DEVELOPMENT OF A MAINTENANCE STRATEGY FOR FLOUR MILLING INDUSTRY: A CASE STUDY OF CORN MILLING INDUSTRY IN KENYA

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DECLARATION

This thesis is my original work and to my knowledge has not been presented in any University/ Institution for a degree or for consideration of any certification.

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DEDICATION

I dedicate this research work to my beloved family, my wife, daughter and son for their immense support during my studies. May the almighty God bless you abundantly.

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ABSTRACT

Good maintenance planning and proper resources scheduling in corn milling industry are of fundamental importance for safe and efficient operation of corn milling plants. This leads to production optimization due to reduced cost of operation. The interactions of aspects of plant safety and reliability with issues related to economic performance, such as production revenues, repair and maintenance costs, renders the problem of managing maintenance and repair activities highly complicated, especially for complex systems with many 'interacting' components. Corn milling industries experience frequent shutdowns and lack of equipment optimization resulting to high operations and maintenance costs. This has been occasioned by over reliance on failure based maintenance policy with consequence of non-production during the period of down time or reduced through put due to sub-systems not running at full capacity. This has become a common occurrence on the production line equipment resulting to costly production operations. A case study field failure statistics for a 28 metric tonnes per day milling plant production line indicate that, 81 critical sub-system random failures were witnessed leading to total plant shutdown. This translated to 18,877 minutes per year in 2014 of production downtime with production down time cost of US$ 168,892.52, a huge cost that needs to be controlled by either minimising or entirely eliminating the unplanned frequent plant failures. Plant field failure data was systematically collected and analysed for condition parameters that affected the milling plant production process optimization directly or indirectly to establish criticality of failure in terms of failure frequencies, failure downtime and the corresponding failure downtime cost. Tools of reliability analysis for a failure risk based maintenance approach that included failure mode and effect analysis and Pareto analysis tools for failure modes identification, failure mode effects evaluation and failure mode risk prioritization were used. Root cause analysis through application of Ishikawa diagram and Pareto analysis tool were applied for failure root cause identification and failure cause prioritization.

The research established that corn milling plants have priority sub-systems with critical failure modes whose failure consequence caused prolonged downtime and high downtime cost. The milling plant critical sub-systems that required close condition monitoring were ***'run to failure'*** (RTF), a condition that necessitated the application of failure based maintenance policy to rectify the sub-system failure. This maintenance approach did not optimise maintenance function but instead led to failure effect characterised by unplanned prolonged downtime. Potential failure detection techniques and special service tools for sub-system condition monitoring and failure detection were not available for application in the milling industry. Lack of proper service schedules and adequate maintenance documentation affected the quality of plant maintenance. Based on this research, combination of various maintenance policies together with incorporation of maintenance expertise, special service tools, potential failure detection test methods and optimal maintenance procedures and schedules were found to be adequate for corn milling plants maintenance management optimization. In this work, the author developed an optimal maintenance strategy for corn milling industry that mitigates recurrent failures, thus optimizing milling plant production process. Moreover, this maintenance model or frame work developed in this research can be used to develop an optimal maintenance policy that can be applied in industrial set-ups that employ complex multi-functional systems and a decision tree used to aid the maintenance team and decision makers select the most appropriate and optimal maintenance policy.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

5Ms	Machines, Methods, Materials, Man power and Measurements
B1, B2, B3 & B4	Brake rolls or Roller mills Nos. 1, 2, 3 & 4
CAPEX	Capital expenditure
CBM	Condition Based Maintenance
CM	Corrective Maintenance
CMA	Cereals millers Association
CMMS	Computerised Maintenance Management System
DFR	Decreasing failure rate
DM	Drive motor
DS	Degermer screens
DMFDT	Drive motor failure detection test
DMW	Drive motor winding/s
DMWF	Drive motor winding/s failure
DMWT	Drive motor winding test
DT	Down time
DT_{SS}	Down time of a sub-system (Sub-system DT)
DTC	Down time cost
DTC_{SS}	Down time cost of a Sub-system (Sub-system DTC)
F(t)	Failure rate or probability of failure
FC	Failure causes
FDT	Failure detection test

FF_{SS}	Failure frequency of a sub-system (Sub-system FF)
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Mode Effect and Criticality Analysis
FRC/s	Failure root cause/s
GA	Genetic Algorithm
GMA	Grain millers association
IFR	Increasing failure rate
MFMU	Maize flour milling unit
MME	Maize milling equipment
MMP/U	Maize milling plant/ unit
MOA	Ministry of Agriculture
MP	Maintenance policy
MPS	Maintenance policy selection
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NCPB	National Cereals and Produce Board
OEM	Original Equipment Manufacturer
OPEX	Operating expenditure
OTF	Operate to failure
PDCA	Plan, Do, Check, Analyse
PDTC	Production Down Time Cost
PFDT	Potential Failure Detection Techniques

PM	Preventive Maintenance
RC/s	Root cause/s
RCA	Root Cause Analysis
RCM	Reliability Centred Maintenance
RM	Roller mill
RMFRCs	Roller mill failure root cause/s
RTF	Run to failure
SCRA	Symptom, Cause, Remedy and Action
SST	Special Service Tools
TBM	Time Based Maintenance
TTR	Time To Repair
TTF	Time To Failure
TPD	Tonnes per day
TPM	Total Productive Maintenance
UBM	Use Based Maintenance
UGMFA	United Grain Millers and Farmers Association
VDT	Vibration Detection Test
WFDT	Winding Failure Detection Test

OPERATIONAL DEFINITION OF TERMS

Availability	Measure of the % of time milling plant sub-system is in an operable state.
Down time cost	milling plant unavailable production loss
Downtime	Time during which milling plant sub-system is not available for production
Failure	Any event in which any milling plant sub-system cannot accomplish its intended purpose or task.
Frequency	Milling plant sub-system failure count during the year under study, 2014.
Optimization	The action of making the best or most effective use of milling plant resources with optimal recommended standard utilization being above 87%.
Reliability	Measure of the probability that milling plant sub-system will perform its intended function for a specified interval under stated conditions.
Run to failure	Strategy where milling plant sub-system is allowed to operate until it breaks down.

CHAPTER ONE

INTRODUCTION

1.1. Research Background

For any organization to remain competitive in the face of the competing market players, it has to come up with effective strategies that will make the organization remain relevant. However much organization develops and implements these strategies, this does not guarantee the organization an opportunity to achieve its full potential in terms of its objectives. This could probably be attributed to by ineffective strategy implementation. Successful strategy formulation does not guarantee successful strategy implementation (Ginsberg, 1988). It is always more difficult to do strategy implementation than to do strategy formulation (David, 1997). Failure in the implementation process is usually the main weakness for most strategic management processes (Wooldridge and Floyd, 1990).

Maintenance strategy planning and implementation is complex and inherently stochastic, which calls for proper planning and scheduling. The primary objective of maintenance management is to increase equipment availability, reliability and overall effectiveness. Since the cost of maintenance is very high, modern industries require not only the theoretical basis to express the experience of operators, but also the identification of proper techniques to optimize the maintenance action.

Maintenance can be defined as combination of all technical and the associated administrative actions intended to retain an item or system in, or restore it to a state in which it can perform its required function/s (Dhillon, 2002). The rapid growth of industries has complicated the functioning system and has intensified the maintenance process emphasizing the need for effective maintenance planning. Maintenance is a key function used by industrial systems that deteriorate and wear with usage and age.

More specifically, maintenance is used to repair broken equipment, preserve equipment conditions and prevent their failure, which ultimately reduces production loss and downtime as well as the environmental and the associated safety hazards. Maintenance objectives can be summarised under four headings (Dhillon, 2002);

i. Ensuring system functions (availability, efficiency and product quality),

ii. Ensuring system life (asset management),

iii. Ensuring safety and

iv. Ensuring human well-being

For production equipment, ensuring the system functions well should be the prime maintenance objective. In the past, periodic maintenance was the main strategy in industrial plant maintenance. Periodic maintenance strategy is one of the strategies that have given contribution to the development of different strategies such as preventive maintenance, predictive maintenance, Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM) and proactive maintenance (Dudushki et al, 2012).

Maintenance has to provide the right (but not the maximum) availability, reliability, efficiency and capability (i.e. producing the right quality and within the expected limits) of production systems in accordance with the need of the production system. Often norms have to be set to define the failure and benefits of maintenance and one has to minimise maintenance costs in order to meet the norms or conditions on states. Thinking about maintenance should start at design stage or phase of a system. The type of equipment, the level of redundancy and the accessibility will then affect the maintainability of equipment.

1.2. Flour milling in Kenya

1.2.1. Introduction

Cereal milling firms are industries that grind grain to produce flour of different grades either using semi-automatic or fully automatic type mills. The purpose of grain milling is meant to improve the digestibility of the grain for human or animal consumption (FAO, 1996). For human consumption, the milling process aims to produce a palatable meal or flours of different grades. The objective of milling is to mill the grain to a point of coarseness or grade that is acceptable to the consumer. For animal consumption, the milling process aims to prevent the grain passing straight through the animal digestive system without being fully digested. Examples of these cereals that require milling include; wheat, rice, barley, maize/corn, oats, millets, sorghum and mixed grains among other dry grains. The most preferred grain product as staple food in Kenya is corn (USAID, 2010). Corn flour is produced mostly to make corn flour bread named “ugali”, bread, pancake, infant formula, biscuit and porridge.

The flour milling Industry is characterized by many key features which distinguish it from other sectors of the economy. With turnover and earnings driven primarily by market share and capacity utilization, the major determinant of success among its players is organic growth and cost leadership (Owuor, 2009). The level of competition that exists within the industry is extremely keen. The success of each individual company is hinged on its ability to gain market share and this has made the industry players to go through various lengths to increase capacity and to manage their costs. This has encouraged the players in the industry to adopt strategic management in their management systems (Rotich, 2011). However much that they have adopted strategic management to boost their revenues, they have not fully utilized their potential of meeting the needs of the market and this could probably be due to lack of synergy between strategy formulation and strategy implementation (Rotich, 2011).

1.2.2. History of corn flour milling

Corn Milling Industry can trace its beginning back to 1844 in the United States when Thomas Kingsford, working at Wm. Colgate & Company in Jersey City, convinced his employer to try a new alkali process for extracting starch from corn. This plant became the world's first dedicated corn starch plant. Kingsford built his own corn wet milling facility a few years later in Oswego, NewYork (CRA, 2000).

In Kenya, the history of mechanized cereal milling firms dates back to early 1920s with the introduction of the hammer mill (Smale and Jayne, 2003). The sector continued to grow with the introduction of new technology due to the need of hulling mechanism on grains such as wheat, a process that the hammer mill could not achieve. The number of commercial cereal milling firms has grown over the decades. Kenya now has 30 medium to large scale milling firms, milling capacity, 90-610 metric tonnes per 24hrs and 75 small scale millers with an estimated pool capacity of 83 metric tonnes per day [United States Agency for International Development (USAID), 2010], however the number has increased further.

Unga Group limited, a subsidiary of Victus Limited, a Kenya- based holding flour milling industry started way back in 1920's with Unga Group limited headquartered in Nairobi and being the oldest flour milling industry to be established in Kenya. It got its registration on 28th December 1908 with the aim of serving the milling needs of the fledgling wheat growing industry that had established itself in the Rift Valley region. By the 1970's, Unga Limited had become the largest grain miller in East Africa with operations in Nairobi, Eldoret, Nakuru, lringa, Dar es Salaam, Arusha and Jinja. Unga Group Limited has been a publicly listed company in Kenya since 1956. Today, Unga Limited has mills in Eldoret and Nairobi; Unga Farm Care with manufacturing facilities in Nakuru and Nairobi. These facilities are supported by well-equipped analytical laboratories (Mutai, 2013). Unga Holdings Limited established in 1956 runs chain of industries among them Unga Group Ltd, the largest and oldest grain miller in Kenya and the only miller currently listed in the Nairobi Stock

Exchange, NSE. The Unga Group has extensive holdings that include wheat and maize milling and animal feeds production. Unga group currently operate six mills, five in Kenya and one in Uganda namely, Unga Limited (human nutrition), Unga Farm Care (EA) Limited (animal nutrition and health), Unga Millers (Uganda) Limited (human and animal nutrition) and Bullpak Limited (paper packaging).

1.2.3. Corn milling industry in Kenya

The corn milling industry in Kenya is premised on the liberalized market where prices are determined by the market forces. Most of the corn milling plants in Kenya are owned by individual entrepreneurs and are located in urban centres. The industry is comprised of two levels of private players i.e. small-scale or medium players and large scale milling players with no government owned milling firm (Owuor, 2009). The large scale millers are the firms with production capacity of 90-610 metric tonnes per 24hrs and small scale and medium millers have an estimated pool capacity of below 90 metric tonnes per day, United States Agency for International Development [USAID, 2010]. Majority of the large milling firms are located in the cities and major urban centres. The current market in the milling industry allows for free entry and exit by various milling firms in the market.

Operations and maintenance challenges together with shortages of the raw materials coupled with fluctuation and volatility of raw materials prices especially at the local market and world market are adversely affecting the operations of the milling industry in Kenya and Eastern Africa at large.

Through a report published by The National Cereals and Produce Board of Kenya (NCPB survey report, 2010), the number of registered millers in Kenya was 103 by end of 2007. Installed capacity of these mills is not exactly known, however, the estimated milling capacity for corn was approximately 1.62- 1.77 million metric tonnes per annum with anticipation of 2.50 million metric tonnes by 2015. Most of these milling plants are operating below the original equipment manufacturer (OEM) capacity specifications due to a number of reasons and factors which have not yet been established by the milling plants operators. This inability of milling plants to meet the production targets set by the OEM is the main driving factor that informed this research endeavour.

The production capacity of the largest 19 mills whose capacity is more than 150Mt/24 hours in the country is estimated to be (85-90) % of total corn milling capacity in Kenya. The rest of the other mills are small and medium mills with capacity between 15- 89 Mt/24hours. The total milling capacity in Kenya at present is about 3,500 Mt/24 hours (Grain Millers Association, 2007). According to the “Staple Foods Value Chain Analysis Report” prepared by United States Agency for International Development (USAID), the primary miller group in the country is industrial corn millers with low or middle and high capacity production. The report further states that there are other many small mills whose number is not exactly known. Comparing Kenya with Tanzania, most of the mills in Tanzania are village mills in rural areas unlike in Kenya where most of the millers are located in major urban centres and cities (Lofchie, M. F., (1989).

Report by GMA (2007) indicated that by 2010, the millers with substantial milling capacities were located in Nairobi and Thika and were identified by NCPB to mill on contract for supply to NCPB depots or the strategic grain reserves, SGRs in the country. Some of the giant corn milling industries in Kenya listed by NCPB included; Unga Ltd, Uzuri Foods Ltd, Mombasa flour Millers (Nairobi), Pembe Flour Mills, Kabansora Millers, Nairobi Flour Mills, Chania Flour Mills, Capwell Industries, Mwanzo milling plant among others. The millers were paid Kshs 1,750 per 90kg bag for contract milling. Cost of milling 58,631 bags for the Government was estimated to be approximately 11.8 million shillings. Most of these millers are members of the East African grain council (GMA, 2007).

1.2.4. Milling Market projection

Maize is the key food crop in Kenya. By 1998, the estimated production was 3 million tons of maize of which about 40% are marketed either for flour milling or sold to the government central grain reserves. Maize production has increased tremendously in the past years and this has resulted to growth of the milling industry in Kenya. A report from Grain Millers Association (GMA), estimated that the total installed corn milling capacity stood at 1.62 million tons per annum as at 2007. This capacity was an estimate from all the 103 installed mills, however, there were 19 mills with high capacity milling and the capacity of them was 1.41 million tons/ annum. This was equal to (85-90) % of total milling capacity in Kenya. The milling capacity is expected to be above 3 million metric tonnes/ year by 2030, as in Figure 1.1 and Table 1.1.

Table 15.1: *Corn milling capacity projection in MT/Annum since 2000 (GMA, 2007)*

Year	Capacity (Million tons per annum)
2000	1.128
2005	1.547
2010	1.975
2015	2.239
2020	2.463
2025	2.874
2030	3.512

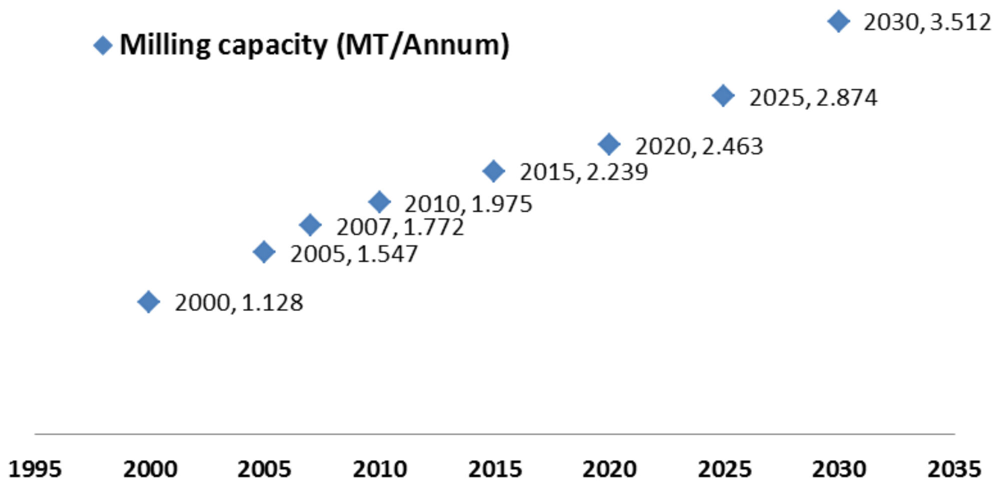

Figure 15.1 : *Corn milling projection in Kenya since 2000, (GMA/Min. of Industrialization).*

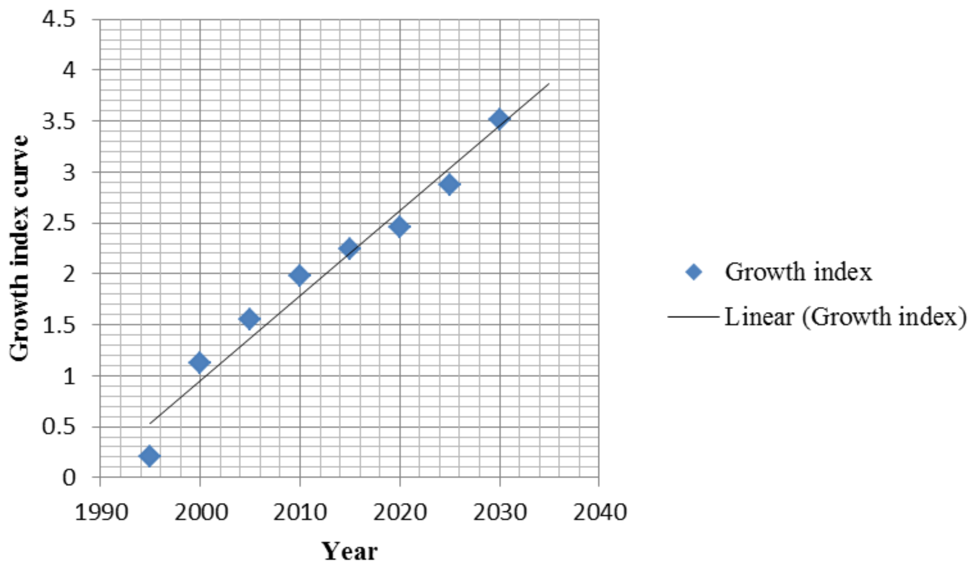

Figure 15.2: *Milling Industry growth index since 2000, (Grain Millers Association)*

1.3. Overview of Mwanzo Milling Industry

Mwanzo milling industry, which was rebranded in 2011 as mwanzo millers is located in the proposed industrial park in the outskirts of Machakos town, 86 Km from Nairobi and was commissioned in July 2010. This milling plant was identified among other millers by NCPB in 2011 to mill on contract for supply to national strategic grain reserves (SGR) in Lower Eastern region including Kitui, Makueni and Kibwezi NCPB depots and also supplement supply done by Eastern flour millers to Machakos strategic grain reserve, (Machakos NCPB depot). The strategic grain reserves are owned and managed by the national cereals and produce board of Kenya, NCPB. Due to this contract milling and its internal expansion, the plant installed a second production line so as to meet the demand from the NCPB and its distribution depots. It was out of this contract mwanzo millers got its fame and was later to become one of the largest cereals (corn) milling plant in Lower Eastern parts of the republic of Kenya, with its products spanning across four counties.

This milling industry has two production lines with capacity ratings of 20 TPD and 28 TPD (OEM plant specifications manual manual) but unfortunately, the production lines are unable to meet the target quite often due to frequent shutdowns and loading problems. The plant employs a total of 67 employees operating in different shifts. Out of this team, 11 are millers who double- up as the technical staff in charge of maintenance function of the entire plant. The plant serves the expansive lower Eastern region of Kenya among other areas. Just like other corn milling plants, mwanzo milling plant produces several products that include; corn flour of different grades, corn grits, corn germ and bran. The bran and the corn germs are by-products which are sold at low price for manufacture of animal feeds.

1.3.1. Mwanzo corn milling process

Mwanzo milling plant undertakes dry corn milling. This is a sequential flow process which includes the following main steps;

1. Corn storage (silos, or warehouse)- Raw corn acceptance loading hopper or elevator
2. Raw corn cleaning system- Sifter, de-stoner/stone rake, separator, magnet
3. Dampening- Dampener or conditioning
4. Degerming- Impact detacher / degermer, (Corn germ and bran removal from corn

   Milling system, roller mill/ brake rolls, plan sifter, purifier
5. Cyclones- Flour packing and stacking (mill unit open mouth bag packer).

