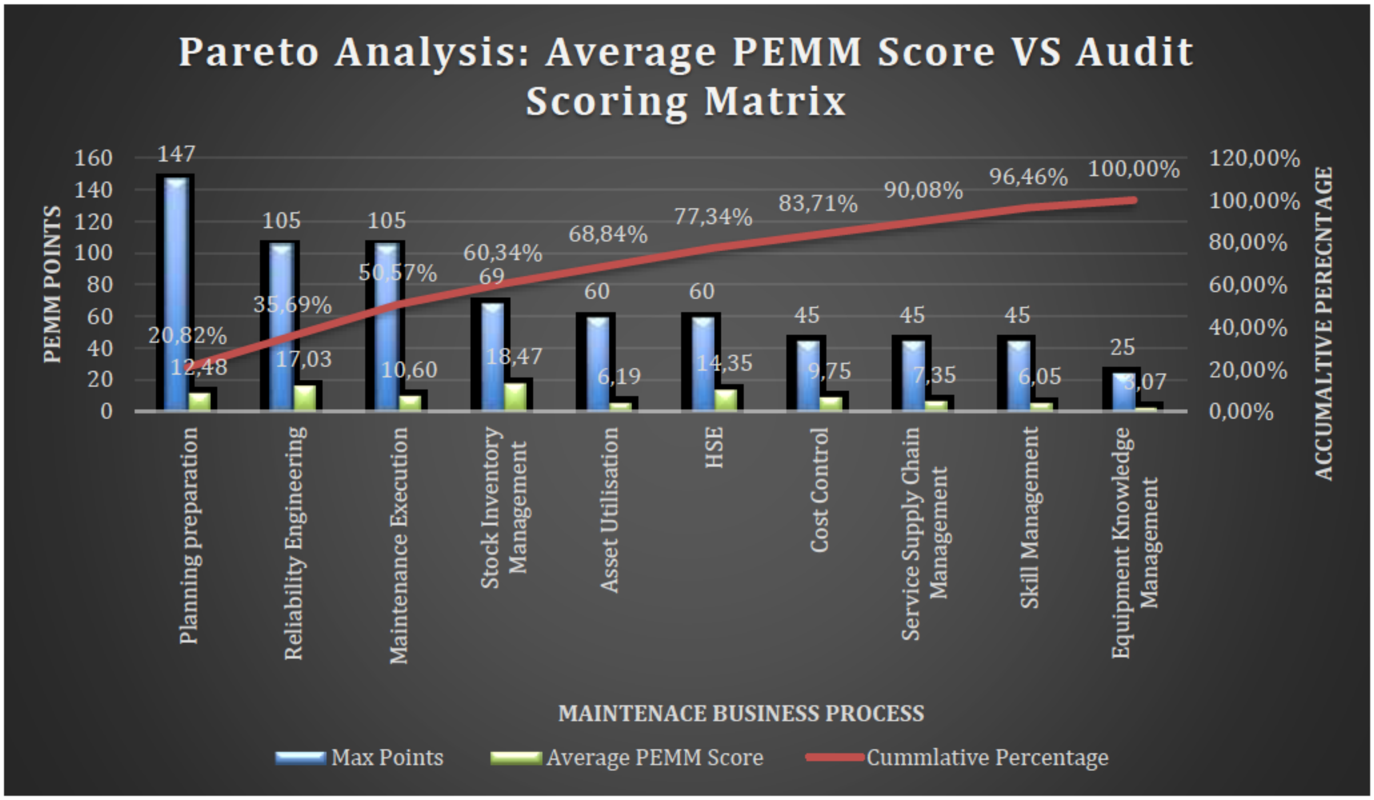

Figure 4. 6 Pareto Analysis of PEMM Score

4.8.3: Data Triangulation: Cross-Verifying Qualitative and Quantitative Findings

This section will cross-verify findings from both quantitative and qualitative tools to determine if the results align with each other.

To ensure the validity and reliability of the study, a data triangulation approach was used to compare and consolidate findings from both qualitative (interviews, thematic analysis, content analysis) and quantitative (RPN calculations, statistical trend analysis, Pareto analysis) methods. This process confirmed whether the results aligned and provided a comprehensive understanding of the challenges and opportunities in improving packaging equipment reliability at PepsiCo Durban.

4.8.4 Maintenance Ratios: Corrective vs. Preventive

The quantitative analysis of maintenance records revealed that PepsiCo Durban's current maintenance ratio was 67.86% preventative and 32.14% corrective, significantly deviating from the industry benchmark of 80% preventative and 20% corrective (Maseola, 2022). This imbalance was further supported by Figure 4.1, which showed that preventative maintenance efforts averaged only 20% post-2022, while corrective maintenance was four times higher than best-in-class standards.

The qualitative interviews reinforced these findings, with maintenance staff confirming that reactive repairs dominated their workload due to frequent unplanned stoppages. Engineering managers acknowledged the need to shift toward proactive maintenance but cited resource constraints, time pressures, and insufficient training as key barriers.

Regarding Triangulation Insights, both datasets confirmed that PepsiCo's maintenance strategy was over-reliant on corrective actions, highlighting an urgent need to rebalance efforts toward preventative measures.

4.8.5. Critical Failure Modes in Packaging Equipment

The quantitative Risk Priority Number (RPN) analysis (Table 4.2) identified sensor damage (RPN = 384) and belt snapping (RPN = 240) as the most critical failure modes due to their high severity, occurrence, and poor detectability. Pareto analysis (Figure 4.6) further emphasised that planning and preparation were the weakest areas in maintenance practices.