Summary of milling main processes:

a) Loading

b) Cleaning

c) Conditioning

d) Degerming or Peeling

e) Crushing and or Milling

f) Packaging

Figure 15.3 : *Block diagram for corn milling process (OEM, 2012)*

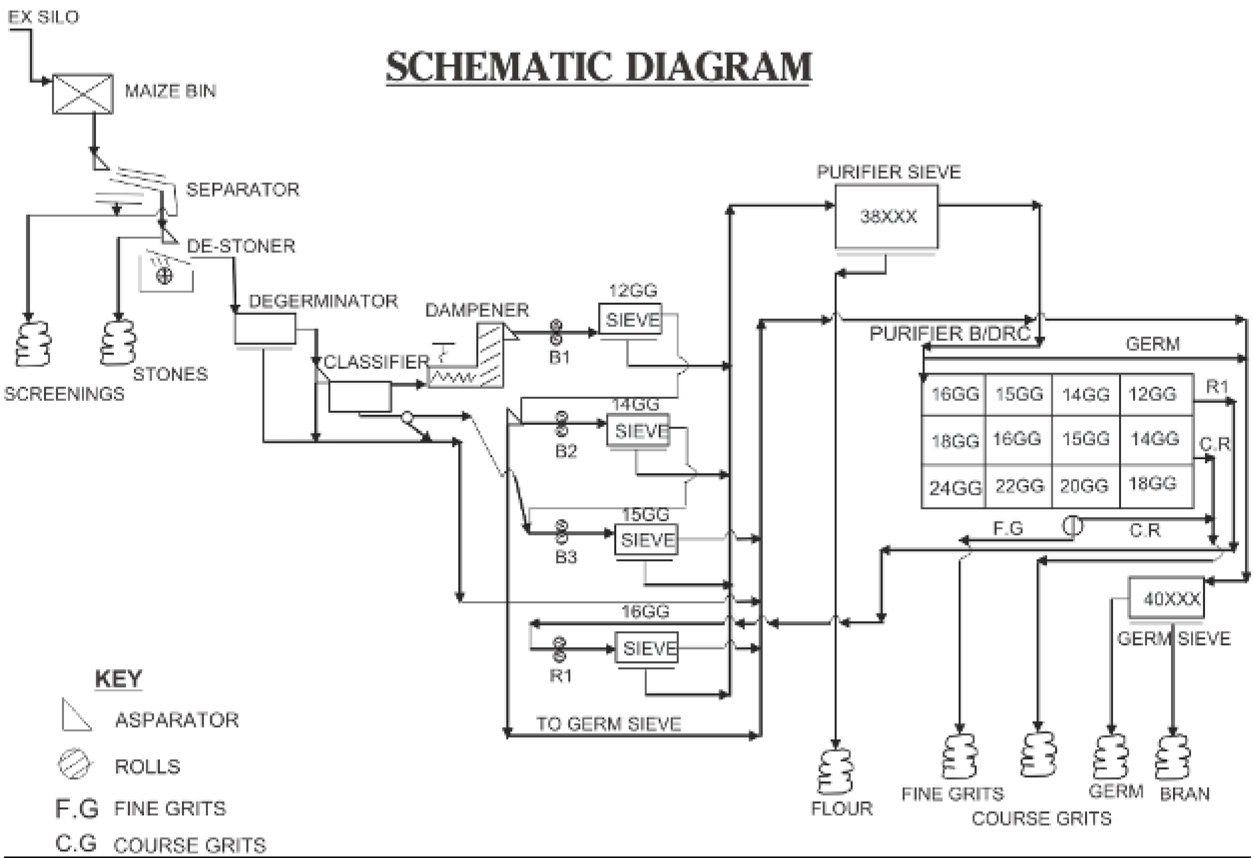

Figure 15.4 : *Schematic diagram for corn milling plant* (OEM, 2012)

1.3.2. Corn milling processing and value addition

Milling maize is the main form of value addition to the commodity. Globally, processing of maize occurs either as dry or wet milling. The main dry milling products include maize flour (for making "Ugali", bread and pancake mixes, infant foods, biscuits and porridge among others; fine meal flaking grits (for making ready to eat breakfast cereal cornflakes; coarse and medium grits (for cereal products and snack foods); and fine grits (for brewing) among other products.

The principal food products from the wet maize milling are corn starch-which can be variously modified to obtain the desired results in foods (baked products and candies); corn syrup which is mainly used in confections, bakery and dairy products; high fructose syrup, dextrose and corn oil. By-products are used for livestock feed and other applications. Although wet maize milling to make cooking oil occurs in Kenya, the most predominate form of processing is dry maize milling to make maize meal, flour and maize grits. Other products are oil and by-products for animal feed. In Kenya, the extraction rate among medium-large industrial millers average about 80% for grade 1 and 95% for grade 2, implying that it requires 2.5 Kgs of maize to produce 2 Kgs of maize meal flour, (Karuga S. and Afred, 2010). Reports from MOA indicate that extraction rate amongst some millers is as low as 70% which is mainly attributed to the efficiency of existing machinery (Mulinge et al; March, 2009).

There are three main groups of actors in the maize processing function. One group comprises the medium to large industrial maize millers of whom 109 (maize and/or wheat millers) are members of the Cereal Millers Association (CMA) - a business membership organization. The second group comprises a large but unknown number of small maize millers commonly who are affiliated to the United Grain Millers and Farmers Association (UGMFA). The third group comprises also of a large number, but unknown micro-millers commonly known as Posho millers. In addition, NCPB, which is however not a member of either CMA or UGMFA, sometimes contracts millers to carry out maize processing on their behalf.

According to NCPB records, there are 103 registered maize millers in the country. The exact installed and utilized milling capacities of these millers are not well known because most millers are always reluctant to disclose related information either for reasons associated with income tax related matters or allocations of maize rations as happened recently in Kenyan milling market (Karuga et al 2010). In this regard, NCPB estimates the total national maize milling capacity at 1.77 million MT per year. At the same time CMA data indicates that the combined maize milling capacity of both the medium-large maize millers and micro-small maize millers (Posho millers) is in the order of 1.62 million MT per year. Of this total, CMA estimates that 19 of the medium-large millers have combined maize milling capacity of about 1.41 million MT per year or 85-90% of total national maize milling capacity. The association also estimates that Posho millers have a combined milling capacity of about 0.21 million MT per annum or about 10-15% of total national installed maize milling capacity. The table below shows milling capacity by category of millers;

Table 15.2: *Milling Capacity by Category of Millers*

Milling Capacity by Category of Millers		
Category of Millers	Estimate of Milling Capacity by CMA (Million MT/Year)	Estimate of Milling Capacity by NCPB (Million MT/Year)
Share of 19 CMA millers	1.41	-
Share of all Posho millers	0.21	-
Total National Milling Capacity	1.62	1.77

(Karuga S. and Alfred, 2010)

1.3.3. Corn milling industry operation challenges

The corn milling industry in Kenya is typically characterized by stiff competition, high volumes and price volatility and sensitive demand (Adewole, 2008). Other critical issues facing the milling industry are counterparty risks, price volatility and profitability margin (Rabobank, 2012).

These challenges are occasioned by either operation or maintenance strategy formulation and implementations or both. Increase in corn and wheat flour demand in Kenya due to increase in population has caused increase in the number of Milling industries, however, the milling plants are faced with myriads of problems resulting to frequent down times, reduced TBF among other problems and thus resulting to increased cost of operations and maintenance.

Mwanzo millers, the case study for this research is not different from other milling plants in Kenya. It is facing production capacity challenges occasioned by unplanned frequent downtimes thus affecting the production process. This plant is located in the proposed industrial area of Masii town in the outskirts of Machakos town, 88.3 Km from Nairobi and was commissioned in July 2010. This Milling plant was identified among other millers by NCPB in 2011 to mill on contract for supply to NCPB depots in Lower Eastern region including Kitui NCPB depot, Makueni NCPB depot, Kibwezi NCPB depot and also supplement supply done by Eastern flour millers to Machakos NCPB depot. Due to this, the plant installed a second production line so as to meet the demand from the NCPB and supply to its distribution points or outlets. Due to demand occasioned by the contract milling and internal customer demands, this milling plant has been going through tough economic times due to frequent down times leading to reduced equipment optimization. Lack of proper maintenance planning and scheduling, inability to achieve production level targets, high operation and maintenance costs and inability to meet the demands of its customers are other key problems facing this plant.

The existing maintenance methods for Mwanzo millers and other corn milling industries in Kenya is most often FBM, a corrective maintenance approach. The choice of the best maintenance policy and its optimization to enhance equipment availability has not yet been explored for implementation. Failure to develop and implement a maintenance strategy that mitigates milling industry equipment recurrent failures has resulted to frequent unplanned and prolonged plant shut downs that impact negatively on the industry performance. For instance, Reliability Centred Maintenance (RCM) which is a methodology for determining the most effective approach for maintenance has not been tried in the milling industry for implementation and this is what informed this research.

Figure 1.5 shows maintenance policy mix employed in corn milling industry in Kenya to address corn milling plants sub-systems recurrent failure occurrences.

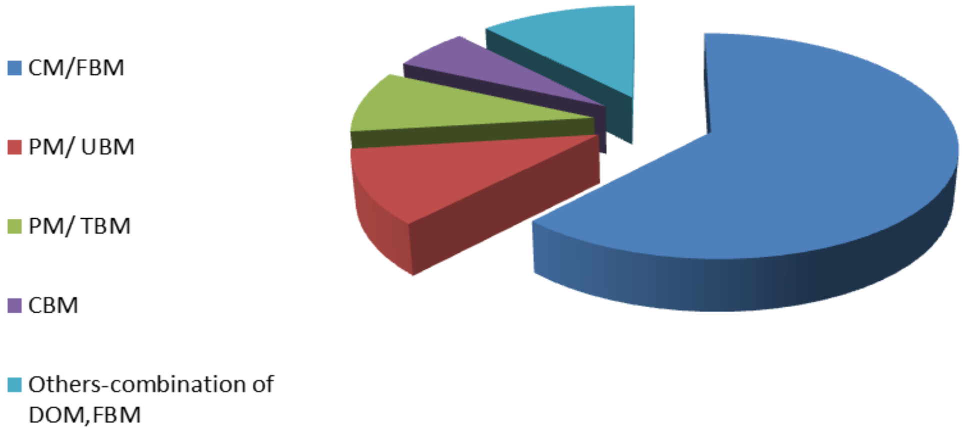

Figure 15.5: *Maintenance policies employed in corn milling industry in Kenya*

1.4. Problem environment

Milling plants accomplish milling process through use of several milling plant sub-systems that work in a sequence to accomplish the milling process. The turbulent and competitive environment in the milling industry however has prompted the players in the milling industry to come up with effective strategies in order to remain competitive and to survive in the dynamic market, (Rotich, 2011). One of the ways of matching this competition in corn milling industry is through ensuring maximum equipment uptime or availability. No matter how much this has been done, milling industries continue to suffer from unplanned milling plant sub-system frequent failures and down times. Some of the milling plant critical sub-systems that form the milling production line are as below;

1.4.1. Critical corn milling plant equipment

Corn bin

The corn grains from silo/ ware house are fed to the corn bin by means of a screw conveyor which uses the mechanism of a rotating helical screw blade worm or elevator driven by a drive motor (37KW) coiled around a shaft, driven at one end and supported on the other. The rate of the corn grains intake is directly proportional to the speed of rotation of the shaft (worm). From the corn bin, the grains are fed to the separator by means of a screw conveyor.

Separator

The separator has a series of two metallic sieves laid successively with some meshed wires in between them and it is inclined at an angle (acute angle). Corn grains from the bin slides over the top most sieve and any foreign matter smaller than the size of a corn grain is allowed to pass through, the bigger materials, like pieces of corn cob, slide down the sieve as it has two vibrators attached to the separator making them slide down and be collected as cereals screenings. The corn grains slide down and are conveyed to the de-stoner by means of a screw conveyor.

There is an aspirator connected to the air compressor to remove dust from the corn grain stream as they are conveyed to the de-stoner.

De-stoner/ Vibrator

Used for efficient removal of stone, glass and other high density foreign material from the grain stream. It has also an aspirator connected to remove dust from the grain stream. It is complete with air circulation fan and inclined surface, bottom in C 72 steel screen, stone collection box.The de-stoner also has an inclined sieve, where fluidized bed results from vibrations. Lighter material flow downward along the sieve and is fed to the de-germinator via a screw conveyor. Heavier material gets upwards due to the vibrations of the sieve and passes through the hole at the top and collected at the bottom of the de-stoner. There is also a de-stoner sifter, for the separation of lighter impurities, complete with inspection window and adjustable air lock.

Degermer or dry maize degerminator

The core function of degermer is to separate germ from maize. It is a complete sub-system with the following parts; degerminator system with interchangeable separator grate; blower system to facilitate germ separation from maize; germ discharge hopper; maize discharge hopper; sifter to separate germ from degerminated maize; germ residual; electrical motor 37kW for degerminator transmission. Corn degermer accomplishes the degerming process which is the most vital process in corn milling by separating the corn germ and bran from corn seeds via impacting and gets the corn seed with high purity. It takes advantage of the hitting and cutting between the rotor and toothed plates and blades, centrifugal impact and collision and friction between corn seeds to destroy the structure of corn endosperm and germ. The peeled off material, the ‘germ’ passes through the meshed metal plate called the screen and is driven out of the system for collection as by- product. Most of the major milling process failures leading to plant shut downs are experienced in this sub-system.

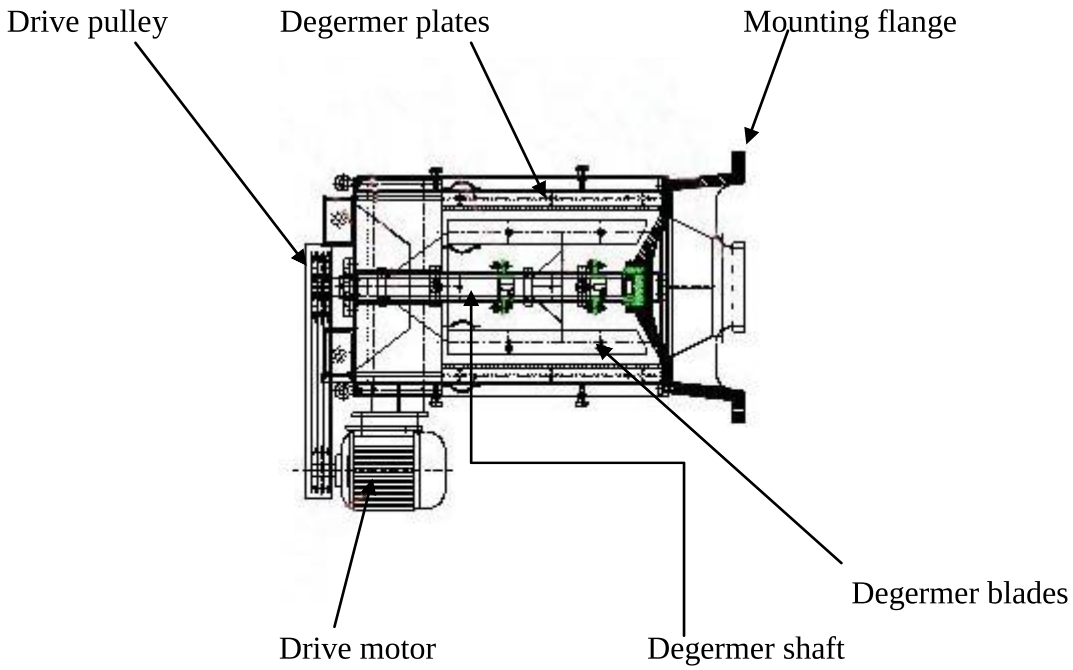

Figure 15.6 : *Degermer unit (OEM, 2010)*

Classifier

The broken down pieces of corn grain from the de-germinator gets into the classifier, where it passes through a cylindrical metallic sieve, allowing only grains to pass through to the dampener and sieves out any powdery substance (which might have resulted from the breaking process in the de-germinator) to B3 roll.

Dampener

A vertical cylindrical structure, used for moistening of grain skins layers. Corn grains move into the chamber through the feeding pipe and simultaneously water flows into the spray pipe via pipelines. Then the spray pipe will spray water to the corn grains inside the chamber. These corn grains are then conveyed to B1 roller mill by means of suction.

Roller Mills/ Brake rolls

These are four passage mills that use cylindrical rollers composed of 8 cylinders ∅ 250 x 500 mm (AGS4/1750-GR-1SE) working in pairs with automatic approach and disengagement, either in opposing pairs or against flat plates, to crush or grind various materials, such as corn grains, ore, gravel, plastic, and others. From dampener and degermer, the grains go to B1 where they pass through a purifier sieve before passing through B1 rollers where they are ground according to the adjustments of the rollers.

The sieved out flour passes through another purifier sieve, where the fine flour gets out and conveyed to the flour outlet by means of suction. The larger particles pass to the shaker where they go through a series of sieves and graded out as fine grits, course grits or germ. From B1, the ground grains go to B2, where they pass through a sieve and then taken to B2 rollers where they are ground further according to the adjustments of the rollers. The sieved material further passes through a purifier sieve where it is graded as fine grits, course grits or germ. There is an aspirator connected to B2 and the dust is taken to the germ sieve. From B2, the ground grains pass to B3 where it is sieved and passed through B3 roller mills. The sieved out flour passes through another purifier sieve where the fine flour is transported by means of suction to the flour outlet and the larger particles graded by the shaker sieves into either fine grits, course grits or germ. The germ from B3 is transported directly to the germ sieve.

Corn grains fed between rotating rollers

Opposing pair of roller mills.

Figure 15.7: Set up of a *Roller mill (OEM, 2012)*

With only 2 rollers fitted, the larger ingredients can become isolated on the rollers, rotating with them and remaining uncrushed. This prevents other ingredients from being able to pass through the rollers and therefore reducing speed and capacity. The third roller, set away a little more than the others and fully adjustable, traps the larger ingredients and pre-crushes them, thereby helping to maintain a fast processing time and ensuring the machine works at its optimum efficiency.

1.4.2. Cleaning and conditioning

Cleaning and conditioning of the corn is an important step in the corn milling process. Cleaning refers to the removal of foreign material and all that is not corn from the to-be milled grain that lowers the quality of the product such as husk, straw, dust, sand and everything else too big or too small and lighter than a corn kernel. It also refers to the removal of poisonous seeds, and material harmful to the milling equipment such as metals and stones. Conditioning refers to the addition of moisture to the corn to allow the bran to be peeled off in flakes during degerming by degermer plate and blades and also ease milling by roller mills, allowing easy separation in a sifter.

For good quality corn flour, de-germination is a very vital milling process which results to corn degerming then milling of the degermed corn by means of a roller mill. (The de-germinator or polisher separates the bran, germ meal and endosperm before degermed corn proceeds for milling).

1.5. Problem statement

Mwanzo milling plant has continuously experienced frequent failures despite adoption of FBM, a corrective maintenance policy which the firm felt suited best its field operating conditions. This milling plant has two production lines rated at 20 TPD and 28 TPD but due to frequent critical milling plant equipment unplanned down times, the plant is more often unable to meet OEMs operating production capacity and standard recommended utilization of 98%.

Field failure statistics for the 28 metric tonnes per day milling plant production line experienced 81 critical sub-system random failures leading to total plant shutdown. This translated to 18,877 minutes per year in 2014 of production downtime with production down time loss of US$ 168,892.52, a huge cost that needed to be controlled by either minimising or entirely eliminating the unplanned frequent plant failures.

The milling plant has no systematic method of identifying the critical failures and prioritizing them so as to institute optimal maintenance strategy that would eliminate or minimize frequent failure occurrences and prolonged shut downs, which adversely affected the production process.

The failure effect caused by the unplanned down time experienced was high cost of operations due to the down times resulting from costly corrective maintenance actions with consequence of non-production over the period of shut- down, low level of production due to production equipment not running at full capacity or poor quality throughput due to faulty equipment within the production line. It is due to these unplanned frequent failures resulting to milling plant equipment utilization of between 61 to 73% that there was a need to develop a maintenance policy that would mitigate these recurrent failures. Moreover, there was availability of maintenance and failure data that was very vital in carrying out this research.

1.6. Objectives

1.6.1. Main objective of the study

This research aims at developing an effective maintenance strategy that mitigates recurrent failures in corn milling industry for production process equipment optimization.

1.6.2. Specific objectives of the study

The specific objectives of this research are to:

i. Identify and prioritise failure modes on critical corn milling plant equipment (Using Reliability analysis tool, FMEA).

ii. Establish potential failure root causes of the prioritized critical milling plant equipment failure modes (Through RCA).

iii. Develop an optimal maintenance strategy that mitigates critical milling plant equipment recurrent failure modes with emphasis to increase equipment uptime or availability and reduce or eliminate downtime and cost.

1.7. Research questions

The study sought to answer the following research questions:

i. Which are the most critical failure modes of corn milling plant equipment?

ii. What are the failure root cause/s of the prioritised critical failure modes?

iii. Which is the most optimal maintenance strategy that can mitigate recurrent failures in corn milling industry?

1.8. Significance of the study

Mwanzo milling industry is operating below capacity due to lack of optimal maintenance policy resulting to frequent downtimes caused by production line equipment failures and under-utilization due to delayed, wrong work procedures or poor maintenance schedules. The plant has two production lines designed to produce 20 TPD and 28TPD but due to poor resources scheduling and maintenance optimization problems, the plant is more often unable to meet OEMs operating production capacity.

The maintenance method for this milling plant is FBM, a corrective maintenance approach, and sometimes condition based maintenance, a predictive approach which does not solve the equipment recurrent failure problems. Field failure statistics for the 28 metric tonnes per day milling plant production line indicated that, 81 critical sub-system random failures were witnessed leading to total plant shut down. This translated to 18,877 minutes of production downtime with production down time cost of US$ 168,892.52, a huge cost that needs to be controlled my either minimising or entirely eliminating the frequent plant failures.

Optimization of the milling plant elements of production (5Ms) too has never been implemented to maximize production with least possible cost and meet the expected output.With application of RCM which focuses on actions that will ensure equipment and systems achieve their inherent reliability and safety performance capability, proper maintenance standards for milling plants needs to be established to restore equipment functional capability at almost all times. It is critical to obtain information for design modifications and improvements when inherent reliability proves inadequate for functional requirements.

To identify milling plant critical equipment failure modes, failure modes and effects analysis was performed for purposes of failure modes effect identification. Statistical analysis tool, Pareto chart was then applied to quantitatively perform failure modes prioritization by isolating the most critical failure modes based on criticality of failure. Failure criticality was dictated by failure frequencies, DT and the corresponding DTC. The prioritised failure modes were then further subjected to RCA for failure root cause identification. With this information, all the feasible maintenance policies were developed and a decision tree used in selection of the most optimal MP. The inability of the case study milling plant to achieve production targets due to frequent unplanned failures is what formed the basis for this research.

Field failure data for the year 2014, figure 1.8 shows electrical and mechanical failures and the corresponding downtimes in minutes. Milling plant shutdown is majorly caused by either electrical failure or mechanical failure or both leading to total plant shutdown. The consequence of these failures to the production process is expressly inherent and results to the inability of the milling plant to achieve equipment optimization.

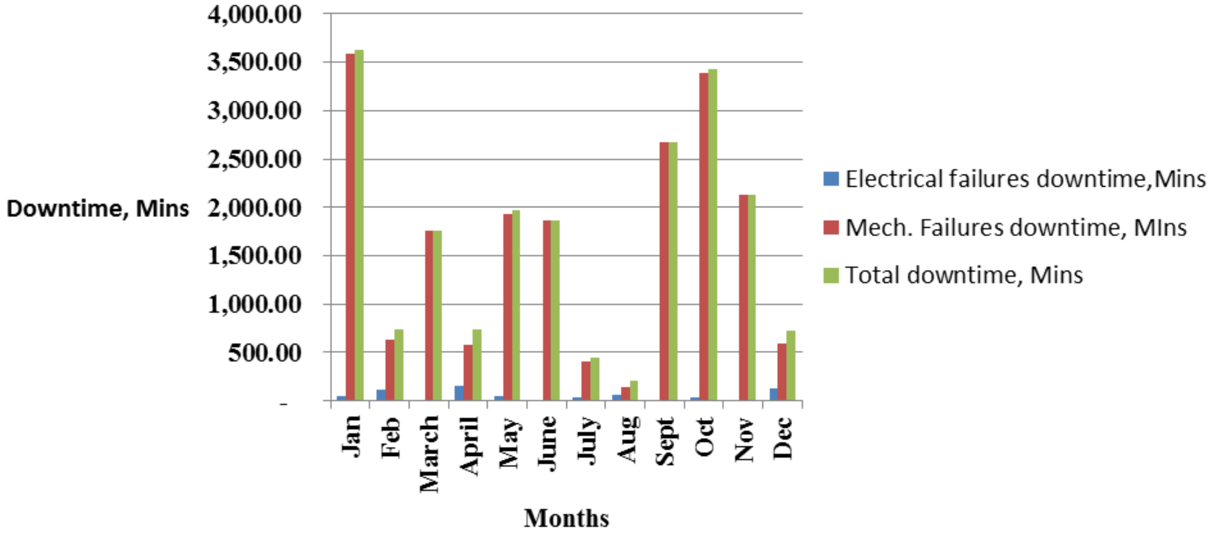

Figure 15.8: *Milling plant PDT, 2014*

The primary objective of RCM is to preserve systems function and hence reduced cost of operations. This therefore, made this research very core as it was aimed at developing an optimal maintenance policy that would mitigate milling plant recurrent failures and guarantee production equipment availability.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

There is a lot of literature on maintenance methods and philosophies (actions, policies and strategies). In addition, there is a large number of Computerized Maintenance Management Systems (CMMS) software packages devoted to help managing and organizing the maintenance activities. Despite this abundance, the optimization of decision variables in maintenance planning like preventive maintenance frequency or spare parts inventory policy, is usually not included as a capability of the software packages (Sum and Gong, 2006; Saranga, 2004). Again, the use of CMMS in milling industries has not been embraced to enhance maintenance effectiveness.

The role of maintenance as an effective tool to increase profit margin, improve plant reliability and reduce safety and environmental hazards has become increasingly important. The perception about maintenance has shifted from being a "necessary evil" to being an effective tool to improve processing efficiency and ultimately larger profits (Neely et al., 2005). The trend is part of the new approach to processing named Smart Plants, which advances the concept that such plants anticipate problems instead of reacting to them, (Humphrey et al. Smart Manufacturing Plants, 2010).

The most common optimization criterion is minimum cost and the constraints are requirements on system reliability measures: availability, average uptime or downtime. More complex maintenance models that consider simultaneously many decision variables like preventive maintenance (PM) time interval, labour work force size, resources allocation are usually solved by Genetic algorithm (Saranga, 2004; Tan and Kramer, 1997) utilized both Monte Carlo simulation and GA.

In Kenya, studies conducted in the milling industry are mostly on the challenges facing the sector (Tegemeo Institute, 2009; and Gitau *et al.*, 2010). Future research should seek to find out how firms in the milling sector can use lessons from previous experiences to improve on their operations (Tegemeo Institute, 2009). Moreover, under the Kenya Vision 2030 economic pillar, increasing value in agriculture products through processing (Ministry of State for Planning, National Development and Vision 2030) is one of the ways that will help drive the economic stability of Kenya. More research done on cereal milling industry in Kenya touched on strategy implementation challenges in Unga Group Limited (Rotich, 2011) and CI strategies in the milling industry (Musyoka, 2011). No or little research studies have been done on milling plant failure identification, analysis and prioritization or maintenance policy development that aims at mitigating recurrent failures in the milling industry and this is what again formed the basis of this research.

Plant reliability analysis, example for milling plants, is highly affected by lack of accurate data or no data leading to sub-optimal parameter estimates and inaccurate decisions about replacement intervals, repair times and maintenance activities that need to be performed on any industrial system or equipment before failure occurs or as most often done after failure. The economic loss caused by equipment failures leads to reduced production rate or downtime and it is the economic indicator for maintenance performance, i.e., the better the maintenance plan is, the smaller the economic loss. Thus by minimizing the maintenance cost plus the economic loss, one simultaneously optimizes the cost and the performance of maintenance.

Managers are normally very conservative in PM decision making and implementation because of the expensive cost of PM and thus the system or equipment may lack enough maintenance and cause serious potential risks. In addition, since the system may have been affected by actual operating environment and maintenance activities, there is a significant difference between the field reliability and design reliability. Manufacturers usually recommend PM system according to the design reliability, which easily leads to inaccurate or non-optimal PM. In other words, if managers blindly use the PM system recommended by the manufacturer, excessive or insufficient maintenance could be caused. Therefore, it is very meaningful to optimize PM based on the field failure data, (Murthy, 2002). The cost term in maintenance includes four types of costs namely;

The PM cost and CM cost- these are the costs associated with preventive maintenance and corrective maintenance activities, respectively. The economic loss term includes two types of losses; Economic loss associated with failed equipment that have not been repaired (for example, a slack belt for drive motor may continue operating but at reduced drive motor speed due to slippage and Economic loss due to unavailability of equipment before repair time. The economic loss is calculated as a loss rate (per day) multiplied by the duration of the period within which the loss is realized.

To determine economic loss rates, an analysis is carried out on each piece of equipment to determine the economic effects of equipment failure, which include reduced production rate or even shutdowns, the deterioration of product quality etc.

2.2 Maintenance, Maintenance policies and Practices

2.2.1 Maintenance

Maintenance is defined as a combination of all technical and associated administrative activities required to keep equipment, installations and other physical assets in the desired operating condition or restore them to this condition (BSI 1984; Pintelon et al. 1997; Pintelon and VanPuyvelde, 2006 cited in Muchiri et al. 2010). Good maintenance assumes that maintenance objectives and strategies are not determined in isolation, but are in some way derived from factors such as company policy, manufacturing policy and other potentially conflicting demands and constraints in the company (Swanson, 1997, 2001; Jonsson and Lesshamar, 1999; Pinjala et al. 2006). Assuming that the maintenance objectives pursued at a given plant influence the kind of performance indicators used.

Muchiri et al. (2010) has summarized the maintenance objectives under five headings: ensuring the plant functionality (availability, reliability and product quality etc.), ensuring the plant achieves its design life, ensuring plant and environmental safety, ensuring cost effectiveness in maintenance and effective use of resources (energy and raw materials). Maintenance again is defined as all actions appropriate for retaining an item/part/equipment in, or restoring it to a given condition (Dhillon, 2002). Maintenance is used to repair broken equipment, preserve equipment conditions and prevent their failure, which ultimately reduces production loss and downtime as well as the environmental and the associated safety hazards. It is estimated that a typical refinery experiences about 10 days downtime per year due to equipment failures, with an estimated economic loss of $20,000-$30,000 per hour (Tan and Kramer, 1997). Maintenance of industrial manufacturing equipment may be defined as: "all activities necessary to restore equipment to, or keep it in, a specified operating condition" (Pintelon et.al 1991). From, Balasaheb, 2012, he defined maintenance as the combination of technical and associated administrative actions intended to retain an item or system in, or restore it to, a state in which it can perform its required function.

The key objective of maintenance is to ensure optimal life cycle costs through prudent asset management practices (Balasaheb, 2012). Asset management is a concept designed to examine the assets over its entire life cycle. It is hoped that through a better awareness of the assets value, reviewing the assets in a more satisfactorily way can be carried out.

2.2.2 Maintenance concept

Maintenance concept can be defined as a set of maintenance policies and actions of various types and the general decision structure in which these are planned and supported.

2.2.3 Maintenance Policies

Plant maintenance policies can be defined as set of rules describing triggering mechanism for different maintenance actions. For this research, the relevant policies considered will be divided into three main types:

Corrective Maintenance (CM): Maintenance is performed whenever an equipment failure is noticed to correct the failure and restore equipment function.

Preventive Maintenance (PM): Pre-planned maintenance that is performed at a scheduled time to prevent/mitigate equipment failure, detects any small hidden failure, and retains equipment function.

Predictive maintenance: In this type of maintenance, maintenance personnel monitor (online or periodically) the set of equipment during its operating period- not to be used since the plant is unable to do online monitoring.

In this section the various concepts relevant to this research are discussed here below;

2.2.4 Total productive maintenance

The goal of TPM is to maximize equipment effectiveness through improved availability, through more assured quality and through labour saving as a result of plant modification. In order to achieve that goal, investments in human resources are preferred over capital investments. TPM tries to eliminate the different losses that interfere with the effective operation of the system down-time losses (failures, set-up and adjustment), speed losses (idling and minor stoppages, reduced speed) and defect losses (defects in process, reduction in yield). TPM emphasizes improving maintenance efficiency and effectiveness, that is, you must understand your defects or failure modes and work proactively to avoid them and/or detect them early enough to minimize their consequences. In order to identify faults in terms of where they are located in a system and how serious their consequences are, a risk analysis should be a prerequisite to any major operation (Chee, 2013).

2.2.5 Reliability centred maintenance (RCM)

Nowlan and Heap (1978) defined Reliability Centred Maintenance (RCM) as a methodology for determining the most effective approach for maintenance. Effectiveness is determined by considering both reliability (probability of failure) and overall cost. RCM focuses on those actions that will ensure that; Equipment and systems achieve their inherent reliability and safety performance capability; Proper standards are established for restoring equipment to functional capability when deterioration occurs; Information is obtained for design improvements when inherent reliability proves inadequate for functional requirements and accomplishes all this at a minimum life cycle cost. With this focus, the primary objective of RCM is to preserve system function. Reliability of a piece of equipment enables us to decide on the quality and frequency of maintenance that will be required. Reliability centred maintenance (RCM) is a recent technique. It has proved to be an effective technique in development of preventive maintenance programmes in the areas of aviation, defence and nuclear power plants. RCM has been developed with the emphasis on safety and no “tool” exists for deciding optimal maintenance intervals. To date, the quantitative approach to RCM has taken a back seat to the qualitative approach. This is because of the unavailability of plant-specific historical data and appropriate statistical methods to interpret the data.

2.3 Failure reliability analysis

2.3.1 Failure Modes and Effects Analysis (FMEA/ FMECA)

This is also known as potential failure modes and effects analysis. FMEA is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service or FMEA is a systematic method for proactively evaluating facilities or a process to identify where and how they might fail; and to assess the relative impact of different types of failures.

Failure Modes and Effects Analysis (FMEA) or Failure Mode, Effects and Criticality Analysis is a systematic method for analyzing and ranking the risks associated with various products (or processes), failure modes (both existing and potential), prioritizing them for remedial action, acting on the highest ranked items, re-evaluating those items and returning to the prioritization step in a continuous loop until marginal returns set in. It includes review of the following; Failure modes- What could go wrong? Failure causes- Why would the failure happen? Failure effects- What would be the consequences of each failure?

FMEA starts with identifying defects. The widely accepted FMEA procedure starts with identifying all potential failure modes of the system. Following identification, all possible causes, effects and hazards of each failure should be related to the failure modes. After identifying the causes and effects of failure modes, a target for improvement should be chosen, (Chee, 2013).

2.3.2 Equipment failure and operating conditions

Equipment failure refers to any event in which any equipment cannot accomplish its intended purpose or task. It may also mean that the equipment stopped working, is not performing as desired, or is not meeting target expectations. Machines are never built to run forever, but they can last a lot longer than one may expect. Machine maintenance is an essential component to any industrial operation, but all too often, these processes are neglected if not ignored entirely. The P-F curve is an essential component to any reliability centred maintenance program, and being able to understand it can help extend the lifespan of your machines by more than you might think.

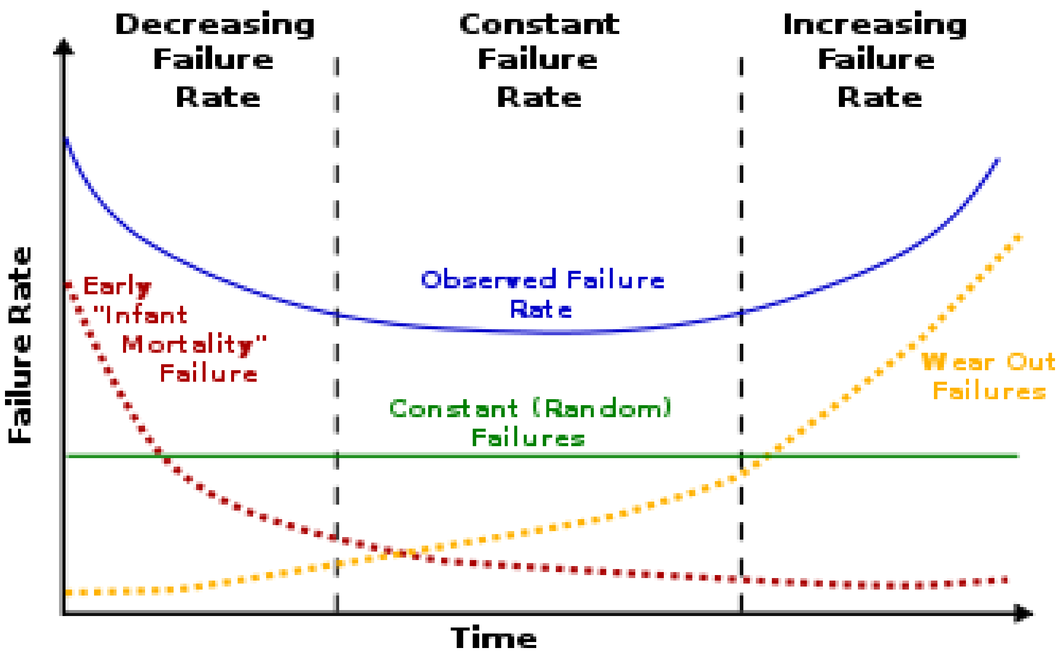

Figure 3.1 : *Bathtub curve showing failure rate versus Time*

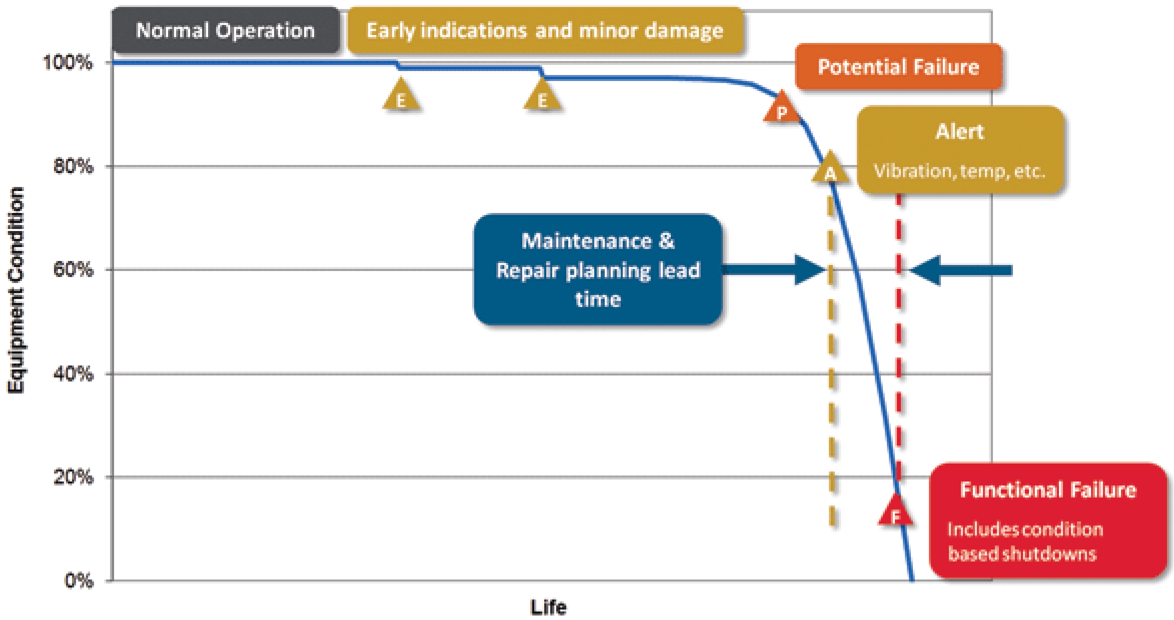

Figure 3.2 : *PF curve indicating different stages of failure*

2.3.3 Failure modes

Failure modes mean the ways, or modes, in which an equipment or machine fails. Failures are any errors or defects, especially ones that affect production or the customer, and can be potential or actual.

2.3.4 Failure effect/s analysis

Failure effect analysis refers to studying the consequences of those failures. Failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones.

2.3.5 Root cause analysis (RCA) or Failure root cause analysis (FRCA)

This is a methodology of problem solving used for identifying or pinpointing the root causes of system faults or problems, and the information gathered is used to avoid recurrence of failures (Sharma and Sharma, 2010). All types of problems require an effective root cause analysis and identification to reduce resistance and the risk associated with changing a process (Monroe, 2010).

A factor is considered a root cause if removal thereof from the problem- fault- sequence prevents the final undesirable event from recurring, whereas a causal factor is one that affects an events outcome, but is not a root cause. Though removing a causal factor can benefit an outcome, it does not prevent its recurrence within certainty.

The goal of RCA is to understand not only “what” and “how” a failure occurs but also “why” it happened. RCA attempts to address all the underlying causes of the failure and also to learn as much as possible from the occurred failure (Heuvel, 2008). Although several measures (methods) may effectively address the root causes of a problem, RCA is an iterative process and a tool for continuous improvement. RCA is applied to methodically identify and correct the root causes of events, rather than to simply address the symptomatic result. Finding the root cause of a problem provides the necessary understanding needed to solve the problem (Pojasek, 2000). Liker, (2004) highlighted that emphasis is placed in solving the true problem through identifying the root causes.

2.3.6 Ishikawa diagram

The Ishikawa diagram also known as the cause and effect diagram or fish bone diagram is a visualization tool for categorising the potential causes of a problem in order to identify its root causes. It is a systematic approach which tries to identify all the possible causes of a chosen failure mode and the associated failure effects.

Sharma and Sharma, (2010) explained Fish bone diagram as a comprehensive classification of failure causes related to different factors of production i.e. the man, machine, material and methods, which he referred to them as the 4Ms. Ishikawa diagram is used to determine the potential causes of a failure found in a plant and has the advantage that it offers the possibility of identifying and analysing all the factors that are related to the identified failure mode or defect.

Although fish bone diagram is a qualitative approach, it has the advantage that it is a visual tool which is easy to understand and analyse. It provides a comprehensive failure mode cause possibilities and guides the service department through a brain storming process to establish the most probable failure cause to the identified failure mode. Ishikawa diagram is a global tool used in various industrial set-ups including manufacturing and service industry (Doshi et al, 2012).

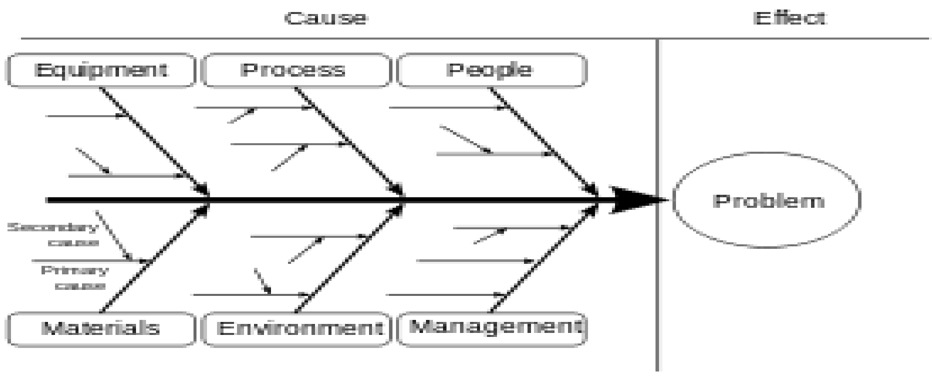

Figure 3.3 : *Example of cause and effect diagram*

2.4 Summary of research gaps

From the literature, it is evident that in order to improve and attain optimum performance of a manufacturing system, a good maintenance management should be in place in the organization. Maintenance managers need a good track of performance on maintenance process and maintenance results to ensure the plant achieves the desired performance (Muchiri et al. 2010).