The qualitative thematic analysis of interviews aligned with these results, with maintenance teams frequently citing electrical failures (69.42%) and mechanical breakdowns (30.58%) as the primary causes of downtime. Additionally, content analysis of PEMM audits revealed that spare parts shortages and poor backlog management exacerbated these failures.

Triangulation Insight: Both methods pinpointed sensors, belts, and planning deficiencies as the most pressing reliability issues, providing a clear focus for improvement efforts.

4.8.6. Challenges in Optimising Maintenance Ratios

Statistical trend analysis (Figures 4.4 & 4.5) showed that downtime peaked at 5.01% in 2023, correlating with declines in maintenance execution and inventory management. The data also revealed inconsistent maintenance strategies over the years, likely due to frequent management changes.

Interviews provided deeper context, with corrective maintenance teams (89.61%) reporting excessive time pressure, while preventative teams (72.73%) highlighted skills gaps as a major constraint. Engineering managers stressed the need for better data systems and standardised processes to improve efficiency.

Triangulation Insight revealed that the quantitative trends matched qualitative feedback, confirming that time constraints, skills shortages, and inconsistent processes were key obstacles to optimising maintenance ratios.

4.8.7 Implementation of PEMM and ISO 9001 Audit Findings

PEMM audit scores showed a decline from 35.16% (2022) to 18.25% (2024), far below the 40% target. Content analysis of audit reports identified recurring issues, such as missing spare part lists, poor backlog tracking, and lack of statutory compliance follow-ups.

Interviews revealed that only 5.5% of responses referenced PEMM, indicating low awareness and implementation of audit recommendations. Supervisors admitted that corrective actions were often overlooked due to competing priorities and resource shortages.

Triangulation Insights in both datasets confirmed that audit recommendations were poorly executed, leading to persistent inefficiencies in maintenance practices.

4.8.8: FMEA Integration into Quality Management

The RPN and Pareto analyses demonstrated that FMEA could effectively prioritise high-risk failures (e.g. sensors, belts) and guide maintenance improvements. However, interviews revealed minimal FMEA knowledge (7.7% of references) among maintenance teams, with engineering managers noting resistance to change and lack of cross-functional collaboration as adoption barriers.

Triangulation Insight: While FMEA was recognised as a valuable tool, cultural resistance and knowledge gaps hindered its integration into PepsiCo's quality management framework.

The next chapter summarises key theories explored in this study. It assesses how effectively the research objectives were met, provides practical recommendations, outlines the study's limitations, and suggests areas for future research.

Chapter 5: Summary, Conclusions, Recommendations and Limitations

This chapter offers a consolidated overview of the key theories and concepts explored in the study. It also evaluates how well the research objectives have been met, presents practical recommendations based on the findings, and outlines the study's limitations. Finally, it proposes areas for future research to build on the current work.

5.1 Attainment of research objectives

This section revisits the objectives outlined in Chapter 1 and assesses the extent to which they have been accomplished.

The study set out to enhance equipment reliability in the packaging department at PepsiCo Durban by applying FMEA within an existing quality management framework. Through a mixed-method approach, each of the five research objectives was addressed, ensuring the study's overall aim was met.

The first objective was to benchmark PepsiCo Durban's historical corrective and preventative maintenance ratio against industry standards. This was achieved through a literature review and document analysis of ten years' worth of internal maintenance records, specifically drawn from SAP IW28 and IW38 reports. The analysis revealed that the organisation operated with a maintenance ratio of 32.14% corrective and 67.86% preventative. These results were then compared with FMCG industry best practices, where a 20:80 corrective-to-preventative ratio is widely recommended. The deviation indicated an over-reliance on corrective maintenance, with corrective actions being more than 60% higher than optimal levels. This finding not only confirmed the presence of inefficiencies in the current maintenance strategy but also highlighted the urgent need for proactive measures to improve equipment reliability. These findings align with the literature reviewed in Chapter 2, where Maseola (2022: 4) and Elsawaf (2023: 1) emphasised that optimal maintenance ratios for FMCG industries require preventive maintenance levels above 70% to ensure reliability, reduce downtime, and enhance operational efficiency.

The second objective focused on identifying the most critical failure modes within the packaging equipment. This was accomplished through document analysis of maintenance records and the application of quantitative tools such as RPN scoring and Pareto Analysis. The results pointed to sensor damage as the most critical failure mode, with an RPN score of 384, followed by belt snapping (RPN 240) and vacuum pump damage (RPN 192). The data further showed that 69.42% of failures were electrical in nature, while 30.58% were mechanical. This level of analysis allowed the study to prioritise failure modes based on severity, occurrence, and detectability, enabling the development of targeted maintenance strategies to address the most impactful issues. These findings are consistent with the literature, where Dong (2020: 763), Tsarouhas (2020: 240), Ilhan *et al.* (2021: 326) , and Gellerich and Majschak (2023: 383) similarly identified mechanical wear, sensor failures, electrical malfunctions, and sealing equipment defects as dominant contributors to packaging equipment downtime within FMCG operations.

To address the third objective, ascertaining the challenges in optimising the maintenance ratio, the study conducted in-depth interviews with twelve staff members, including Maintenance Managers, Preventative Maintenance Team Members, Line Support Instrument Technicians, and Millwrights. Thematic analysis of the interview data revealed several recurring challenges. Time constraints were a significant issue, with corrective teams spending nearly 89.61% of their time on unplanned repairs. Additionally, 72.73% of preventative maintenance personnel reported lacking formal training in modern reliability or FMEA techniques. Other challenges included inefficient spare parts management, poor communication between departments, and resistance to cultural change within the maintenance function. These insights confirmed that both operational and behavioural factors were limiting the organisation's ability to shift from reactive to preventative maintenance. These barriers reflect what Stenstrom *et al.* (2016: 603) described as resource allocation and planning challenges in maintenance optimisation, while Hamasha *et al.* (2023: 2) emphasised the impact of skills shortages, inadequate training, and cultural inertia as critical obstacles in transitioning to proactive maintenance models.