From maintenance engineering, it is known that machines are never built to run forever, however, they can last a lot longer than one may expect. Likewise, cereals milling plant sub-systems are not designed to run forever, they will always fail at some point during operation and thus maintenance is an essential function to any industrial operation, but all too often, these processes are neglected if not ignored entirely. While it may seem like a hassle or expensive endeavour, having Reliability

Centered Maintenance (RCM) program in place, it can do wonders for the lifespan of milling plant sub-systems and avoid massive costs incurred during periods of failure or shut down.

Failure of milling plants technical personnel to develop and keep updated maintenance records makes research on milling plant maintenance and other emerging challenges difficult. Equipment availability and failure data is critical to establishing a good basis for milling plant performance. Most respondents met during period of this research and milling plant technical team and the experience witnessed in this case study is that the milling plant had data record in place, however, the data was not well organised in maintenance records that could be retrieved with ease and thus the researcher took time organising and piecing the data together.

Milling plant performance is an unexploited area of research that needs further research. This research established that most of the milling plants are operating below OEM's output ratings and thus this opens up a research gap that needs to be filled. Milling plants top managers see maintenance as a duty that should be left solely to the millers to give advice and where necessary deal with. There are no key performance indicators set by the organization that can act as the standard milling plant equipment performance control measure so that any event of deviation from the norm attracts the necessary maintenance interventions.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the approach and technique used in the research methodology. The research identified mwanzo milling plant as the case study due to frequent unplanned failures recorded in 2014 and availability of maintenance and failure data that could be organised and used in the research analysis.

The methodology included research design, data collection and data analysis through the application of tools of data collection, interpretation and analysis.

3.2 Research Design

The research employed a case study design. A case study research method is an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used (Yin, 1984).

This research study focused on in-depth investigation of milling plant critical failure modes and failure causes by application of FMEA or FMECA and RCA or FRCA respectively. Failure criticality in terms failure frequency, down time and down time cost was accomplished through quantitative application of histogram and Pareto charts.

This research methodology was chosen to be the most appropriate for this research due to its capability to establish and prioritise milling plant failure modes, failure criticality and the failure root causes with an aim of developing a Reliability Centred Maintenance, RCM that will mitigate by either elimination or minimising recurrent failures in milling plants and thus enhancing milling plant equipment availability.

3.2.1 Research design methodology

Research objective 1*:* To address this objective, a modified FMEA or FMECA was used as a tool of failure analysis. This reliability analysis tool identified all the failure modes of the prioritised critical milling plant equipment and their effects on the production process. Pareto charting was then used to perform quantitative failure mode risk prioritization. This research prioritised six (6) sub-systems for study; Roller mills, Degermer, Elevator, Drive Motors, plansifter and Screens.

Research objective 2*:* To achieve this objective, FRCA or RCA and Ishikawa diagram were used to establish failure root causes for the prioritised critical equipment failure modes. Ishikawa diagram also known as the cause and effect diagram or fish bone diagram considered 5Ms-manufacturing process potential failure cause parameters and considered failure causal effects attributed to or contributed by Machine (machine parts and condition), Method (Process), Material (Raw material), Man power (technology, skills, knowledge level) and Measurement (Inspection and adjustments). Pareto charting was then applied to quantitatively assist in FRCs prioritization.

Research objective 3: To achieve this objective, variety of the feasible maintenance policies applicable to the identified critical milling plant sub-system failure modes were considered. The most optimal maintenance policy applicable was not considered in isolation, but also considered alongside other production process parameters including; Work procedures, service schedules, personnel trainings and measurements, among others.

MP selection: This was by extension objective 3 and was achieved through selection of the most feasible and optimal maintenance policy applicable to solve the prioritized failure modes. The choice of the most optimal maintenance policy was guided by use of a decision tree. The MP applicability considered sub-systems risk of failure in terms of FF, DT and DTC and the reliability of maintenance policy applicable to every specific sub-system failure mode.

3.3 Data collection

To meet the objectives of the research study, the relevant primary and secondary failure data was collected. Primary failure data for field operating condition was collected from employees of the milling plant which included production manager, human resource manager and members of junior management level, milling plant general duty workers, milling team, laboratory quality inspectors, technicians and packaging staff. This was done by way of personnel interviews and inquiries guided by a printed interview guide.

Secondary data was obtained from the plant operation log books, maintenance personnel hand books, maintenance and repair records, OEMs service and operation manuals, Gantt charts and staff training schedules.

3.3.1 Sampling procedure

Before administration of the research instrument for the full study, purposeful sampling for a pilot study was conducted through administration of a questionnaire guide with printed test items. Purposeful sampling is used for identification and selection of information rich cases for most effective use of limited resources (Patton, 2002). The purpose of this preliminary study was to pre-test the research instrument to be used in the full study. This was administered to five respondents, representing a sample population of the milling plant work force. Since purposeful sampling was carried out, the choice of sample respondents was guided by experience of the staff in the milling plant who were involved directly in the milling operation along the plant production line.

The responses were analysed and found to contain internal consistency and vital response information that could lead to giving valid information about the milling plant.

For the full study, stratified purposeful sampling was done where again employees working directly on the milling operation at various levels were selected as respondents. 55 questionnaires representing 82.09% of the total milling plant population was given out and administered to a total of 67 workers from the milling firm as shown on below table;

Table 3.1: Sampled employees working directly on the milling production line

Milling plant sections	**Mill section employees**	**Sample size**	**Percentage**
Cleaning and loading	19	16	29.09%
Milling	11	10	18.18%
Mill operations	26	22	40.0%
Insp. And QC	6	4	7.27%
Packaging	3	2	3.64%
HR	2	1	1.82%
Total	67	55	100%

According to Mugenda (2008), reliability is the measure to which a research instrument yields consistent results. Reliability in research is influenced by random error, as error increases, reliability decreases (Mugenda and Mugenda, 2003). A statistical analysis tool, SPSS was used to carry out analysis of variance (ANOVA).

3.3.2 Questionnaire survey

A detailed questionnaire was structured with test items to be responded to. The survey tool used in the research was aimed at establishing the type of maintenance policy and practices used in corn milling plants, the level of maintenance optimization and milling plant equipment utilization (availability and reliability levels). The tool was used to collect vital information related to milling plant performance information.

The data collected was analysed and presented in form of frequency tables and descriptive statistics in tabular form.

3.3.3 Respondents response rate

A total of 55 questionnaires representing 82.09% of the total milling plant workforce was given out and administered to a total of 67 workers from the milling firm. Of this, 42 questionnaires were returned. This represented a response rate of 76.36%. Out of the 42 questionnaires, 4 had some question items not responded to and thus, were declared incomplete and invalid and not considered during analysis. A total of 38 questionnaires were thus complete and considered validly filled for analysis. This is as shown in the table below;

Table 3.2: Respondents response rate

Responses	**Frequency**	**Percentage (%)**
Returned questionnaires	42	76.36%.
Validly filled questionnaires	38	90.48%
Invalid questionnaires	5	11.90%

3.4 Form of data collected

For each prioritised sub-system, field operating data over a period of one year, 2014 was collected.

This data entailed;

a. Failure data for each critical sub-system in terms of frequency of failure, time of failure, time of return and down time.

b. Reliability data for each critical equipment in terms of previous FF, TBF/ MTBF and TTR/ MTTR

c. Information on the failure modes and the associated failure occurrence or frequency for each type of failure mode.

d. The time and the associated material cost of performing corrective maintenance (CM) and preventive maintenance (PM) for each type of failure mode

e. The economic loss associated to each type of failure mode, (DTC or PDTC)

f. The inventory cost rate for each type of spare parts, (spare parts cost, C_S)

g. Consequence of failure, (failure risk or failure criticality or failure effects)

3.5 Data structuring

The data obtained was entered into MS excel sheet and in tabular form to enable easy and accurate interpretation. Important milling plant elements such as TTF or TBF, TTR, equipment DT, equipment PDTC, equipment DTC, spare parts cost and cost of labour or MHC among other important failure parameters were considered and entered appropriately.

3.6 Experimental design

This research considered six milling plant sub-systems that were considered to be the most critical along the milling line and picked for analysis. These are; Roller mills/ Brake rolls, Degermer, Elevator, Drive Motor, Plansifter and Screens.

Choice was determined by sub-system's failure risk criticality, decision informed by the field failure data obtained during research period- Failure Risk based FMEA approach through application of Pareto analysis tool.

Failure criticality was evaluated considering three fundamental failure parameters; FF, DT and DTC and Quantitatively evaluated using Pareto analysis tool.

Primary and secondary failure data was systematically collected from the prioritised critical sub-systems for milling plant and entered into a data sheet and the following analyses were performed.

a. Pareto analysis for sub-system failure risk prioritization

The six milling plant sub-systems were subjected to Pareto analysis. The purpose of this analysis was to establish the sub-systems with the highest risk of failure. The Pareto analysis considered each sub-system failure occurrence frequency, Down Time (DT) and the corresponding Down Time Cost (DTC) during the period of study.

Results from analysis were used to identify the sub-system with the highest risk of failure.

b. Pareto analysis for prioritised equipment failure modes

After identification and prioritization of the milling plant sub-systems with the highest risk of failure, each prioritized sub-system and its associated failure modes were considered separately and Pareto analysis done to establish the most critical failure modes in terms of failure occurrence frequency or failure count, DT and the corresponding DTC.

c. Pareto analysis for failure root causes

After identification of the critical failure modes of the prioritised sub-systems, RCA was performed with the aid of cause and effect diagram and 5Ms manufacturing process potential failure cause parameters to establish probable failure root causes. Pareto analysis for the failure root causes was then carried out to rank the FRC and this majorly considered sub-system failure cause frequency.

3.7 Failure risk calculations

All the failure data collected from primary and secondary sources (maintenance records/ maintenance logbooks, maintenance team, millers and management officials) was used for the different calculations for every parameter in question in this research. The maintenance records examined were for January to December 2014 and the same period again for 2015 for 20TPD and 28TPD production lines, however for consistency, the data for 28TPD production line was considered for analysis. This section explains the approach and the method used by the researcher to establish failure mode risk level parameters so as to do failure prioritisation.

Failure risk level was considered as the criticality of failure or consequence of the failure mode/s to the production process. Failure was prioritised according to three failure parameters; Sub system failure occurrence or failure frequency (FF) or failure count, sub-system downtime (DT) or Unavailability and the failure cost or sub-system Failure Down Time Cost, (FDTC or DTC).

i. *Downtime production cost, C_{PDTC} or PDTC*

This is the cost associated with loss of production or loss of value creation due to Sub-system failure occurrence or Unavailability. This was calculated by the equation;

$$C_{PDTC} = C_{UP} + C_F \quad \text{.......} 3.1$$

Where

C_{PDTC}- Downtime production cost

C_{UP}- Unavailable production cost or lost production cost due to failed sub-system

C_F – Fixed cost

ii. *Failure down time cost/ potential failure down time cost, C_{DTC}/ C_{PDTC}*

For each failure mode, the total cost of failure was calculated. Total failure cost included downtime production loss due to equipment failure, spare parts cost and labour or Mh costs. It was given by the equation;

$$C_{DT}=C_{PDTC}+C_{MH}+C_S \quad \text{.......} 3.2$$

Where

C_{DT}- Total failure cost of a given failure mode

C_{PDTC}- Downtime production loss

C_{MH}- Man hour cost

C_S-Spare parts cost

iii. Failure occurrence

For each of the subsystem or equipment, frequency of failures was calculated. This was interpreted as the number of times a certain failure mode occurred within the study period.

Example; The elevator mechanism experienced twelve failures in 2014, two resulting from worn sprocket failure mode, four as a result of worn drive chain and pins and six failures as a result of drive motor defects/ faults.

iv. ***Man hour cost or Labour cost, C_{MHC}***

This is the cost incurred in failure repair or cost associated with rectifying a sub-system failure mode. This cost is based on industrial plant labour rate as stipulated in the industrial labour Act. It was calculated as;

$$C_{MHC}= L_R x TTR \quad \text{.......} 3.3$$

Where

C_{MHC}- Man hours cost per failure mode

L_R- Industrial Std. labour rate, E.g., Ksh600 for skilled personnel for 8 hours

TTR-Time To Repair,

TTR- In this research, TTR was considered as the time taken during faults diagnosis and repair of failed equipment. It was calculated as the difference between the time failure repair work ended and time failure repair work started.

v. ***Materials cost and or spares parts cost, C_S***- In this research, material cost was considered to be the cost of replacement kit or spare part as a result of failure occurrence for the sub-system failure modes. It was obtained by the equation;

$$C_S= F_N \text{ x } N_C \text{ x } C_C \quad \text{.......} 3.4$$

Where,

C_S - Spare parts cost

F_N- Number of failures recorded within the study period

N_C- Number of similar components replaced for given failure mode

C_C- Component cost

Note: C_S- This referred to material or spare parts cost per failure mode of a failed subsystem or equipment.

3.8 Sub-systems failure risk prioritization

Milling plant subsystem or equipment prioritization in this research considered failure risk or consequence based on failure mode criticality in terms of failure effect and or failure consequence to the production process and considered three failure effect parameters; failure occurrence rate/ frequency, duration of downtime, DT and failure DTC which considered production DT cost, repair or service cost, spares cost and MHC. This was done as below;

i. Sub-system failure occurrence rate, (FF_{SS}) %

This was calculated as the ratio of the total failure frequency of a subsystem to the total failure frequency of the milling plant prioritised sub-systems during the period of study. Thus,

$$\text{Subsystem failure occurrence rate, \%} = \frac{\text{No. of failure of the sub-system}}{\text{Total No. of failures in the plant prioritised sub-system}} \times 100 \quad \ldots 3.5$$

ii. Subsystem downtime, (DT_{SS}) %

This was calculated as the ratio of total downtime in hours of a subsystem to the total downtime of the milling plant prioritised sub-systems in the period of study.

Thus,

$$\text{Subsystem downtime, \%} = \frac{\text{Total downtime for the subsystem (hrs)}}{\text{Total DT for the entire plant prioritised sub-systems (hrs)}} \times 100 \quad \ldots\ldots 3.6$$

iii. Subsystem failure cost, (DTC_{SS}) %

This was calculated as the ratio of the total failure cost of a subsystem to the total failure cost of the plant prioritised sub-systems for period of study.

Thus,

$$\text{Subsystem failure cost, \%} = \frac{\text{Total failure cost of a subsystem}}{\text{Total failure cost of the prioritised plant sub-systems}} \times 100 \quad \ldots\ldots\ldots 3.7$$

All the six (6) prioritised MP sub-systems were subjected to Pareto analysis to establish the sub-systems with the highest risk of failure in terms of failure occurrence, downtime and failure cost or failure DT cost. The sub-systems with the highest risk of failure were then recommended for further analysis.

3.9 Sub-systems failure mode prioritization

The research considered the prioritized sub-systems with the highest failure risk for failure modes prioritization. Sub-systems have different failure modes and each failure mode had its distinct failure effect on the plant production process. Prioritization of each failure mode was done on the selected critical sub-systems or equipment. This was done as below;

i. Failure mode occurrence rate, %

This was calculated as the ratio of frequency of a failure mode of a subsystem to the total failure frequencies of the subsystem during the period of study.

Thus,

$$\text{Failure mode occurrence, \%} = \frac{\text{Failure mode frequency in the subsystem}}{\text{Total No. of failure frequencies in the sub-system}} \times 100 \quad \ldots\ldots\ldots\ldots..3.8$$

ii. Failure mode downtime, %

This was calculated as the total downtime in hours of the failure mode of a subsystem to the total failure mode downtime of the subsystem in a milling plant for the period of study. Thus,

$$\text{Failure mode downtime, \%} = \frac{\text{Total downtime for failure mode (hrs)}}{\text{Total downtime for failure modes in the subsystem (hrs)}} \times 100 \quad .....3.9$$

iii. Failure mode cost, %

This was calculated as the ratio of the total failure mode cost in a subsystem to the total failure cost of all failure modes in a subsystem of the milling plant for the period of study.

Thus,

$$\text{Failure mode cost, \%} = \frac{\text{Total failure cost of a failure mode}}{\text{Total cost of failure modes of a subsystem}} \times 100 \quad ....3.10$$

After computing the failure mode risks, Pareto analysis chart and histogram were drawn considering the analysis results for the prioritised sub-system modes to establish the most critical failure mode for every sub-system. This again considered three key failure parameters; frequency of failure or

Failure occurrence (Failure count), downtime (Unavailable production time, PDTC) and cost of failure, (Down Time Cost, DTC).

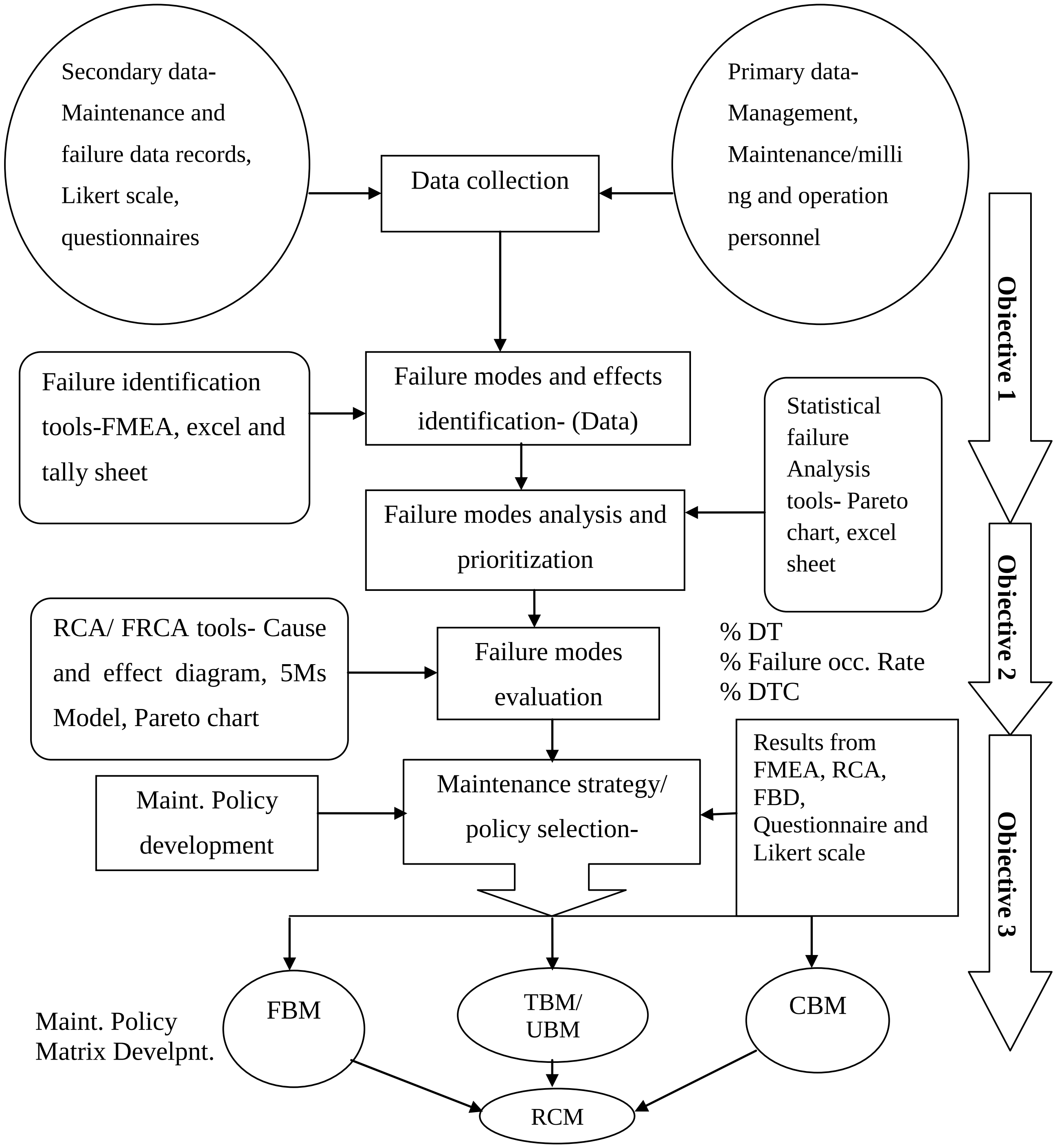

Figure 0.1: *Research methodology model used*

CHAPTER FOUR

RESULTS, FINDINGS AND DISCUSSIONS

4.1 Introduction

This chapter outlines and discusses results and discussions of the research findings to aid in formulation of effective corn milling plant maintenance strategy.

The chapter has been developed in accordance with the research objectives and systematically outlines how the research objectives have been addressed;

- ***Critical milling plant equipment failure modes identification and prioritization:*** To address research objective I, the research considered application of FMEA or FMECA to identify and prioritize milling plant equipment critical failure modes.

- ***Critical milling plant equipment failure modes root cause analysis:*** To addresses objective II, RCA was applied to identify and or establish and analyse potential failure root causes of the identified failure modes. This made use of Ishikawa or the cause and effect diagram which considered the 5Ms production process potential failure cause parameters. To perform failure root cause prioritization, Pareto analysis tool was used to quantitatively prioritise the failure root causes.

- ***Maintenance policy development and selection***: To achieve objective III, a matrix of all the feasible maintenance policies was developed together with other elements or parameters of production process which included service schedules, work procedures, special service tools availability and application, potential failure detection test method and equipment etc. A decision tree (DT) was then used for selection of the most feasible and optimal maintenance policy that will effectively and optimally mitigate milling plant equipment critical failures.