The fourth objective examined the extent to which audit findings and recommendations from the PEMM and ISO 9001 had been implemented. Document analysis of QIPs, PEMM scorecards, and ISO audit reports, combined with interview data from supervisory staff, revealed significant gaps. PEMM audit compliance declined from 35.16% in 2022 to just 18.25% in 2024, falling well short of the 40% target. Interviews also revealed a lack of system ownership, with only 5.5% of responses referring to PEMM practices. Missing spare parts lists, inadequate backlog tracking, and a failure to follow up on statutory work were common findings, highlighting weaknesses in both compliance and execution. These audit findings reflect issues identified by Felipe and Nunez (2020: 1) and Calderón, Caleb and Collao (2024: 1067), who noted systemic weaknesses in audit execution, limited accountability, and feedback loop breakdowns, which often hinder the effective translation of audit recommendations into sustainable operational improvements.

The final objective was to develop a customised FMEA Implementation Strategy to be integrated into PepsiCo’s existing quality management framework. This was accomplished by building upon the study’s empirical findings and aligning the strategy with ISO 9001 principles and PEMM requirements. The proposed strategy involved institutionalising FMEA within the QIP, establishing a cross-functional task team, and incorporating high-RPN failure modes into the CMMS. Preventative maintenance schedules were adjusted to address critical failure points, while audit compliance tools were updated to reflect FMEA controls. Key performance indicators such as MTBF, maintenance ratios, and audit scores were proposed to monitor progress. By embedding FMEA into the organisation's operational and quality systems, the strategy enabled a shift from reactive to proactive maintenance and supported broader sustainability goals under SDGs 12, 13, and 15. This proposed strategy directly aligns with the literature for hybrid frameworks that integrate FMEA with complementary tools such as RCA and SPC, as stated by Tang, Chen and Lin (2020: 4) and Hii *et al.* (2024: 1). Furthermore, the inclusion of cross-functional teams and enhanced training specifically addresses adoption challenges as mentioned by Zulfiqar *et al.(* 2024: 13).

In summary, each of the study's objectives was systematically addressed through a combination of literature review, document analysis, quantitative risk evaluation, and qualitative inquiry. The integration of findings into a practical FMEA-based strategy demonstrated how a structured quality framework can drive significant improvements in equipment reliability, operational sustainability, and audit compliance within the FMCG sector. Importantly, the study's findings not only validated existing theoretical benchmarks but also extended the literature by contextualising FMEA applications within PepsiCo Durban's operational environment, while highlighting important gaps in audit follow-through and workforce capability development.

The next section leverages the knowledge gained from the previous chapters to develop a customised FMEA implementation strategy.

5.2 Customised FMEA Implementation Strategy

In this section, the knowledge gained in the previous chapters is used to create a customised FMEA Implementation Strategy within the current quality management framework to improve the reliability of equipment in the packaging department.

In response to the study's findings, which highlighted elevated corrective maintenance levels (32.14%) compared to the industry benchmark of 20%, recurring failure modes (notably sensor damage, belt snapping, and vacuum pump failures), and declining PEMM audit compliance (18.25% in 2024 against a 40% target), this section presents a customised Failure Mode and Effects Analysis (FMEA) implementation strategy. The objective of this strategy is to embed FMEA into PepsiCo Durban's existing Quality Management Framework, comprising ISO 9001, the PepsiCo Europe Maintenance Methodology (PEMM), and the Quality Improvement Plan (QIP), to proactively address risks, improve reliability, and reduce packaging waste.

The first step in this strategy is to institutionalise FMEA within PepsiCo's quality planning processes. Currently, the organisation's QIP focuses primarily on post-audit corrective actions, with limited emphasis on forward-looking risk assessments. To shift toward proactive maintenance, it is recommended that FMEA be embedded into Clause 6 of the ISO 9001 framework (Actions to Address Risks and Opportunities). FMEA outputs should be formally included in preventive maintenance schedules and reliability analyses, ensuring that risk identification and mitigation occur during planning stages rather than as a response to failures.

To support this integration, a cross-functional FMEA Task Team should be established. This team should include maintenance engineers, line support technicians, production supervisors, and quality assurance personnel. A designated FMEA Co-ordinator will facilitate alignment between departments and ensure consistent application of the methodology. This initiative is particularly vital given that 72.73% of preventative maintenance staff reported lacking formal training; a skills gap that must be closed to enable successful implementation. Training programmes should, therefore, be rolled out to build internal capacity and sustain long-term adoption.

Additionally, the organisation should prioritise the analysis of high-risk equipment based on historical data. The study revealed that failures such as sensor damage (RPN 384), belt snapping (RPN 240), and vacuum pump damage (RPN 192) were the most critical. Using Pareto Analysis and the Risk Priority Number framework, these assets should be targeted first for FMEA development. By focusing on the 20% of equipment responsible for 80% of downtime, the organisation can deploy resources effectively and gain rapid improvements in reliability.

Once priority equipment is identified, FMEA findings must be translated into actionable maintenance interventions. This includes integrating critical failure modes into the Computerised Maintenance Management System (SAP IW28/IW38) and updating preventive maintenance schedules accordingly. For example, if sensor failure is determined to occur frequently and without warning, periodic sensor inspections or replacements should be implemented. This alignment between FMEA and preventive maintenance activities will support the strategic goal of achieving an 80% preventive maintenance ratio, in line with FMCG industry best practices.