4.1.1 Reliability analysis using FMEA/ FMECA

In this research, failure identification and failure risk prioritization was done using FMEA as a reliability analysis tool. FMEA was considered to be most appropriate and applicable tool for reliability analysis due to its capability to identify, prioritize and rank the sub-systems failure modes. Failure risk was regarded as the sub-system failure criticality in terms of down time and the corresponding downtime cost, (i.e. down time cost was considered as the production loss caused by sub-system unavailability).

For purposes of failure cost analysis, failure cost was considered as having three cost elements; materials cost (spare parts cost), labour cost (Man Hour Cost, MHC) and downtime production loss or cost, DTPC (Milling equipment unavailable time, quantified in monetary value due to lost production time for 28TPD production line) which was an **'hidden cost'** but very critical in this research. All these costs were evaluated and their values tabulated to assess each equipment failure risk. In the calculations, labour cost was regarded as the service cost per failed equipment, materials cost was taken as the cost of spare parts based on the prevailing market rates whereas the production down time cost was taken as the equivalence of unavailable production time cost for 28TPD milling plant production line. Pareto analysis was performed to quantitatively prioritise the failure modes and present the results.

4.1.2 Milling plant sub-systems prioritization

Although maize milling plant production process has many sub-systems and units, this research identified six (6) critical sub-systems which were considered as the most critical for milling plant production process. The choice of these six critical equipment was based on criticality of equipment in terms of failure risk, decision informed by the field failure data obtained during research period.

Table 0.1 : *Critical MMP Sub-systems identified for analysis*

S/.No.	*Sub-system*	*Sub-System/ Unit function on production process*
1.	Degermer	Performs the degerming process- Removing corn skin, corn germ, root and black hilum from corn seed to ensure the final product is in consistent colour without any black products or black colouration.
2.	Roller mill	Breaking down or grinding or particle size reduction of corn to produce flour or grits of different sizes, texture or fineness.
3.	Elevator	Belted or chained mechanism for vertical conveyance of corn along the plant milling production line.
4.	Drive motors	Provides turning moment or drive to different milling plant units
5.	Plansifter	A nest of sieves mounted or stack together so that grits or flour being sieved is divided into a number of fractions of different sizes.
6.	Screens	Device meshed or highly perforated used for separating coarse flour and grits from fine parts of loose particle matter that proceeds for further milling or packaging as the final finished product.

4.1.2.1. Milling plant field failure data collection and structuring

Table 0.2: *Example of a modified milling plant field failure data entry form as used in this research*

Date of failure	Unit failure entry form No.	Equipment	Failure description	Time of failure	TTR (mins)	Spares Cost (US$)	DTPC (US$)
2-Jan-14	MMP/1/14	Degermer	Bearing thermal failure	11:27am	147	78	1,315.21
4-Jan-14	MMP/1/14	Degermer	Worn out degermer plates and blades	8:32am	1740	420	15,563.33

Field failure data for the six (6) prioritised maize milling plant critical sub-systems was collected and entered into a modified failure risk based FMEA data entry sheet with various computed failure risks or failure cost parameters for the various failure modes, Table 4.2. Field failure data collected for the prioritised critical sub-systems is as shown in the following tables;

Table 4.3 shows failure data for RM sub-system failure modes for the year 2014. RM is one of the most critical sub-systems in the milling production line. Research conducted shows that the sub-system recorded 10 critical random failures that resulted to the milling plant shutdown. 4 failures were due to milling surface failure, 3 failures by RM vibration, 2 by RM shaft bearing seal leakage and 1 failure caused by RM belt trip. The results were analysed and presented, (Figs. 4.5, 4.6, 4.7).

Table 0.3 : *Field failure data for roller mill sub-system failure modes, model no.AGS615B2*

Failure mode	**Failure Date**	**Time of failure**	**Unavailable Time(hrs)**	**Repair Time(TTR)**	**Spare cost (US$)**	**Labour cost(US$)**	**No. of technicians**	**Downtime Production Loss (US$)**	**Total PDT cost (US$)**
Milling surface failure (B1&B2)	13.11.14	5.23pm	32	32	140	160	2	17178.24	17,478.24
Milling surface failure (B1 &B3)	13.01.14	6.13am	24.21	24.21	140	160	2	12992.7	13,292.70
Milling surface failure (B3&B4)	6.10.14	12.08pm	28.17	28.17	140	160	3	12958.2	13,258.20
Milling surface failure (B2 &B4)	26.05.14	7.32pm	28.00	28.00	140	160	3	12880	13,180
Intense vibration (B1 &B4)	18.09.14	11.43pm	23.00	23.00	12	6	2	12343.33	12,361.33
Roller mill shaft bearing failure (B1)	22.09.14	4.47am	15.13	15.13	30	6	2	8122.09	8,158.09
Roller mill vibration (B1)	13.03.14	11.05am	5.70	5.70	43.2	6	2	3059	3,108.20
Excessive roller mill vibration (B2)	3.10.14	8.52am	2.70	2.70	30	6	2	2581.3333	3,051.00
B3 roller mill shaft lubricant leakage	9.06.14	1.47pm	2.20	2.20	7	6	2	1181	1,194
Roller mill belt trip	16.10.14	9.04am	0.82	0.82	2.4	3.5	1	536.82	542.72

Table 4.4 shows field failure data for degermer sub-system failure modes. Degermer is as well a very critical sub-system in the milling plant production line. The sub-system registered 11 critical failures during the year under study leading to plant shutdown. 3 failures were caused by degermer plates and blades failure, 1 failure by degermer screens, 2 failures by unit vibration, 2 failures by bearing thermal failure, 1 failure by degermer shaft lubricant leakage, 1 failure by belt trip during operation and lastly 1 failure was caused by loose degermer mounting flange. Results for the degermer sub-system were analysed and results presented (Figs. 4.8, 4.9. 4.10).

Table 0.4 : *Field failure data for degermer sub-system failure modes, model no.DG208OR*

Failure mode	**Failure Date**	**Time of failure**	**Unavailable Time (hrs)**	**Repair Time (TTR)**	**Spare cost (US$)**	**Labour cost (US$)**	**No. of technicians**	**Downtime Production Loss (US$)**	**Total PDT cost (US$)**
Degermer screens failure	3.09.14	6.13am	32.67	32.67	19.2	30	3	17536.1	17,585
Worn degermer plates and blades	4.01.14	8.32am	29.00	29.00	32	30	2	15567.8	15,630
Worn degermer blades	16.06.14	7.42am	26.00	26.00	32	30	3	13957.3	14,019
Intense unit vibration	3.03.14	12.11pm	15.27	15.27	64	30	2	8195.45	8,289.5
Unit vibration and noise	25.10.14	11.26am	9.77	9.77	32	30	2	5242.94	5,304.9
Worn degermer plates and blades	6.12.14	7.47pm	8	8	32	30	2	4294.56	4,356.6
Bearing thermal failure	15.12.14	8.46am	2.60	2.60	9.6	3.5	2	1395.73	1,408.8
Bearing failure	2.01.14	11.27am	2.45	2.45	32	30	1	1315.21	1,377.2
Degermer shaft lubricant leakage	4.07.14	9.12am	1.30	1.30	2	3.5	1	697.866	703.37
Belt trip during operation	6.01.14	5.11pm	1.13	1.13	0	6	1	608.396	614.4
Loose mounting flange	26.01.14	11.23am	0.27	0.27	0	3.5	1	143.152	146.65

Table 4.5 shows field failure data for drive motor sub-system. Again, this is a very critical milling line production sub-system. Research showed that this sub-system recorded 11 critical failures during the period under study, 2014. 4 sub-systems failures were caused by armature windings failure, 2 failures were caused by the unit vibrations, 2 by bearing thermal failure, worn brush, faulty switch and noisy DM shaft bearing registered 1 failure during the period under study. The results were analysed and presented, (Figs. 4.11, 4.12 and 4.13).

Table 0.5 : *Field failure data for drive motor sub-system failure modes, model no.AGS4GR1.11*

Failure mode	Failure Date	Time of failure	Unavailable Time(hrs)	Repair Time(TTR)	Spare cost (US$)	Labour cost(US$)	No. of technicians	Downtime Production Loss (US$)	Total PDT cost (US$)
Armature windings failure	30.04.14	11.49am	2.57	2.57	12	3.5	1	1377.84	1,395.13
Motor vibration	8.04.14	6.18pm	2.03	2.03	12.6	3.5	2	1089.74	1,105.84
Armature short circuiting	17.02.14	11.56am	1.32	1.32	150	6	1	708.6	864.6
Bearing thermal failure	23.06.14	3.13am	1.15	1.15	0	0	1	617.34	617.34
Armature failure	3.01.14	11.33am	0.75	0.75	45	30	1	402.615	477.615
Motor vibration	24.06.14	5.14am	0.87	0.87	0	0	1	465.24	465.24
Worn brushes	21.08.14	11.13pm	0.8	0.8	4.8	3.5	1	429.46	437.76
Faulty switch	8.05.14	9.38am	0.77	0.77	1.2	3.5	1	411.56	416.262
Noisy DM shaft bearing	7.03.14	1.24pm	0.75	0.75	5	6	1	402.615	413.615
Burnt windings	16.10.14	11.12am	0.617	0.617	0	3.5	1	331.22	334.71
Faulty switch	13.07.14	4.14am	0.50	0.50	0	3.5	1	268.41	271.91

Tables 4.6, 4.7 and 4.8 shows field failure data for milling plant elevator sub-system, plansifter and screens sub-systems respectively for the milling plant recorded during the period of research. The results were analysed and results presented.

Table 0.6: *Field failure data for elevator sub-system failure modes*

Failure mode	Failure Date	Time of failure	Unavailable Time (hrs)	Repair Time(TTR)	Spare cost (US$)	Labour cost(US$)	No. of technicians	PDT Loss (US$)	Total PDT cost (US$)
Intense chain vibration	23.05.14	12.28pm	1.30	1.30	0	6	2	697.866	703.866
Worn chain roller pins	30.06.14	6.13am	1.27	1.27	6.6	6	2	679.972	692.572
Drive chain off from sprocket	4.06.14	11.23am	0.98	0.98	0	3.5	2	529.584	526.084
Loose sprocket	7.05.14	7.19am	0.97	0.97	0	3.5	1	518.926	522.426
Slack chain	11.04.14	11.21pm	0.93	0.93	0	3.5	1	501.032	504.532
Intense noise	4.09.14	9.07pm	0.93	0.93	0	3.5	2	501.032	504.532
Worn chain and sprocket	27.02.14	12.33pm	0.82	0.82	6.6	1.2	1	438.403	446.203
Chain trip from sprocket	14.04.14	7.07pm	0.7	0.7	0	3.5	1	375.774	379.274
Worn drive chain	2.01.14	4.52pm	0.57	0.57	50.4	8	1	305.987	364.387
Insufficient torque	26.02.14	7.32pm	0.57	0.57	0	6	1	304.198	310.198
Excessive noise	26.02.14	6.13am	0.43	0.43	0	3.5	1	232.622	236.122
Chain vibration	18.12.14	7.51am	0.28	0.28	0	3.5	1	152.099	155.599
Misaligned drive mechanism	8.10.14	4.16pm	0.18	0.18	0	3.5	1	98.417	101.917

Table 0.7 : *Field failure data for plansifter sub-system failure modes*

Failure mode	Failure Date	Time of failure	Unavailable Time(hrs)	Repair Time(TTR)	Spare cost (US$)	Labour cost(US$)	No. of technicians	Downtime Production Loss (US$)	Total PDT cost (US$)
Screens clogged	22.04.14	6.14pm	1.27	1.27	0	0	1	681.22	681.22
Screens torn	23.02.14	12.28pm	2.23	2.23	3.2	3.5	2	1199	1205.6
Misaligned screens	18.07.14	4.19am	0.62	0.62	0	0	1	331	683.47
Torn screens	3.03.14	6.13am	0.82	0.82	19.6	3.5	1	438.4	461.5
Pitted screens	1.12.14	9.29am	0.633	0.633	4.8	4.8	1	340	349.6
Screens clogged	11.03.14	8.32am	0.62	0.62	7.2	3.5	1	331	341.74
Screens misaligned	30.10.14	10.43am	0.57	0.57	4.8	3.5	1	304.2	312.5
Screens pitting	2.03.14	7.05pm	0.53	0.53	9.6	3.5	2	286.3	299.4
Screens clogged	11.06.14	8.32am	0.30	0.30	19.6	3.5	2	161.1	184.15
Screens pitting	2.02.14	9.37am	0.23	0.23	3.2	3.5	2	123.5	130.17
Screens pitting	11.01.14	8.15am	0.20	0.20	12	3.5	1	107.4	122.86

Table 0.8 : *Field failure data for screens sub-system failure modes*

Failure mode	Failure Date	Time of failure	Unavailable Time(hrs)	Repair Time(TTR)	Spare cost (US$)	Labour cost(US$)	No. of technicians	Downtime production Loss (US$)	Total PDT cost (US$)
Intense chain vibration	23.05.14	12.28pm	1.30	1.30	0	6	2	697.866	703.866
Worn chain roller pins	30.06.14	6.13am	1.27	1.27	6.6	6	2	679.972	692.572
Drive chain off from sprocket	4.06.14	11.23am	0.98	0.98	0	3.5	2	529.584	526.084
Loose sprocket	7.05.14	7.19am	0.97	0.97	0	3.5	1	518.926	522.426
Slack chain	11.04.14	11.21pm	0.93	0.93	0	3.5	1	501.032	504.532
Intense noise	4.09.14	9.07pm	0.93	0.93	0	3.5	2	501.032	504.532
Worn chain and sprocket	27.02.14	12.33pm	0.82	0.82	6.6	1.2	1	438.403	446.203
Chain trip from sprocket	14.04.14	7.07pm	0.7	0.7	0	3.5	1	375.774	379.274
Worn drive chain	2.01.14	4.52pm	0.57	0.57	50.4	8	1	305.987	364.387
Insufficient torque	26.02.14	7.32pm	0.57	0.57	0	6	1	304.198	310.198
Excessive noise	26.02.14	6.13am	0.43	0.43	0	3.5	1	232.622	236.122
Chain vibration	18.12.14	7.51am	0.28	0.28	0	3.5	1	152.099	155.599
Misaligned drive mechanism	8.10.14	4.16pm	0.18	0.18	0	3.5	1	98.417	101.917

Table 0.9 : *Field failure data summary for MP prioritised sub-systems, 2014*

Sub-systems	DT (Mins/Yr)	Failure freq.	PDT cost (US$)	% DT cost
Roller Mill/ Brake rolls	10,214	9	91,384.66	54.11%
Degermer	5,740	10	51,355.78	30.41%
Drive Motor	1220	20	10,915.34	6.46%
Screens	850	19	7,604.95	4.50%
Elevator	524	13	4,688.23	2.78%
Plansifter	329	11	2,943.56	1.74%
	18,877	**82**	**168,892.523**	**100.00%**

(Plant filed failure/ maint. data analysis)

Table 4.9 shows milling plant field failure data collected for analysis. This data was obtained from six prioritised milling plant sub-systems and analysed for failure effect or DT results. For purposes of milling plant sub-system prioritization, the data was quantitatively analysed using Pareto charts. Sub- system prioritization considered failure frequency/count, DT and the corresponding production DTC. The results are as shown in figures 4.1, 4.2 and 4.3.

4.1.3 Sub-system failure risk prioritization Pareto analysis

All the critical sub-systems were analysed by considering the failure occurrence frequencies and their corresponding failure costs for each sub- system failure mode. Pareto analysis was performed on each sub-system on the basis of sub-system failure occurrence counts. This was done to identify the sub-system with the highest failure frequency and highest criticality of failure (DT and DTC) as in the figures 4.1, 4.2 and 4.3;

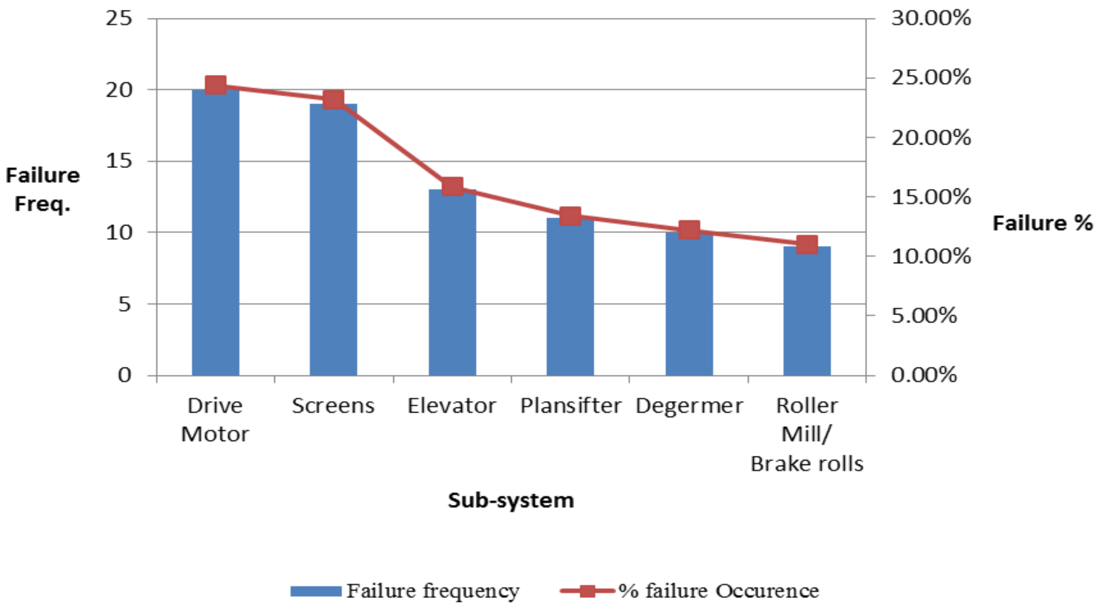

Figure 0.1 : *MMP critical equipment DT analysis (Failure Freq., % Failure)*

Fig. 4.1 shows the six MMP sub-systems that were identified and prioritized for analysis. The x-axis represents the critical sub- systems and the y-axis represents the failure frequency or failure count and the % failure (% failure rate). From the analysis, it was discovered that the drive motors and screens registered the highest failure frequencies registering percentage failure frequencies or counts of 24.39% and 23.17% respectively. The roller mills and degermer recorded the least failures which represented 12.20% and 11.00% failure rates respectively. Elevators and plansifters recorded average failures that represented % failure rates of 15.85% and 13.41% respectively.

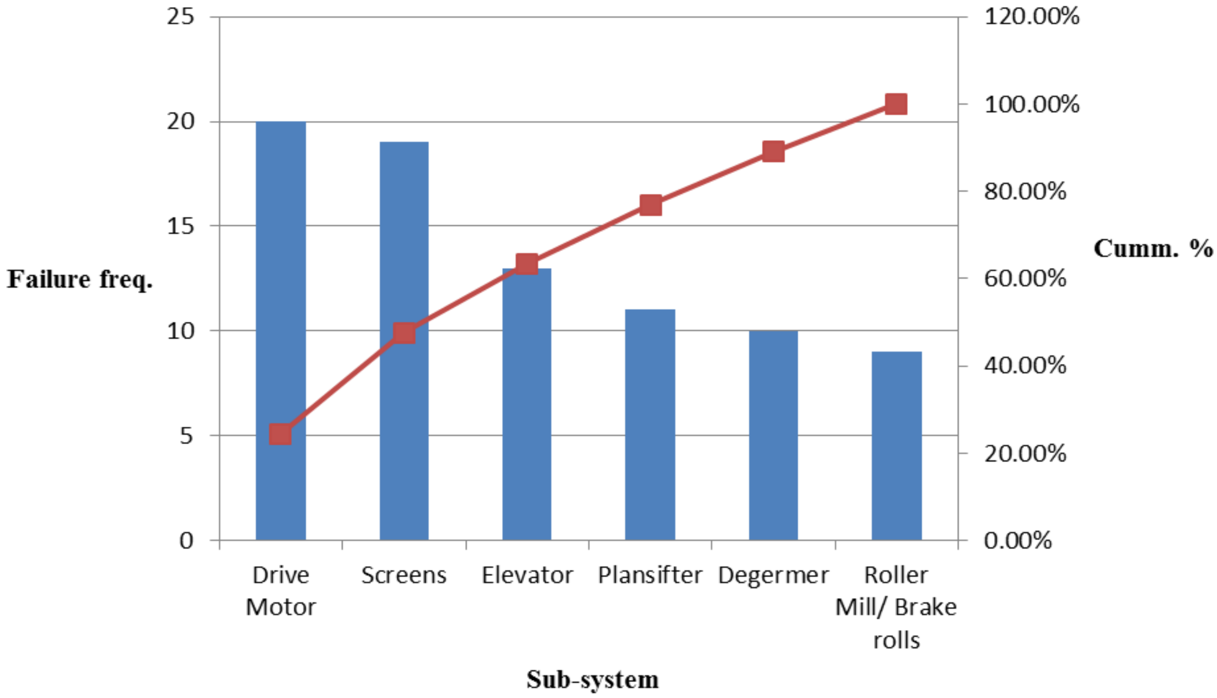

Figure 0.2 : *Critical sub-systems failure analysis*

From fig. 4.2, the x-axis represents the critical sub- systems and the y-axis represents the failure frequency and the % cumulative failures. Again from the Pareto analysis, the findings show that the drive motors and screens had the highest failure frequencies whereas the roller mills and degermer recorded the least failure counts during the year under study. The fact that the DM and screens respectively experienced the highest failure frequencies during the period under study, this does not necessarily give a direct indication or direct proportion of failure criticality of the sub-system.