In parallel, FMEA must be leveraged to address audit compliance gaps. The study found that many ISO 9001 and PEMM requirements, such as spare parts tracking, backlog management, and follow-up on statutory maintenance, were not being adequately addressed. FMEA can help close these gaps by identifying failure modes linked to systemic process weaknesses. For instance, an FMEA analysis might reveal that delayed repairs are often due to missing spare parts; this insight can be used to update the Bill of Materials (BOM) and improve spare parts inventory planning. Additionally, internal audit tools and checklists should be revised to include questions derived from FMEA findings, thereby strengthening the link between technical analysis and quality assurance.

To ensure sustainability, all FMEA activities should be formally documented and integrated into the organisation's quality records, in compliance with ISO 9001 Clause 7.5 (Documented Information). Standardised FMEA templates, preferably aligned with the 7-step AIAG/VDA model, should be developed and stored within the QMS. Using an FMEA template aligned with the 7-step AIAG/VDA model ensures a structured, standardised, and globally recognised approach to risk analysis that enhances reliability, audit readiness, and cross-functional collaboration. Unlike traditional RPN-based methods, this model incorporates Action Priority (AP) for better decision-making, aligns seamlessly with ISO 9001 and PEMM frameworks, and supports more effective prevention strategies (Kluse 2020: 71). For organisations like PepsiCo Durban, it provides a robust foundation for improving maintenance planning, reducing downtime, and integrating FMEA into the broader quality management system. These documents will serve as a valuable knowledge base for future training, audits, and continuous improvement initiatives.

Ongoing performance review is essential for maintaining the relevance and effectiveness of FMEA implementation. Key metrics such as MTBF, maintenance ratios, PEMM scores, and reductions in RPN values should be tracked on a quarterly basis. These insights should be reviewed as part of the organisation's management review meetings (ISO 9001 Clause 9.3), ensuring that corrective actions and reliability improvements are continuously refined.

In conclusion, this FMEA implementation strategy responds directly to the empirical findings of the research. By embedding FMEA into PepsiCo Durban's quality management framework, the organisation can transition from a reactive to a proactive maintenance culture. This strategy addresses operational inefficiencies, audit non-compliance, and high-risk equipment failures, while also promoting a data-driven and sustainable approach to packaging reliability. In doing so, it advances the company's goals of reducing waste, improving productivity, and aligning with global sustainability standards such as SDG 12 (responsible consumption and production), SDG 13 (climate action), and SDG 15 (life on land).

The next section provides an overall conclusion of the study.

5.3 Conclusion of the Study

The motivation for the study stemmed from excessive waste that was generated in the packaging department, which resulted from equipment reliability issues. Reliability was a key aspect considering the nature of snack food manufacturing at Durban PepsiCo. It then sought to explore the application of FMEA through a quality management framework to enhance equipment reliability in the packaging department of the manufacturing site. The study utilised five objectives to achieve this aim by adopting qualitative and quantitative design methodologies.

This study has successfully demonstrated that the integration of FMEA into an existing quality management framework can significantly enhance the reliability of packaging equipment in the FMCG sector. Through a comprehensive benchmarking exercise, the study highlighted that PepsiCo Durban's corrective maintenance levels exceed industry norms, contributing to operational inefficiencies and waste. By identifying critical failure modes and assessing departmental challenges through document analysis and interviews, the study provided clear evidence of technical, behavioural, and systemic barriers to optimal maintenance performance.

The findings also underscored gaps in the implementation of audit recommendations from ISO 9001 and PEMM, indicating a disconnect between strategic goals and operational execution. The customised FMEA Implementation Strategy proposed in this research offers a proactive, structured approach to addressing these gaps, positioning maintenance as a driver of sustainability, compliance, and productivity.

Ultimately, this research contributes to both academic knowledge and practical solutions by applying a well-established reliability tool in a novel context. The study supports PepsiCo's broader commitment to responsible consumption and sustainable operations, while providing a scalable framework for continuous improvement in the FMCG sector.

5.4 Recommendations

Based on the findings, several strategic recommendations are proposed to improve the reliability of packaging equipment at PepsiCo Durban:

I. Increase Preventive Maintenance Coverage

   The current maintenance ratio of 32.14% corrective to 67.86% preventative, should be aligned with the FMCG industry benchmark of 20% corrective and 80% preventative. This can be achieved by enhancing the use of condition monitoring tools, updating maintenance schedules, and increasing planned downtime for preventative checks.

II. Prioritise High-Risk Failure Modes

   Components with high RPN, such as sensors (RPN = 384), belts (RPN = 240), and vacuum pumps (RPN = 192), should be addressed immediately. Upgrading these components or integrating condition-based monitoring can prevent unexpected breakdowns.

III. Address Skills Gaps Through Training
With 72.73% of preventative maintenance personnel lacking formal training in FMEA and predictive maintenance strategies, capacity-building programmes should be implemented to improve technical competencies and foster a proactive maintenance culture.

IV. Strengthen Audit Compliance and QMS Integration
The organisation should strengthen compliance with ISO 9001 and PEMM requirements. This includes updating spare parts lists, backlog tracking systems, and QIPs to reflect FMEA outcomes and audit recommendations.

V. Implement and Institutionalise the FMEA Strategy
A formal, cross-functional team should oversee the implementation of the FMEA strategy across packaging lines. The strategy should be integrated into the QMS and linked to KPIs such as MTBF, audit compliance scores, and waste reduction metrics.

5.5 Recommendations for future study

This study opens several avenues for further research:

I. Wider Application Across FMCG Departments
Future research could explore FMEA implementation across other departments within PepsiCo or other FMCG facilities, such as processing or warehouse operations, to assess broader impacts on organisational efficiency.

II. Comparative Studies Between Sites
A multi-site comparative study could provide insights into how equipment reliability varies across different PepsiCo facilities or competitors using alternative maintenance frameworks like TPM or RCM.

III. Integration of Emerging Technologies
Further studies could examine the integration of Internet of Things (IoT), Machine Learning, and Predictive Analytics into FMEA strategies to build intelligent, data-driven maintenance systems.

IV. Behavioural and Organisational Culture Factors
Investigating the impact of organisational culture, leadership engagement, and employee motivation on the adoption and sustainability of FMEA practices would add value to change management efforts in technical environments.

5.6 Limitations of the study

Although this study achieved its objectives, it was subject to several limitations:

I. Small Sample Size: The qualitative component was based on a small population (12 staff members), which may limit the generalisability of findings to larger or more diverse departments.

II. Departmental Scope: The research was confined to the packaging department at PepsiCo Durban, excluding insights from other departments or broader regional trends.

III. Historical Data Constraints: The study relied on 10 years of maintenance records. Gaps or inaccuracies in documentation may have influenced trend and RPN analysis.

IV. Subjectivity in Qualitative Analysis: Thematic and content analyses, though methodologically sound, are inherently interpretive and may carry potential researcher bias despite triangulation efforts.

v. Exclusion of Non-Maintenance Personnel: Perspectives from quality control, production management, and supply chain staff were not included, which may have limited the holistic understanding of interdepartmental challenges.

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Annexure 1: Consent Letter

CONSEN

T

Title: Utilizing Failure Mode and Effects Analysis (FMEA) to Improve the Reliability of Packaging Equipment at PepsiCo Durban

Names of Researcher/s: Dean Govender

Statement of Agreement to Participate in the Research Study:

I hereby confirm that the researcher, Dean Govender, has fully explained the purpose, procedures, potential benefits, and possible effects of this study (Research Ethics Clearance Number: IREC 307/24) to me.

The Participant Information Letter is understandable and provides sufficient details about the study.

I am aware that the findings of this research, including personal information, will be treated confidentially and reported anonymously in the final study report.

I understand that the data collected from me will be stored and processed electronically by the researcher for the purposes of this study.

I understand that my participation is entirely voluntary and that I am free to withdraw from the study at any time without facing any negative consequences.

I have had ample opportunity to ask questions and, of my own free will, I consent to take part in this research study.

I understand that any important new information that may arise during the course of this research and that is relevant to my participation will be shared with me

____________________ __________ ______ _______________

Full Name of Participant **Date** **Time** **Signature / Right Thumbprint**

I, Dean Govender (researcher), hereby confirm that the participant named above has been fully informed about the purpose, procedures, and potential risks associated with this study.

_________________ __________ ___________________

Full Name of Researcher **Date** **Signature**

_________________ __________ ___________________

Full Name of Witness (If applicable) **Date** **Signature**

Full Name of Legal Guardian (If applicable) Date Signature

Annexure 2: Letter of information

LETTER OF INFORMATION

Title of the Research Study: Utilizing Failure Mode and Effects Analysis (FMEA) to Improve the Reliability of Packaging Equipment at PepsiCo Durban

Principal Investigator/s/researcher: Dean Govender MBA Candidate, Durban University of Technology

Co-Investigator/s/supervisor/s: Professor Ramchandra D. Com

Brief Introduction and Purpose of the Study:

Good [morning/afternoon],

My name is Dean Govender, a Master of Business Administration (MBA) student at the Durban University of Technology. As part of my academic research, I am conducting a study on the application of Failure Mode and Effects Analysis (FMEA) to enhance the reliability of packaging equipment at PepsiCo Durban. The purpose of this study is to gain insights into the current maintenance practices, challenges, and potential improvements in the packaging department.

I would like to invite you to participate in this research. Research is a systematic search or enquiry for generalized new knowledge. Your participation is voluntary.

Outline of the Procedures:

This study aims to benchmark maintenance ratios, identify critical failure modes, and develop strategies to implement FMEA in the packaging department. You will be asked to participate in an interview, which will take approximately 60 min. During the interview, we will discuss your role, current maintenance practices, challenges faced, and the implementation of audit findings. Your insights will help us develop recommendations for improving equipment reliability.

- **Venue:** PepsiCo Conference 1
- **Inclusion Criteria:** Employees involved in maintenance management or supervisory roles in the packaging department.
- **Duration:** Approximately 60 for the interview.
- **Number of Participants:** Around 4 participants.

Risks or Discomforts to the Participant:

There are no potential risks associated with your participation in this study. However, if you feel uncomfortable at any point, you are free to withdraw from the study without any consequences.

Explain to the participant the reasons he/she may be withdraw from the Study:

You may choose to withdraw from the study at any time should you wish to do so. The research may also be terminated early in certain circumstances, such as non-compliance, illness, or adverse reactions. Procedures are in place for an orderly termination of participation.

Benefits:

By participating in this study, you will contribute to improving the reliability and efficiency of packaging equipment at PepsiCo Durban. The insights gained from this research could lead to enhanced maintenance practices and operational efficiency.

Remuneration:

There will be no monetary or other types of remuneration for your participation in this study.

Costs of the Study:

There will be no costs incurred by you for participating in this study.

Confidentiality:

Your privacy and confidentiality will be maintained and and Data collected during the study will be anonymised and securely stored. Only the research team will have access to the data, and it will not be identifiable to persons not involved in the research.