Milling plant prioritised critical sub-systems DT Pareto failure risk analysis

The six sub-systems were subjected to Pareto analysis for failure risk prioritization. This considered each sub-system failure frequencies, DT and the corresponding DTC. The Pareto results are given in figure 4.3.

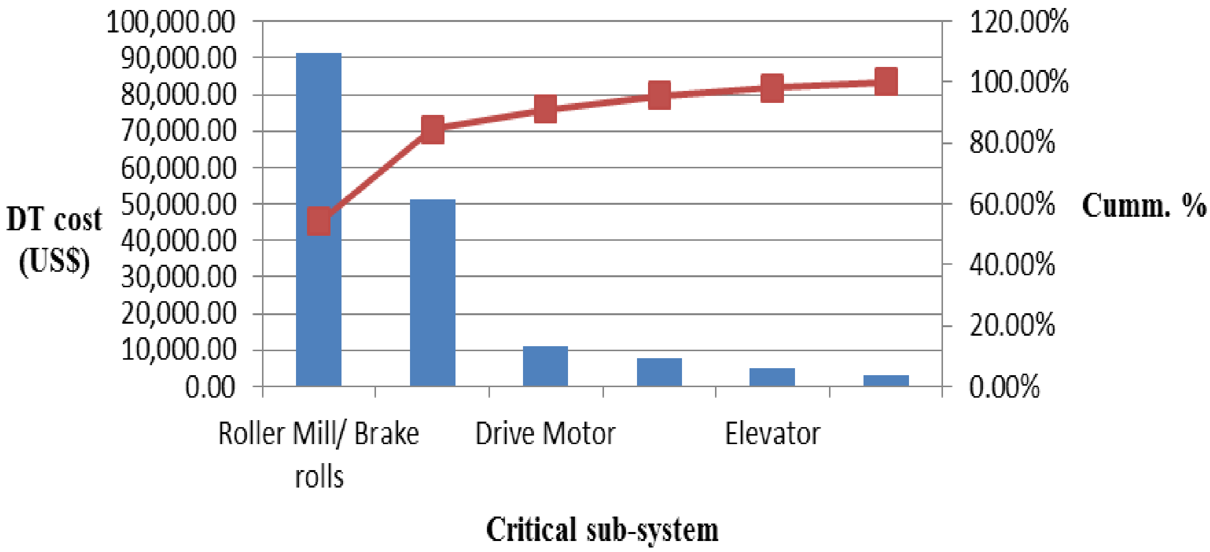

Figure 0.3: *DTC Pareto analysis for MMP critical sub-systems*

The x-axis represents the critical sub-systems, the primary y-axis representing the failure cost in US dollars and the secondary y- axis % cumulative failure cost.

From the Pareto analysis of the MMP critical sub-systems, and considering DT criticality (production DT effect), it was noted that the roller mills and the degermer were the two sub-systems with the highest failure criticality based on the risk of failure. The criticality of failure which explained the risk of failure was due to the high DT and thus a corresponding DT cost.

Although from the failure frequency analysis (fig.4.2), these two sub-systems registered the least failure counts, they exhibited the highest risk of failure after conducting DT failure risk analysis. The cost of failure for the roller mills and degermer was more than 91,000 and 50,000 USD respectively during the period under study.

From fig. 4.2, it is observed that although the drive motor and screens exhibited the highest failure frequencies or counts during the period under review at 24.39% and 23.17% respectively, their failure risk criticality was not as high as with failure of roller mills and the degermer, although the later had recorded the least number of failures during the period under study. The high DT criticality or cost (DTC) for roller mill and degermer was occasioned by the prolonged TTR which translates to high PDT loss coupled with high cost of labour and spare parts.

From the Pareto analysis, it came out that the roller mills had the highest % DT cost of 54.11% of the total plant sub-systems failure cost analysis, followed by the Degermer unit with % DT cost of

30.41%, drive motor with % DTC of 6.46%, screens at 4.50%, elevator at 2.78% and the least was plansifter with % DTC of 1.74%.

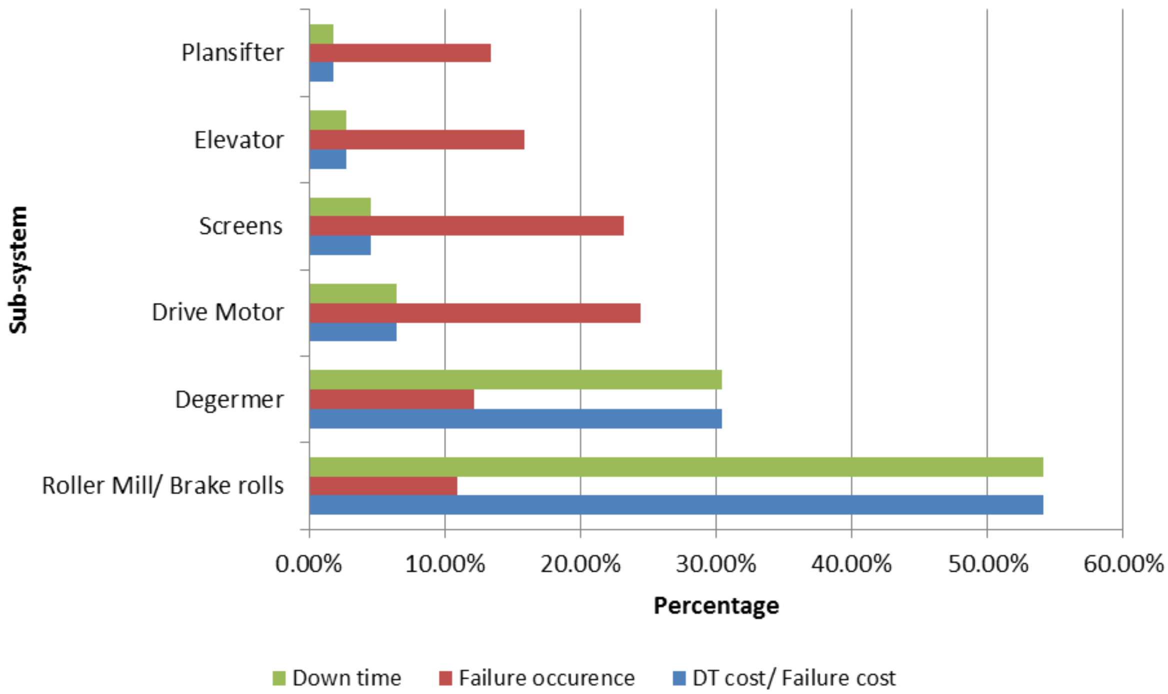

Figure 0.4 : *MMP critical sub-system % failure occurrence, DT and DTC (Cost of Failure)*

From Pareto analysis results for MMP critical sub-systems, considering failure occurrence frequency, DT and the failure DT cost, it is observed that the results identified the roller mill as the most critical sub-system in terms of failure risk criticality followed by the degermer and drive motor sub- systems. The other three sub-systems which include screens, elevator and plansifter did not exhibit high failure criticality and thus not recommended for further analysis. This was because their failures had the least level of criticality in terms of DT and their corresponding production DT cost. The Plansifter was found to be the least critical sub-system for corn milling production line and in maintenance engineering forms part of the equipment that are RTF before maintenance action is taken.

Considering the sub-system failure risk criticality, the roller mills, degermer and drive motors sub-systems exhibited the highest level of failure risk criticality in corn milling plants production line and thus recommended for further analysis. The basis for establishing the sub-system with the highest failure risk criticality was informed by combination of three failure parameters namely; Failure occurrence rate or frequency, DT and the corresponding failure DT cost (DTC).

Although the screens exhibited a high failure frequency (as in figure 4.1), on the other hand, the DT and the corresponding DT cost was quite low and thus just like plansifter and elevator, it was regarded as a sub-system with minor failure risk criticality and thus **not** considered for further analysis.

4.1.4 Critical sub-systems failure modes analysis

The prioritised critical sub-systems were subjected to failure mode Pareto analysis. This analysis considered failure mode occurrence frequency, DT and failure DTC for the respective failure modes. These are the equipment whose failure caused serious consequence to production process in terms of DT and the high DT cost occasioned by prolonged TTR, high labour and materials cost. Failure occurrence frequency for the failure modes although put into consideration, was not a very key parameter to consider, (figure 4.4).

The following graphs explain the failure modes analysis for the sub-systems recommended for failure mode analysis.

a. Roller mill sub-system failure mode analysis

Figure 4.5 shows Pareto analysis for roller mill sub-system failure modes. The x-axis represents all the failure modes of RM during the period under review. The y- axis represents failure DT cost and cumulative % DT cost.

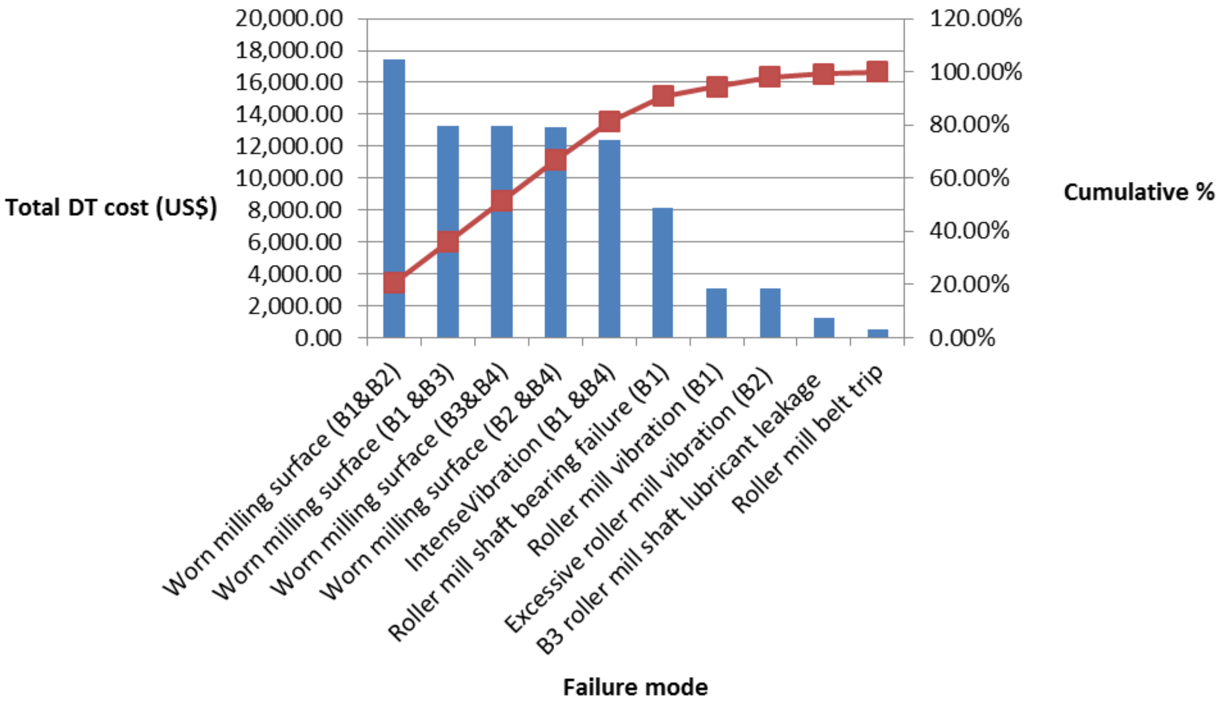

Figure 0.5 : Pareto analysis for Roller mill failure modes

To further refine the analysis, all the similar and or related failure modes for RM were put together to give the total aggregate DT cost and % failure count and analysed as in figure 4.6;

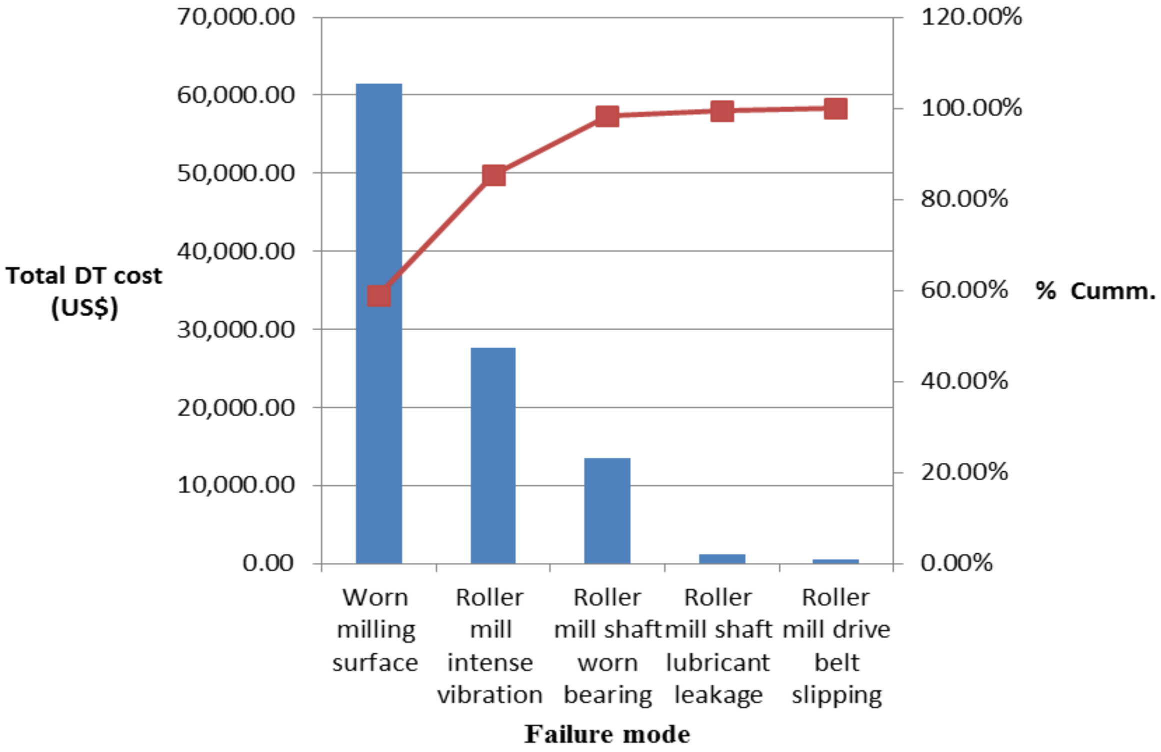

Figure 0.6: *Pareto analysis for Roller mill failure modes DT cost*

The x-axis represents roller mill sub-system failure modes, primary y-axis failure DT cost (USD) and the secondary y- axis the percentage cumulative failure cost. From the Pareto analyses, wearing or failure of the roller mill milling surface and roller mill vibrations were identified to be the most critical RM failure modes and represented 80% of the total failure cost of the sub-system. Roller mill milling surface failure had the highest failure cost of 61,000USD, roller mill vibration with 27,000US$ and RM shaft bearing failure with 13,000US$. The failure mode with the least failure criticality effect was RM drive belt tripping and RM shaft lubricant leakage that recorded 500US$ and 1,000US$ respectively during the period under study.

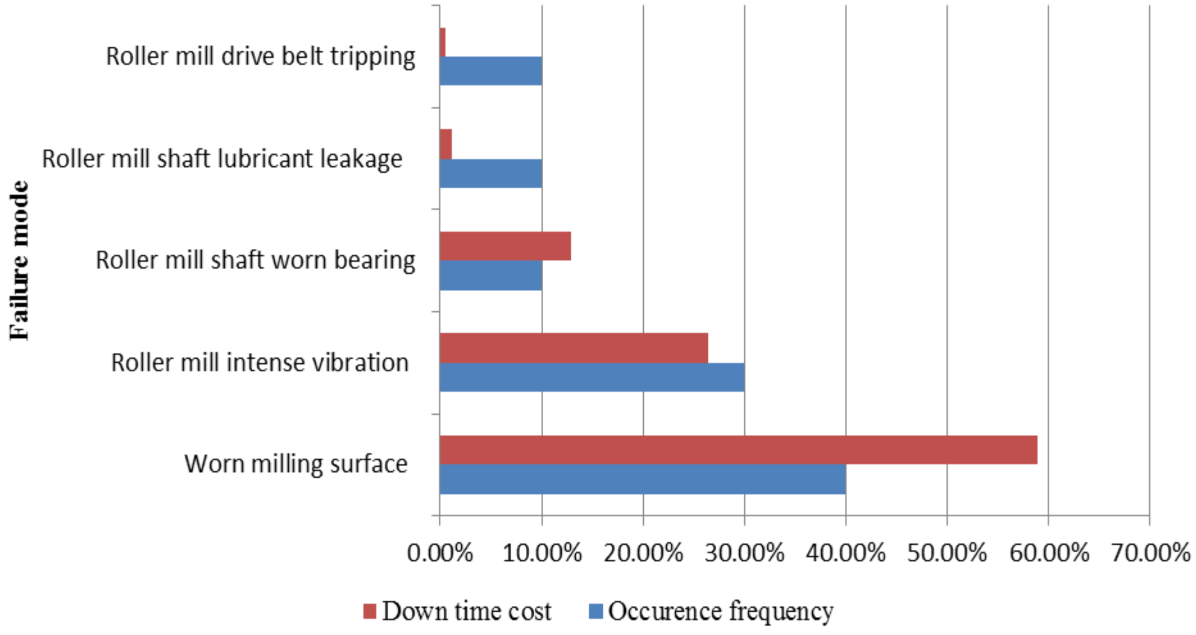

***Figure 0.7 :** % failure occurrence rate and % down time cost for roller mill failure modes*

Figures 4.5, 4.6 and 4.7 show Pareto analysis for roller mill sub- system failure modes. From the graphs, it is noted that the most critical failure cause of the sub-system DT was due to wearing or failure of roller mill milling surface with down time occurrence rate of 40% and DT cost or DT failure cost of 58.90% of the total sub-system failures. This was followed by roller mill vibration due to worn bearing or bush with occurrence rate of 30% of the total sub-system failures and DT cost or DT failure cost of 26.48% of the total sub- system DTC.

Roller mill shaft bearing failure, roller mill shaft lubricant leakage and drive belt tripping had the least contribution to the sub-system DT with almost equal occurrence rate of 10% of the total failures but had different DT costs of 12.95%, 1.14% and 0.52% respectively of the total sub-system DTC. The differentiation in DTC for these three failure modes (Roller mill shaft bearing failure, roller mill shaft lubricant leakage and drive belt tripping) was caused by the difference in DT for the sub-systems.

It was noted that roller mill milling surface failure had the highest contribution towards the sub-system DT and again had the highest failure DT cost. Roller mill shaft bearing failure had moderate failure occurrence rate and DT cost.

From the Pareto analysis results of roller mill sub-system, it is noted that failure of roller mill milling surface and the unit vibration are the most critical failure modes for this sub-system due to their high cost of failure (DTC, failure risk criticality) and high % failure occurrence frequency and thus the two failure modes are identified and recommended for further analysis.

b. Degermer sub-system failure mode analysis

Pareto analysis for degermer (also known as degerminator or Impact detacher) sub-system failure modes was done. The x-axis represents all the failure modes for the unit during the period under review. The y- axis represents DT cost and cumulative % DT cost.

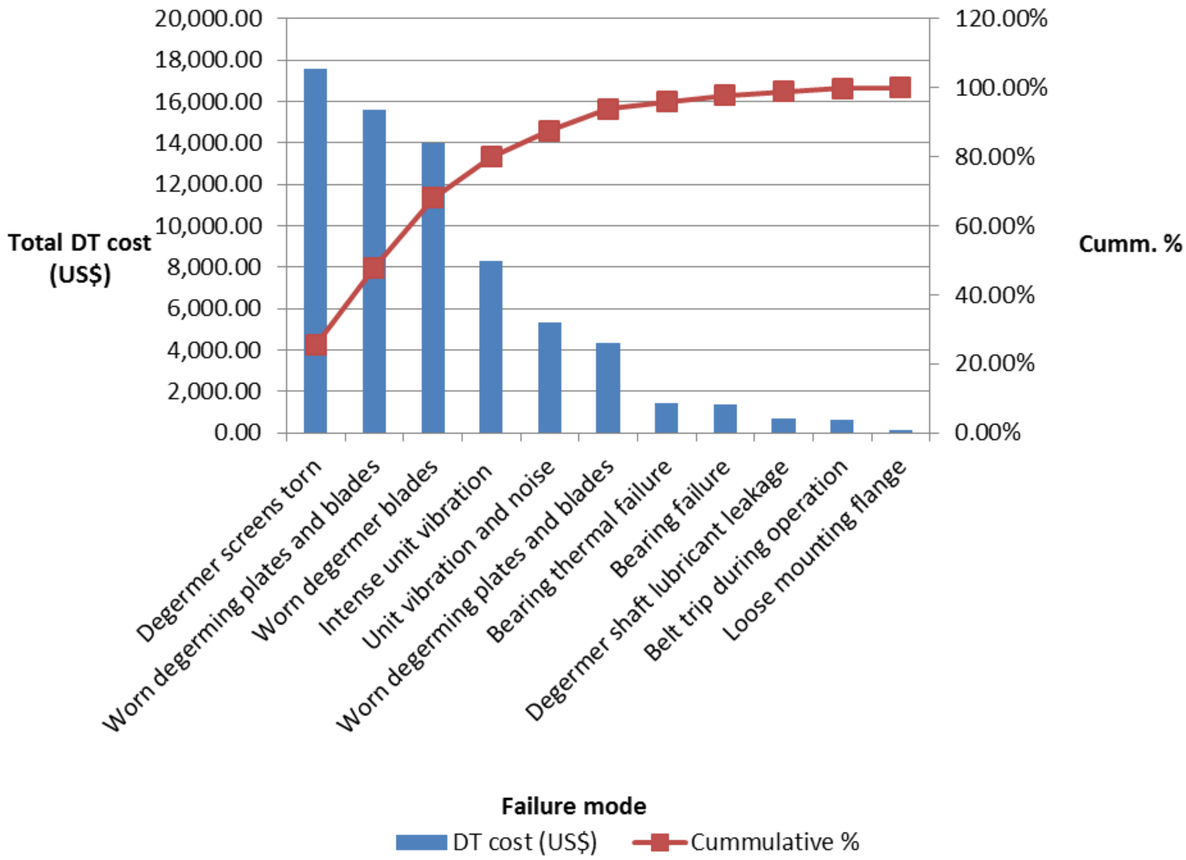

Figure 0.8: *Pareto analysis for degermer failure modes*

To further refine the analyses, all the similar and or related failure modes for degermer unit were put together to give the total aggregate DT cost and analysis results are shown in figure 4.9.