Results:

The results of the research will be disseminated through academic reports and presentations. Should any important new findings emerge during the research, you will be promptly informed.

Research-related Injury:

In the unlikely event of a research-related injury, appropriate measures will be taken to address the issue. No compensation will be provided as there are no foreseeable risks involved.

Storage of all electronic and hard copies including tape recordings

All electronic and hard copies, including tape recordings, will be stored securely for the duration of the study. Only the research team will have access to the data, which will be retained for 5 years after the study's completion.

Who to Contact for Further Information or Assistance:

Please contact the researcher, Dean Govender, at 079 523 8877, my supervisor, Professor Ramchandra, at 074 400 4400, or the DUT-Institutional Research Ethics Administrator at 031 373 2375. Complaints can be reported to the Acting Director: Research and Postgraduate Support at researchdirector@dut.ac.za.

General:

A copy of this information letter is provided to you. Please feel free to take it home and discuss it with your family and friends. The letter and consent form have been translated into [primary spoken language] for your convenience.

Annexure 3: Questionnaire

Interview Schedule: Enhancing Equipment Reliability at PepsiCo Durban through FMEA

Introduction and Purpose of the Study (5 minutes)

Hello:

"Thank you for taking the time to meet with me today. My name is Dean Govender, and I am a Master of Business Administration student at the Durban University of Technology. I am conducting research on utilising Failure Mode and Effects Analysis (FMEA) to improve the reliability of packaging equipment at PepsiCo Durban. The aim of this interview is to gain insights into the current maintenance practices, challenges, and potential improvements in the packaging department."

Interview Format and Confidentiality:

"This interview will take approximately 60 minutes. Your responses will be kept confidential and will only be used for academic purposes. If you agree, I would like to record this interview to ensure I capture all the details accurately."

Consent:

Question 1: "Do you have any questions before we begin? Do I have your permission to proceed and to record this interview?"

Background Questions (8 minutes)

Role and Experience:

Question 2: “Can you please describe your role and responsibilities within the maintenance management/supervisory team at PepsiCo Durban?”

- Probing: “How has your role evolved over time?”
- Probing: “What are the key skills needed for your position?”

Question 3: “How long have you been working in this position and in the packaging department specifically?”

- Probing: “What other roles have you held within the company?”
- Probing: “How does your current role compare to your previous positions?”

Specific Questions Related to Research Objectives (42 minutes)

Objective 1: Benchmarking Maintenance Ratios (8 minutes)

Question 4: “How would you describe the balance between corrective and preventive maintenance in the packaging department?”

- Probing: “Has this balance changed over time? If so, how and why?”
- Probing: “What factors influence this balance?”

Question 5: “Are there any industry standards or benchmarks that you compare your maintenance ratios against? If so, how does PepsiCo Durban’s maintenance performance compare?”

- Probing: “Can you provide specific examples of these benchmarks?”
- Probing: “What actions have you taken to meet or exceed these benchmarks?”

Objective 2: Identifying Critical Failure Modes (8 minutes)

Question 6: “Based on your experience, what are the most common failure modes in the packaging equipment?”

- Probing: “How frequently do these failure modes occur?”
- Probing: “What are the typical consequences of these failures?”

Question 7: “How are maintenance records analysed to identify patterns or recurring issues? Can you walk me through the process?”

- Probing: “What tools or methods do you use for this analysis?”
- Probing: “Can you provide an example of a pattern or issue you identified through this process?”

Objective 3: Challenges in Optimizing the Maintenance Ratio (8 minutes)

Question 8: “What are the main challenges you face in optimizing the corrective to preventive maintenance ratio?”

- Probing: “How do these challenges impact overall equipment reliability?”
- Probing: “What strategies have you employed to overcome these challenges?”

Question 9: “Can you provide examples of specific instances where maintenance practices have fallen short, leading to equipment failures or unplanned stoppages?”

- Probing: “What were the main causes of these failures?”
- Probing: “How were these issues resolved?”

Objective 4: Implementation of Audit Findings (8 minutes)

Question 10: “To what extent have the findings or recommendations from ISO 9001 and PEMM audits been implemented in the packaging department?”

- Probing: “Can you describe some of the key recommendations and their implementation?”
- Probing: “What challenges did you face during the implementation process?”

Question 11: “What impact have these implementations had on equipment reliability and operational efficiency?”

- Probing: “How do you measure these impacts?”
- Probing: “Can you share any specific improvements or successes?”

Objective 5: FMEA Implementation Strategy (10 minutes)

Question 12: “Have you had any experience with Failure Mode and Effects Analysis (FMEA) in your role? If so, can you describe its impact?”

- Probing: “How was FMEA integrated into your existing processes?”
- Probing: “What were the main benefits and challenges of using FMEA?”

Question 13: “What do you think are the key factors to consider when integrating FMEA into the current quality management framework?”

- Probing: “What resources or support would be needed for successful integration?”
- Probing: “How would you ensure continuous improvement using FMEA?”

Question 14: “Have you encountered any resistance to implementing FMEA processes? If so, how was it handled?”

- Probing: “What specific challenges or objections did you face from team members or stakeholders during the FMEA implementation, and how did you address those concerns?”
- Probing: “Were there any organizational or cultural barriers that made it difficult to gain buy-in for the FMEA process? If so, what strategies did you use to overcome those obstacles?”

Closing Remarks (5 minutes)

Summary and Follow-Up:

Question 15: “Thank you for sharing your insights. Is there anything else you would like to add that we haven’t covered?”

- Probing: “Are there any other challenges or opportunities you think are important to mention?”

Question 16: “Would it be okay to contact you for any follow-up questions or clarifications?”

- Probing: “Do you have any preferred methods of communication for follow-up?”

Next Steps:

“The information gathered from these interviews will be analysed and used to develop recommendations for improving the reliability of the packaging equipment. I will ensure you receive a summary of the findings once the research is completed.”

Thank You:

“Thank you again for your time and valuable input.”

Annexure 4: Permission from Gatekeeper

SIMBA (PROPRIETARY) LIMITED
Reg. No. 1995/003667/07
VAT No. 4400150183

Date: 18 February 2025

Details of addressee: 41 Jeffels Road, Prospecton, Durban

Re: Request for Permission to Conduct Research

Dear Dean Govender

I grant you authorization to conduct research for your Masters Mini Dissertation which involves Utilizing FMEA to improve the reliability of packaging equipment: The case of PepsiCo Durban.

I consent to you conducting interviews with the maintenance supervisory team and analyze documentation related to the study, however, please take note of the non-disclosure agreement highlighted in yellow.

Non-Disclosure Agreement: No sensitive information collected during the research will be shared, and the organization will be anonymized.

____

Mandisa Thabethe
Date:

PC Operations Manager Prospecton, Sub Saharan Africa
PepsiCo / Simba (Pty) Limited
Prospecton Plant, 31-41Jeffels Road, Prospecton, KwaZulu-Natal, South Africa, 4113
Mobile : +27 83 785 0072 | Office : +27 87 310 7148 | mandisa.thabethe@pepsico.com

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P.O. Box 99, Isando, 1600, South Africa
Tel: +27 (0) 11 928-6000, Fax +27 (0) 11 974-3079

Annexure 5: DUT Ethics Clearance

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

Tel: 031 373 2375
Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics

www.dut.ac.za

5 March 2025

Mr D Govender
15 Robinson Street
Umkomaas
4170

Dear Mr Govender

Utilizing FMEA to improve the reliability of packaging equipment: The case of packaging equipment at PepsiCo Durban
Ethical Clearance number IREC 307/24

The DUT-Institutional Research Ethics Committee acknowledges receipt of your gatekeeper permission letter.

Please note that FULL APPROVAL is granted to your research proposal. You may proceed with data collection.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the DUT-IREC according to the DUT-IREC Standard Operating Procedures (SOP's).

Please note that any deviations from the approved proposal require the approval of the DUT-IREC as outlined in the DUT-IREC SOP's.

It is compulsory for a student or researcher to apply for recertification on an annual basis. The failure to do so will result in withdrawal of ethics clearance. It is the responsibility of the researcher and the supervisor to apply for recertification.

Please note that you are required to submit a Notification of Completion of Study form together with an abstract to the DUT-IREC office on completion of your study.

Yours Sincerely

Professor P Mashau
Chairperson: DUT-IREC

Annexure 6: Language editors' clearance letter

27th June 2025

To whom it may concern

<u>LANGUAGE EDITING REPORT: Dean Govender (Reg. No 20400656)</u>

This report confirms that the mini-dissertation (masters) titled **"Utilising FMEA to Improve the Reliability of Packaging Equipment. The Case of Packaging Equipment at PEPSICO Durban"** submitted by Dean Govender **of the Faculty of Management Studies, DUT, Business School, Durban University of Technology** has been edited for language. The editing process was undertaken to ensure that the dissertation was free from such English language errors as (but not limited to) those of clarity, coherence, grammar, punctuation, spelling, style and syntax. Neither the research contents nor the researcher's intention was altered in any way.

Should you have any questions or comments, please do not hesitate to contact me.

Sincerely

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Annexure 7: Plagiarism Report

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ORIGINALITY REPORT

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Annexure 8: Certificate of Ethics Training

TRREE

Zertifikat

Certificat

Certificado

Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Clinical Trials Centre
The University of Hong Kong

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Dean Govender

a complété avec succès - has successfully completed

Module 1 (2023) - Introduction to Research Ethics

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2024/08/10

Professeur Dominique Sprumont
Coordinateur TRREE Coordinator

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Annexure 9: Key Supporting Quotations Derived from Thematic Analysis

Theme	Key Supporting Quotations
Collaboration & Planning	*"My department leader has tried to sit down with the leaders in production and the production planner... we are seeing results. We are getting a bit more time to do maintenance."* (Participant 1)
Maintenance Duration Efficiency	*"I will have a separate back seal that I overhaul in the workshop... on the day you take the machine down, it makes it a lot quicker."* (Participant 2)
Mindset Shift & Culture Change	*"We've got the tools, we've got the documentation, we've got the knowledge. We just need to change our mindset to the point where we can actually get preventative mindsets."* (Participant 7)

Theme	Key Supporting Quotations
Spare Part Availability	*"We were waiting for breakdowns... but what we're trying to do now is have it on site even before we need it."* (Participant 2)
Technology & Accessibility	*"We use Teams to upload all our documentation... we try to digitise our workspace so the guys can actually use their technology to interact and capture information."* (Participant 7)
Supplier Support	*"We are using our relationship with our OEMs to give us insight into our machines so we can act in a preventative manner."* (Participant 7)
Time Constraints and Production Pressure	*"A major barrier is the lack of dedicated time for maintenance, due to the continuous operation of production lines."*
Skills Shortages and Workforce Capacity	*"We're short of some skilled artisans at the moment... then you're getting a contractor who is not familiar and up to standard with our protocols."* (Participant 8)