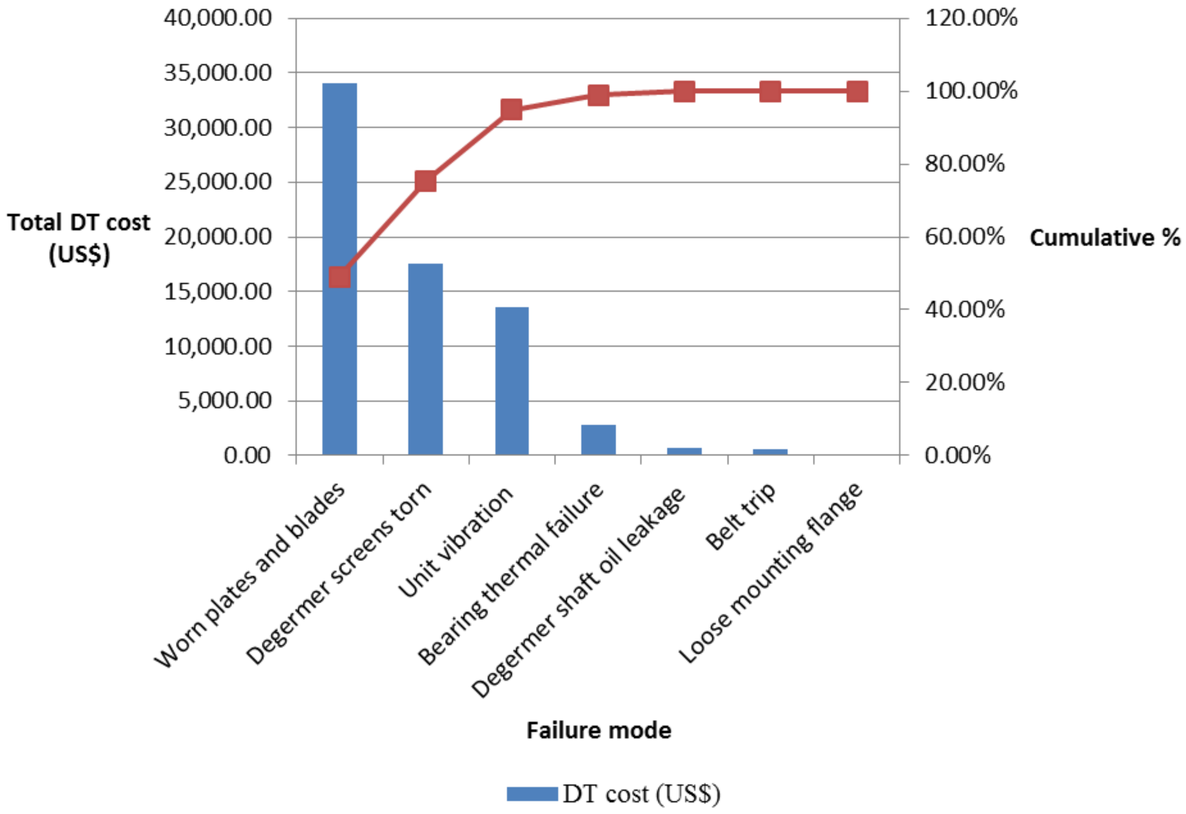

Figure 0.9: *Pareto analysis for degermer sub-system failure modes DT cost*

From the Pareto analysis for degermer sub-system (Fig. 4.9 and 4.10), failure due to worn degermer blades and plates had the highest down time rate or failure occurrence frequency of 27.27% of the total unit failures and % DT cost of 48.97% of the total unit DT cost which translated to 34,005.66 US$. This was due to three failures of the total sub-system eleven failures witnessed during the period under review. This was followed by failure of degermer screens and degermer vibration with DT cost of 25.33% (17,587.11 US$) and 19.58% (13,597.97 US$) respectively of the total unit DT cost.

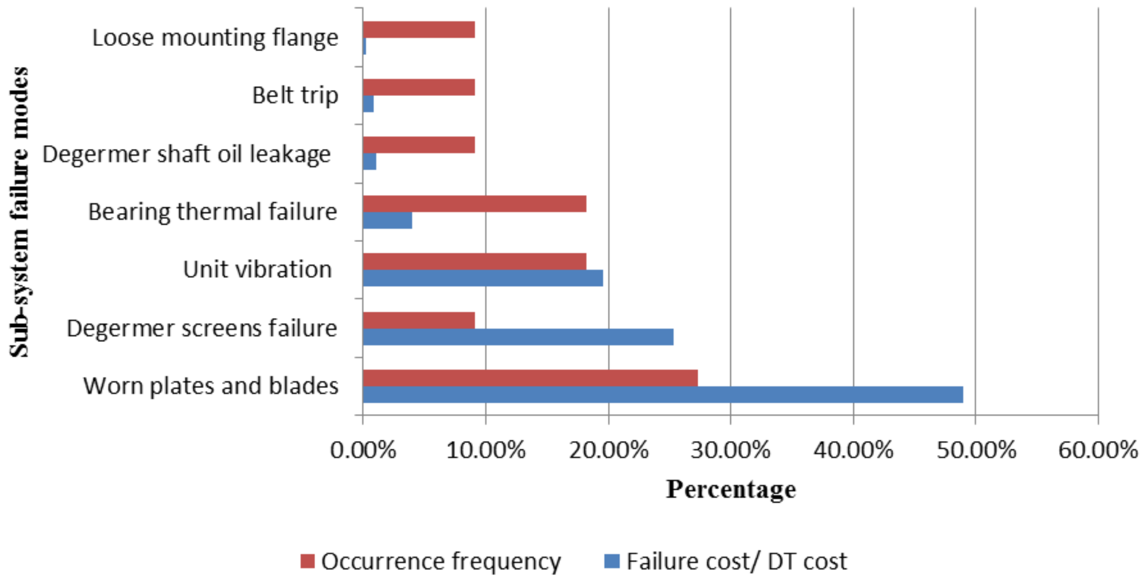

Figure 0.10: *% failure occurrence rate and % down time for degermer sub-system failure modes*

Degermer bearing thermal failure, shaft oil leakage, belt trip and loose mounting flange had the least failure DT cost contribution at a rate of 4.01%, 1.01% and 0.88% respectively with almost equal % failure frequencies of 9.09%. From the Pareto analyses for degermer sub-system, it is observed that degermer blades and plates wearing was the unit part with the highest failure criticality due to the high failure cost and failure frequency. Although failure of degermer screens has a high failure cost, the frequency of failure is not very high and thus its failure criticality is less compared to failure of plates and blades. However, based on the failure cost, this unit was as well recommended for further analysis. The results for % occurrence and DT cost forms the basis for identifying degermer milling plates and blades failure as again very critical failure modes for this sub-system.

c. Drive motor sub-system failure mode analysis

Figs. 4.11, 4.12 and 4.13 show Pareto analysis for drive motor sub-system failure modes. The x-axis represents all the failure modes for the unit during the period under review. The primary y- axis represents DT cost and the secondary y- axis shows cumulative % DT cost.

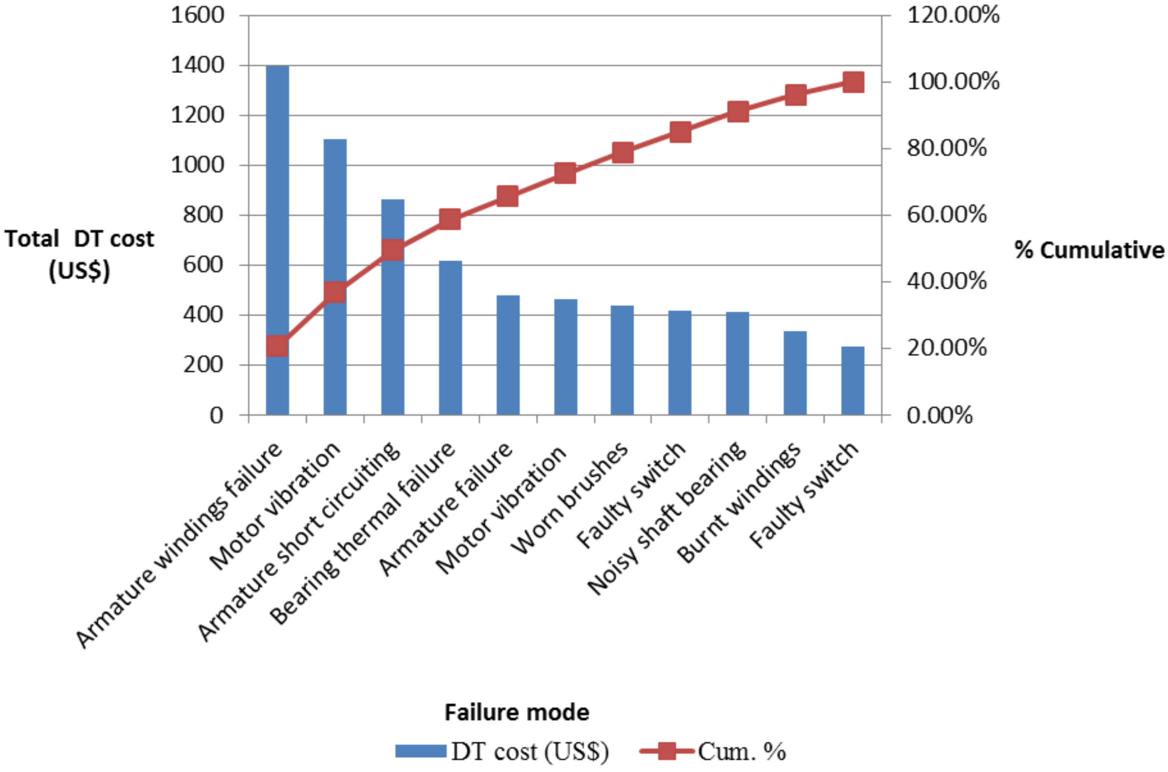

Figure 0.11: *Pareto analysis for drive motor failure modes*

Similarly to further refine the analysis, all similar and or related failure modes for the drive motor sub-system were put together to give the total aggregate DT cost and % cumulative frequency and analysed as in figure 4.12;

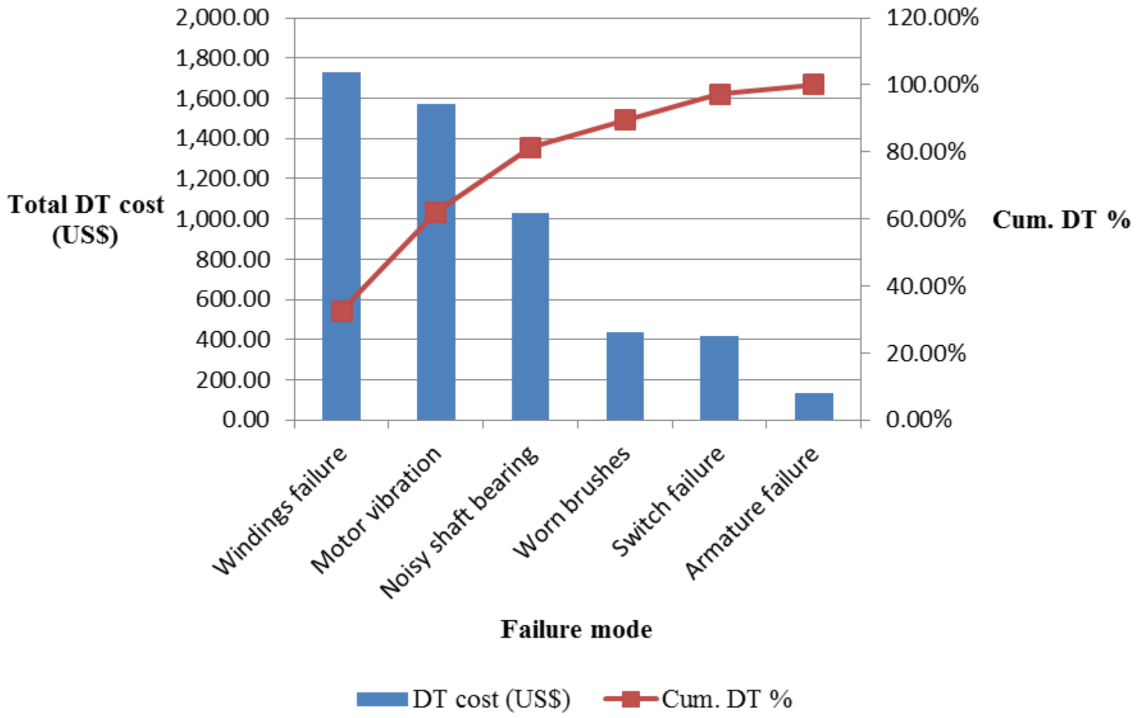

Figure 0.12: *Pareto analysis for drive motor sub-system failure modes DT cost*

Figure 4.12 shows Pareto analysis for drive motor sub-system failure modes DT cost and % cumulative DT cost. The x-axis represents the failure modes for the unit during the period under review and the y- axis represents DT cost and cumulative % DT cost. DM winding failure had the highest criticality of failure with failure DT cost of 1,729US$ followed by motor vibration at DT cost of 1,572US$. Armature failure and switch failure had the least failure cost at 132 US$ and 418US$ respectively which in this research are considered to be negligible failures.

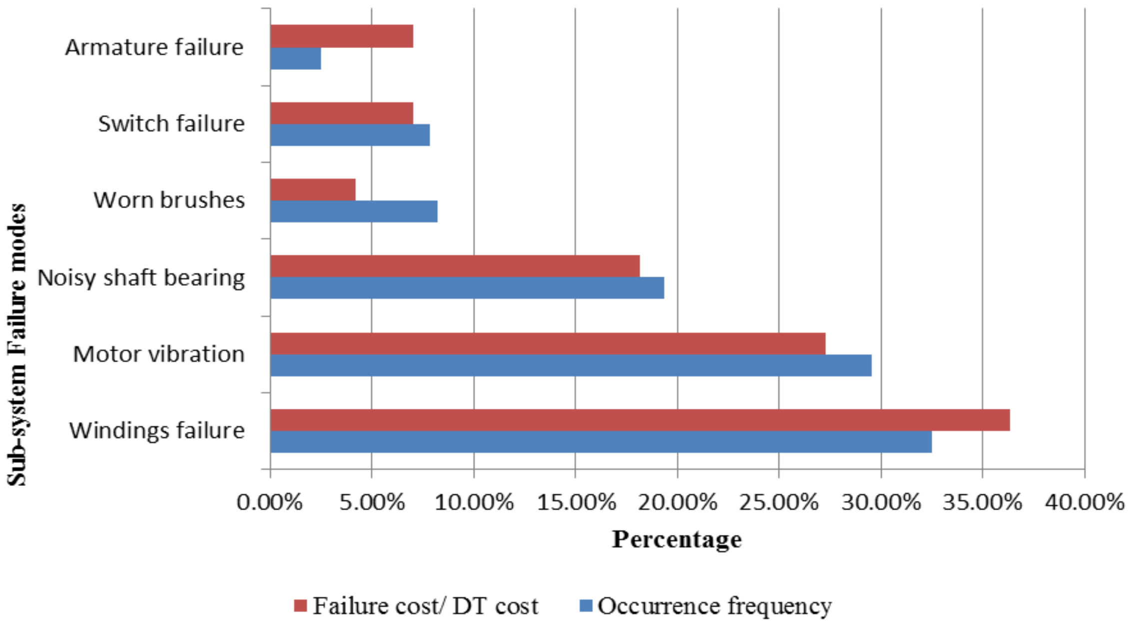

Figure 0.13: *% failure occurrence rate and % down time for DM sub-system failure modes*

From the Pareto chart for DM failure modes (Figure 4.13), motor windings failure was the most critical failure exhibiting a % DT cost of 32.51% of the total failures of the unit translating to DT cost of 1,729 US$ and occurrence rate of 36.36% of the total failure frequency for the unit. Drive motor windings had failed four times out of eleven failures witnessed for the sub-system. This was followed by DM vibration with a % DT cost of 29.56% of the total unit failures, three failures out of eleven failures witnessed, which translates to DT cost of 1,572US$ and % occurrence rate of 27.27% of all the sub-system failures recorded during the period under study. The results from the above Pareto analysis on severity of failure in terms of occurrence rate or failure count, DT and DT cost identified drive motor windings failure as the most critical failure mode for the sub-system.

Although drive motor vibrations exhibited a fairly high failure DT cost, the failure occurrence frequency was not high and the TTR was short and thus this research found it easy to address such a failure resulting from DM vibration. Based on this finding, then it was not considered to be a critical failure mode and thus not recommended for further analysis.

4.1.5 MMP sub-systems critical failure modes identified

From the Pareto analysis of the prioritised MMP sub-systems failure modes, five (5) failure modes from the three (3) prioritised sub-systems emerged to be the most critical failure modes. These included the following failure modes and their corresponding failure DTC;

Table 0.10: *MMP sub-system critical failure modes*

S/No.	MMP Sub-system	Sub-System critical failure modes	DT cost (US$)	% DT cost to the sub-system	% DT cost
1.	Roller mill	Milling surface failure	61,000	60%	43.16%
		RM intense vibration	27,000	26%	19.11%
2.	Degermer	Degerming plates and blades failure	34,005.66	48.97%	24.06%
		Degermer screens failure	17,587.11	25.33%	12.44%
3.	Drive motor	DM windings failure	1,729	32.51%	1.22%

4.1.6 Deductions or Insights derived

From the Pareto analysis done, the results obtained from these three failure parameters, failure occurrence rate, DT and failure DT cost identified the above failures as the most critical failures modes for MMP prioritised sub-systems. The failure effects criticality parameters used in the analysis which included failure occurrence frequency, failure DT and failure DTC explains the sub-systems failures and failure modes criticalities and can be used in other MMP set-ups for sub-systems failures and failure modes prioritization analysis.

Use of FMEA as a tool for reliability analysis for failure identification and prioritization allows milling plants maintenance team analyse sub-system failure risks in terms of failure frequencies, failure DT and failure DT costs associated with the respective failure modes. Further, the most critical sub-system failure modes are identified and isolated based on the risk of failure and thus such failure modes are recommended for further analysis to establish the failure root cause/s (FRCs).

This research approach can be used as a model for failure criticality prioritization in other manufacturing and production industries and thus assist in failure identification and failure cause solutions.

4.1.7 FMEA Pareto summary

From the failure analysis done on the three (3) prioritized milling plant sub-systems, five critical failure modes were identified and prioritized as the most critical failure modes and thus recommended to be subjected to root cause analysis (RCA) for failure root cause identification.

4.2 Root Cause Analysis, (RCA)/ Failure Root Cause Analysis, FRCA

4.2.1 Introduction

Ishikawa diagram, also known as the Cause and Effect diagram or commonly called the Fish bone diagram (FBD) is a graphical tool used for identifying the relationship between a failure mode and the potential failure cause/s in a process, system or a sub-system under study. It is an iterative process and a tool for continuous improvement (CI). Was applied to methodically identify and correct the root causes of events (failures) rather than simply addressing the symptomatic results. The purpose of application of RCA in this research was to identify potential failure root causes of the MMP prioritised sub-system failure modes which forms a key step towards developing an optimal maintenance solution to these failure modes. Since FBD is a qualitative analysis tool, Pareto analysis tool was used to quantitatively analyse the sub-system failure root cause/s frequencies and objectively present the results. To develop the FB diagram, the research analogised milling operation and maintenance engineering team environment and considered all the possible potential failure causes for the prioritised critical sub-system failures and failure modes.

4.2.2 Ishikawa diagram for critical failure modes

The critical failure modes prioritised and recommended for further analysis were subjected to root cause analysis (RCA). The research used a **5Ms** production process potential failure cause parameters model approach (i.e. **5Ms- M**achine, **M**aterials, **M**ethods, **M**easurements and **M**an power). These 5Ms parameters were considered to be affecting production equipment performance directly or indirectly and were considered during development of the FB diagram. The FB diagram was developed taking into account all the **5Ms** production process potential failure cause parameters so as to critically analyse the sub-systems and establish the critical failure modes potential failure causes. As earlier identified, the following MMP critical sub-systems and their corresponding failure modes where considered for RC Analysis.

Table 0.11: *MMP critical sub-system failure modes considered for RCA analysis*

S/No.	MMP Sub-system	Sub-System critical failure modes
1.	Roller mill	Milling surface failure RM intense vibration
2.	Degermer	Degerming plates and blades failure Degermer screens failure
3.	Drive motor	DM windings failure

4.2.3 Ishikawa diagram for RM sub-system milling surface failure mode

The research considered two main units of RM sub-system milling surface failure for root cause analysis. These are the RM unit and the RM unit drive mechanism. These units were considered critical and contributed directly or indirectly to RM milling surface failure mode. The sub-units included; the rolls (brake rolls) and the RM unit drive mechanism which included RM shaft bearings and RM unit drives. FB diagram also known as Ishikawa diagram or cause and effect diagram, Figure 4.14 was developed considering the **5Ms** production process potential failure cause parameters for possible failure cause/s of RM milling surface failure with results of loss of milling process function or poor quality throughput and RM vibration.