Theme	Key Supporting Quotations
Inadequate Resources and Spare Parts	*"There's time and resources, so your time and money, and there's also a mindset challenge."* (Participant 5)
System Complexity and Technical Limitations	*"The challenge was with the use of SAP... you have to have vast knowledge and authorisations with testing codes for engineering planning."* (Participant 9)
Cultural Resistance and Mindset	*"We've got the tools, we've got the documentation, we've got the knowledge. We just need to change our mindset to actually get a preventative mindset."* (Participant 7)
Lack of Alignment Between Maintenance and Production	*"Sometimes you find that there is a lack of balance between the time given for maintenance to do its job from production side."* (Participant 1)

Theme	**Key Supporting Quotations**
High Frequency of Failures	*"Failures occur daily."* (Participant 5) *"Sometimes you can say it can happen three times in one day."* (Participant 8)
Cost Pressures	*"Cost is always a challenge... Overhauling full mechanisms takes more time and money than replacing one part, but it pays off in reliability."* (Participant 7)
Skills Gaps and Technical Competence	*"Quality of work could be one thing... we execute the task, but it's not executed at the right quality and that results in equipment failures."* (Participant 5)
Inconsistent Staffing and Contractor Limitations	*"Short of some skilled artisans at the moment... you need to have a contractor... which he's not familiar and up to standard with our protocols."* (Participant 8)
Soft Skills and Emotional Readiness	*"The moral and also the emotional and mental state of the people that are working on problems, there are several factors, I'd say."* (Participant 7)

Theme	Key Supporting Quotations
Limited Availability of Resources and Spares	*"You have more jobs than the time, so you'll feel like the time is short, but really the jobs are more."* (Participant 3)
Knowledge Systems and Documentation Challenges	*"The challenge was with the use of a program called SAP... it's very detailed."* (Participant 9)
Lack of Awareness or Experience with FMEA	*"To be honest, I don't have FMEA knowledge. I have never had that experience."* (Participant 1) *"What is it---FMEA?"* (Participant 4)
Limited Implementation and Early Rollout of FMEA	*"We're still rolling that part out."* (Participant 2)
FMEA Used for Task Development by Advanced Users	*"FMEA is used to develop the equipment task list so that we are addressing the failure modes."* (Participant 5)

Theme	Key Supporting Quotations
Perceived Challenges in FMEA Implementation	*"It's a big effort to take hundreds of pieces of equipment and start to do this and expect it to be done in a short space of time."* (Participant 5)
Need for Training and Cross-Functional Involvement in FMEA	*"Having a multi-disciplinary team working under FMEA... and giving a basic understanding of how it works."* (Participant 9)
Use of Structured Root Cause Analysis (RCA) Tools	*"We looked at the mean time between failures... we analysed it within a 5-Why analysis and we upgraded the gearbox and the motor... now we haven't had any failures since."* (Participant 5)
Informal Team-Based Trend Detection	*"We sit as a team and we discuss this in our meetings... nothing is done formally, right? But informally, a discussion is held on what could be the corrective action."* (Participant 9)

Theme	Key Supporting Quotations
SAP and Historical Data Monitoring	*"When you look at the SAP system... if we find a common occurrence on the equipment, we can easily identify it."* (Participant 9)
Shift Reports and Cross-Functional Meetings	*"So usually what they do is... we have our shift report. We write the problems, then the responsible person on the planner side works with the technician. You can trace the pattern and see what's giving a problem."* (Participant 3)
Learning Through Experimentation and Feedback	*"We put a sip-lock belt... easy to install... but then we started to see the frequency of breakdowns increasing. When we returned to the endless belt, the frequency dropped from two per month to once every three months."* (Participant 9)
Gaps in Formalised Strategy and Training	*"To be honest, I'll say in my position we don't normally do this... it's more the planner and specialist team who analyse root causes."* (Participant 1)

Theme	Key Supporting Quotations
Partial Implementation and Ongoing Efforts	*"I know it's not implemented 100% as it should be. We're busy working on that."* (Participant 2)
Lack of Familiarity and Clarity	*"Hey, I'm not sure."* (Participant 3) *"I would say PEMM audits are not familiar with those tasks."* (Participant 4)
Need for Structural and Systemic Alignment	*"There's a lot of structure, so the recommendation will be to obviously get the structure and system right."* (Participant 5)
Integration with Planning and Performance Metrics	*"So, in PEMM one of my roles is to manage a certain pillar... planning preparation, artisan utilisation, and EHS compliance."* (Participant 9)
Potential for Deeper Use of FMEA and RCA	*"Within PEMM, I think there could be more focus on FMEA."* (Participant 5)

Theme	Key Supporting Quotations
Awareness of Current Ratios and Transition States	*"Preventative is about say about 40 and corrective is about 60."* (Participant 2) *"I would say the balance for that currently is about 70% corrective and 30% preventative."* (Participant 9)
Ideal Benchmark Targets and World-Class Standards	*"We should be around 15% corrective and 85% preventive."* (Participant 5) *"Most industries have more corrective... I'd say 80% corrective, 20% preventative. Whereas you should have 80% preventative and 20% corrective. That should be world-class."* (Participant 7)
Use of Internal and External Benchmarking Tools	*"We do a benchmark every month with other sites... our target is 2%, and best in class is 1% unplanned downtime."* (Participant 9)
Root Cause Analysis (RCA) and Data-Driven Improvements	*"So, from there you can see your data and see that this type of machine had this repetitive breakdown... benchmark in your RCA phase."* (Participant 4)

Theme	Key Supporting Quotations
Cultural and Systematic Challenges in Achieving Benchmark Ratios	*"Sometimes you find that there is a lack of balance between the time given for maintenance to do its job from the production side."* (Participant 1)