It was observed that Roller mills accomplish size reduction through a combination of forces and design features set out in the rolls. If the rolls rotate at the same speed, compression is the primary force used. If the rolls rotate at different speeds, shearing and compression are the primary forces used and if the rolls are grooved, a tearing or grinding component is introduced. The RM milling surface for MMP has suffered high rate of failure (Wearing) due to a number of reasons;

5Ms Production process potential failure cause parameters RC analysis, RCA

i. Machine

It was noted that failure to maintain RM rolls parallelism or rolls tram was the major cause of RM milling surface failure. Again, worn RM shaft bearings, misaligned shaft, shaft end play also made a significant contribution to RM milling surface wearing and failure. Again, when the rolls are not in tram, it was noted that there was a tendency of the material being processed (corn) drifting in the nip of the rolls towards the open ends. The excess materials with time piled up in the nip of the rolls and caused accelerated wear due to slippage. It was also noted that operating the RM when out of tram or parallelism and trying to make fine grind or product caused the close ends of the RM to actually make metal to metal contact thus aggravating the wear.

When RM operated without tram or parallelism, a lot of thrust force was exerted on the rolls and bearings. This force may be high to cause the rolls shift sideways contacting the mill frame and the problem was more magnified if the bearings were replaced as the fit between the shaft and the bearing was not as secure as those originally supplied with the machine by the OEM. Also noted from the study was that failure to 'dimple' the shaft by the set screws or addition of collars between the roll ends and the bearing to restrain the roll from shifting made the condition more worse. Failure to select the right rolls corrugation based on the required final product texture also contributed to unnecessary wearing of the RM surface. It was noted that coarser grooving provided longer life and higher capacities but coarser finished product, finer corrugations provided finer products but reduced capacity and faster wearing. Worn shaft bearing resulting to axial and radial play was also noted to be one of the major causes of RM loosing tram or parallelism and thus triggering increased wearing of the RM milling surface thus requiring re-corrugation or re-fluting.

ii. Material

In this research, material was considered to be the medium used in the manufacture of RM milling surface i.e. material used to do re-fluting or re-corrugation or the medium being processed (corn or maize).

Increased rolls wearing could be caused by metallurgical problems resulting from quality of the engineering material used in design of the RM milling surface or the RM re-fluting profile or wrong design of the RM flutes. It was also noted that uneven corn feeding to the rolls also made a huge contribution to the rate of wearing of the RM. Again instantaneous change of feed rate also contributed to increased rate of wearing of RM. Over size and abrasive materials such as corn cobs and rolling materials that are naturally abrasive or contain high content of abrasive material e.g. stones, metallurgical materials such as nails and other metal pieces etc. made a significant contribution to the rate of wearing of RM sub-system milling surface. It was also noted that grain pile up at the rolls nip when the rolls are not running at full capacity or speed reduced the effectiveness of roll nips pulling the grains into the rolls and thus pile up. This condition caused grain slippage at the roll nip thus causing accelerated wear.

iii. Method

In this category, lack of proper feeding and or poor loading procedures and methods such as Instantaneous feed rate of grains into the RM and grain pile up at rolls nip was one of the main causes of increased RM milling surface wear.

iv. ***Measurements***

Incorrect RM shaft clearance due to wrong bolts torque and rolls gap or clearance was noted to be major cause of increased wearing of RM milling surface. Poor corn moisture content also contributed to processed product pile up in the rolls flutes and nips thus increased slippage resulting to accelerated wear. Lack of modern equipment for setting rolls clearance and alignment together with lack of expertise to set the right clearances was noted to be the major contributor of RM failures under measurements.

v. ***Man power***

Poor workmanship, human errors (decision errors), lack of adequate knowledge and skills was the main cause of RM failures under this category. It emerged that the millers have different levels of education, knowledge, and expertise and exercise different attitude and thus posed a challenge to the milling process.

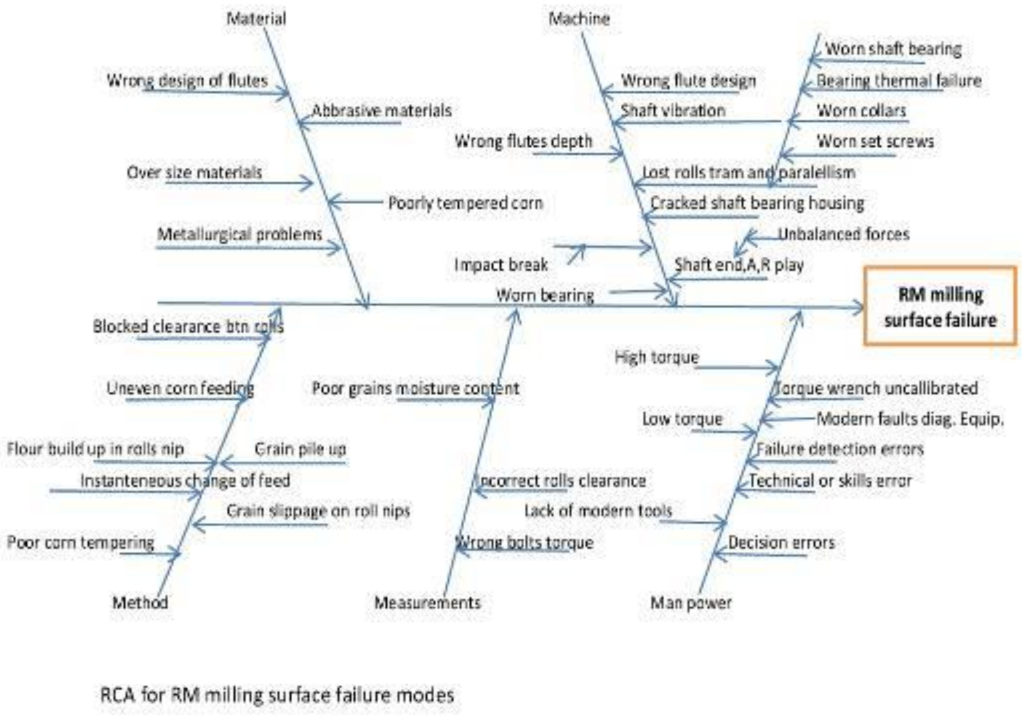

Figure 0.14: *Ishikawa diagram for RM failure mode causes*

4.2.4 Ishikawa diagram for degermer sub-system failure modes

This research established that maize degerminator or degermer utilizes the hitting and cutting between the rotor and the toothed plates and or blades, and the friction and crash between corn kernels, damages the corn endosperm structure, the structural strength of corn germs and the bonding strength between corn endosperm and corn germs so as to realize corn peeling, corn degermination and corn grits production.

Corn flows from the glass cylinder and enters into the space between rotor and toothed plates. Motor drives the rotor spindle. Corns are rubbed and struck to be hulled between rubbing plate and toothed plate and get out through discharge hopper of corn rubbing degermer. The research noted that the degermer sub-system had two critical failures namely wearing or failure of degermer plates and blades and failure of degermer screens due to pitting or clogging. RCA performed on degermer failure modes considered 5Ms manufacturing process potential failure cause parameters, Figure 4.15;

5Ms production process potential failure parameters RC analysis, RCA

i. Machine

The research established that the quality of plates and blades for degermer unit together with the quality of material to be processed highly determined the service life of the degermer plates.

Worn bearings, axial and radial shaft play and end float due to bearing or bushing wearing effect directly contributed to increased degermer unit vibrations.

ii. Material

In this research, material was considered to be the medium (the engineering material, metal quality type) used in the manufacture of degermer plates and blades or the medium being processed.

The possible causes of failure identified in this sub-system included metallurgical problems associated with material used in the manufacture of degermer plates and blades. It came out clearly that the first unit is normally from the OEM which is normally an import as a unit of the equipment, however, after the unit over lives its service life and requires unit replacement, the replacement units are fabricated locally by dealers, in Industrial area, Nairobi who to the view of the researcher, probably are not experts of engineering materials science and do not consider unit field working conditions so as to be able to make right engineering materials choice. The end result becomes sub-standard materials used in the fabrication of degermer plates and blades hence shortened service life.

Over size and abrasive materials such as corn cobs and materials that are naturally abrasive or contain high content of abrasive material e.g. stones, metallurgical materials such as nails, other metallic pieces etc. also made significant contribution to the rate of wearing of degermer sub-system plates and blades. The quality of corn tempering or conditioning was also noted to be another cause of accelerated wearing of degermer units. Poorly tempered or conditioned maize meant high level of abrasion to the plates and blades hence accelerated wearing. The research also established that accelerated wearing was as well caused by corrosion due to the level of acidity of flour.

The major cause of degermer screens failure was identified to be presence of abrasive and hard foreign matter that get their way into the milling production line e.g. stones, large sized maize cobs, metal pieces (example nails) and as well the rate of failure was accelerated by corrosion due to level of acidity of the processed or degermed material.

iii. Measurements

Excessive degermer shaft play or clearance due to inappropriate bolt torque was noted to be the major cause of increased wearing. The rotor developed a tendency of making slight unnoticeable contact with the housing thus aggravating the wearing. High moisture content also contributed to processed product pile up in the degermer plates and blades resulting to accelerated wear.

Lack of modern equipment for setting right shaft bolts torque, maize natural moisture content and quality of tempering or conditioning coupled with lack of adequate expertise was also noted to be another contributor of degermer failures.

iv. Man power

Poor workmanship, human errors, lack of adequate knowledge and expertise was the major trigger of failures experienced in degermer sub-system. It was observed that the millers had different levels of knowledge, skills and expertise due to different levels of both academic and professional training and thus this was a challenge to the milling process efficiency.

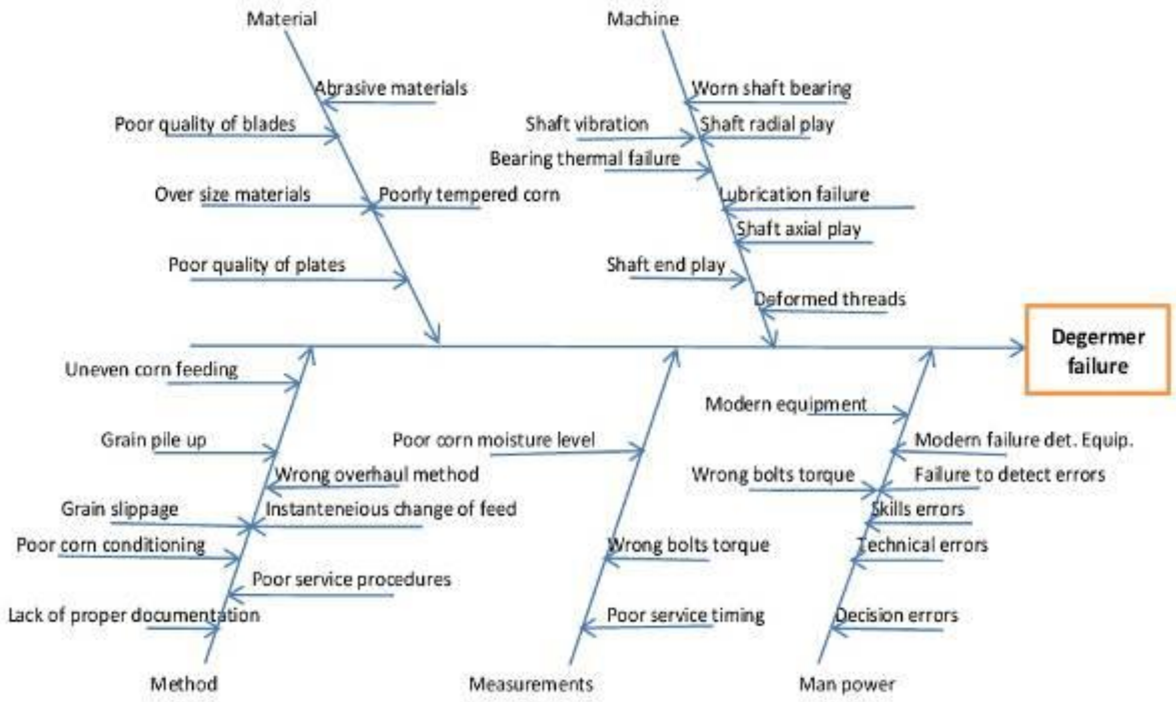

Figure 0.15 : *Ishikawa diagram for degermer sub-system failure mode causes*

4.2.5 Ishikawa diagram for drive motor (DM) windings failure mode

Ishikawa diagram, Figure 4.16 was drawn for possible failure causes of drive motor sub- system. The main failure causes of DM were identified as DM winding failure, DM vibration and DM shaft bearing failure. However, DM winding failure was noted to be the most critical failure of the three failures considered due to the level of failure criticality in terms of DT and the corresponding DT cost.

RCA performed on DM failure modes considered 5M's for RC analysis.

5Ms production process potential failure parameters RC analysis, RCA

i. Machine

The major cause of DM winding failure was noted to be low resistance or low insulation resistance. In the initial stage of DM installation, the insulation resistance is set to be more than one thousand mega ohms (1,000Mohms), however, it was noted that after some time of DM service, the insulation performance started to degrade as the resistance starts to decay gradually. The research also established that decay of insulation was accelerated by overheating of the DM caused by high operating temperature environment. The major contributor to high temperature environment for the

DM was basically due to inefficient DM cooling system due to dust and dirt accumulation blocking cooling fan, heater matrix and insulating the heat sink. Dust and dirt accumulation that settled on the motor winding affected the insulation value thus resulting to rise in motor winding temperature and this contributing directly to insulation decay.

ii. Material

The main cause under this category that was identified to have caused winding failure was metallurgical in nature since at design stage, in view of this research, the OEM didn't factor in or consider the element of gradual decay caused by environmental and field operating conditions. Again, moisture content was noted to greatly affect DM condition due to corrosion noticed on motor shaft, bearings and the rotor in entirety. It also emerged that insulation performance was greatly affected by high moisture (humidity) levels.

iii. Method

In this category, lack of proper procedures to monitor DM operating conditions was noted to be the main cause of DM winding failure. The research established that there was no documentation on proper WP and to monitor and test insulation performance. Again, it emerged that the firm didn't invest in procuring SST for DM test and analysis kit, example, there was no winding resistance test analysis kit for DM tests and there were no proper mechanisms to prevent dust and dirt accumulation on DM windings, cooling fan, heater matrix or heat sink provided in the system to dissipate excess heat.

iv. Measurements

Under this category, it was noted that, DM winding failure was basically caused by failure to monitor DM winding conditions and carry out periodic winding resistance test analysis.

Again, motor vibration which emerged to be second most critical failure was attributed to by misaligned shaft and or excess shaft or bearing clearance emanating from wrong bolts torque thus resulting to radial play during operation (the DM are constant speed types). It came out that there were no proper records for torque values (service manuals) when fixing DM bolts and lack of SST, example torque wrench to give bolts the right torque.

v. Man power

Poor workmanship, lack of proper work procedures, human errors and lack of adequate technical knowledge and skills came out under this category to be the major failure contributors. This was supported by the fact that when failure/s occurred, shift millers who doubled as maintenance technicians would be used for plant maintenance without the right adequate technical skills and right tools for the maintenance tasks.

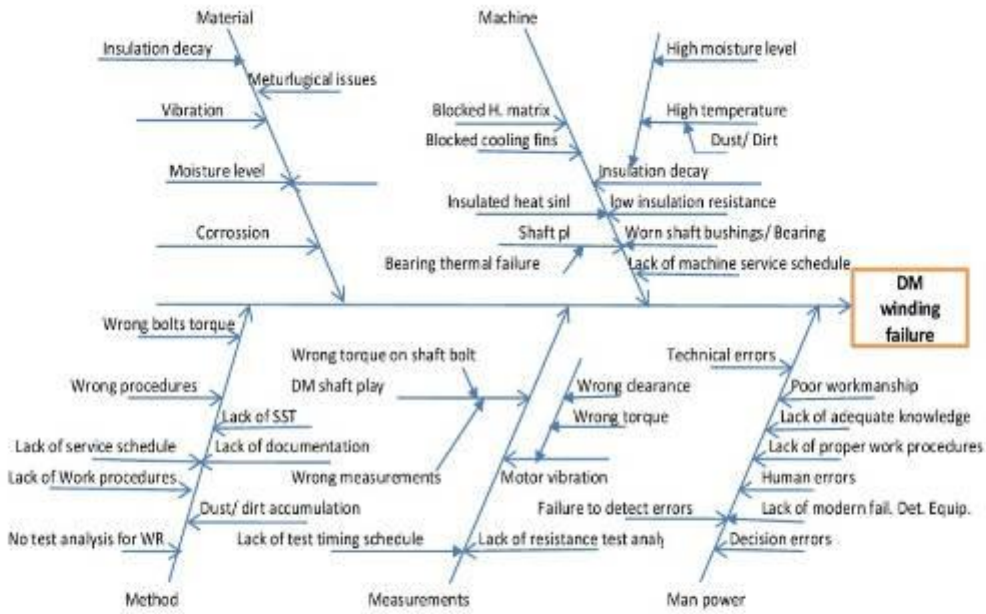

Figure 0.16: *Ishikawa diagram for DM sub-system failure mode causes*

4.2.6 Pareto analysis for MMP critical sub-systems failure root causes (P_AFRCs)

In this section, the research considered all the failure root causes for the three identified or prioritised sub-systems (RM, Degermer and DM) critical failure modes. Pareto analysis was then done to quantitatively prioritise critical failure RCs for the identified failure modes. The analysis was done considering the available MMP failure cause data (primary and secondary data) together with the failure cause/s count or frequency recorded for the failure modes under study.

FRCs Pareto analysis quantitative results for the prioritised milling plant sub-systems are presented as below.

a. Roller mill FRCs Pareto analysis

RM had two critical failure modes, milling surface failure and RM intense vibration. FRCs Pareto analysis was done for each of the two identified RM failure modes to establish the most critical potential failure root cause/s for the sub-system.

Pareto analysis was used to quantitatively analyse the collected field operating failure frequency data and presented the following results, (fig. 4.17 and 4.18);

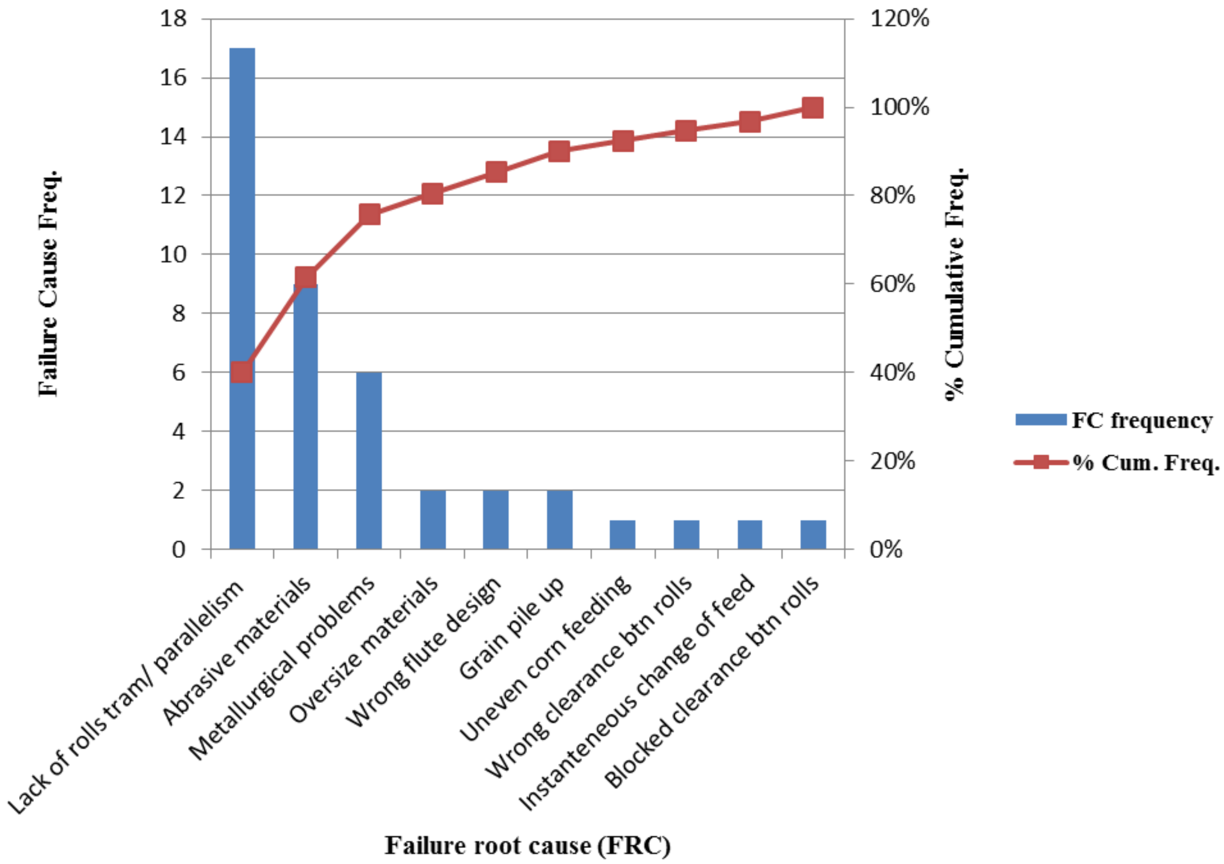

Figure 0.17 : *Pareto analysis for RM milling surface Failure Root Causes*

From fig. 4.17, Lack of rolls tram and or parallelism on RM (rolls) was identified to be the main root cause of milling surface failure among other causes contributing 40% of the failure root causes recorded for the sub-system failure mode. This was followed by FC due to Abrasive materials and metallurgical related problems with % FC of 21.43% and 14.29% respectively. Uneven corn feeding, wrong rolls clearance, instantaneous change of feed and blocked clearance between rolls made the least FC contribution each recorded as 2.38%.

From the Pareto analysis for RMM surface FRCs, it was noted that most of these FC were interrelated and thus addressing one FC consequently indirectly addressed another, example; Addressing the main FRC of roller mill lack of tram and or parallelism automatically addressed another FCs, (example; grains pile up, blocked clearance between rolls).

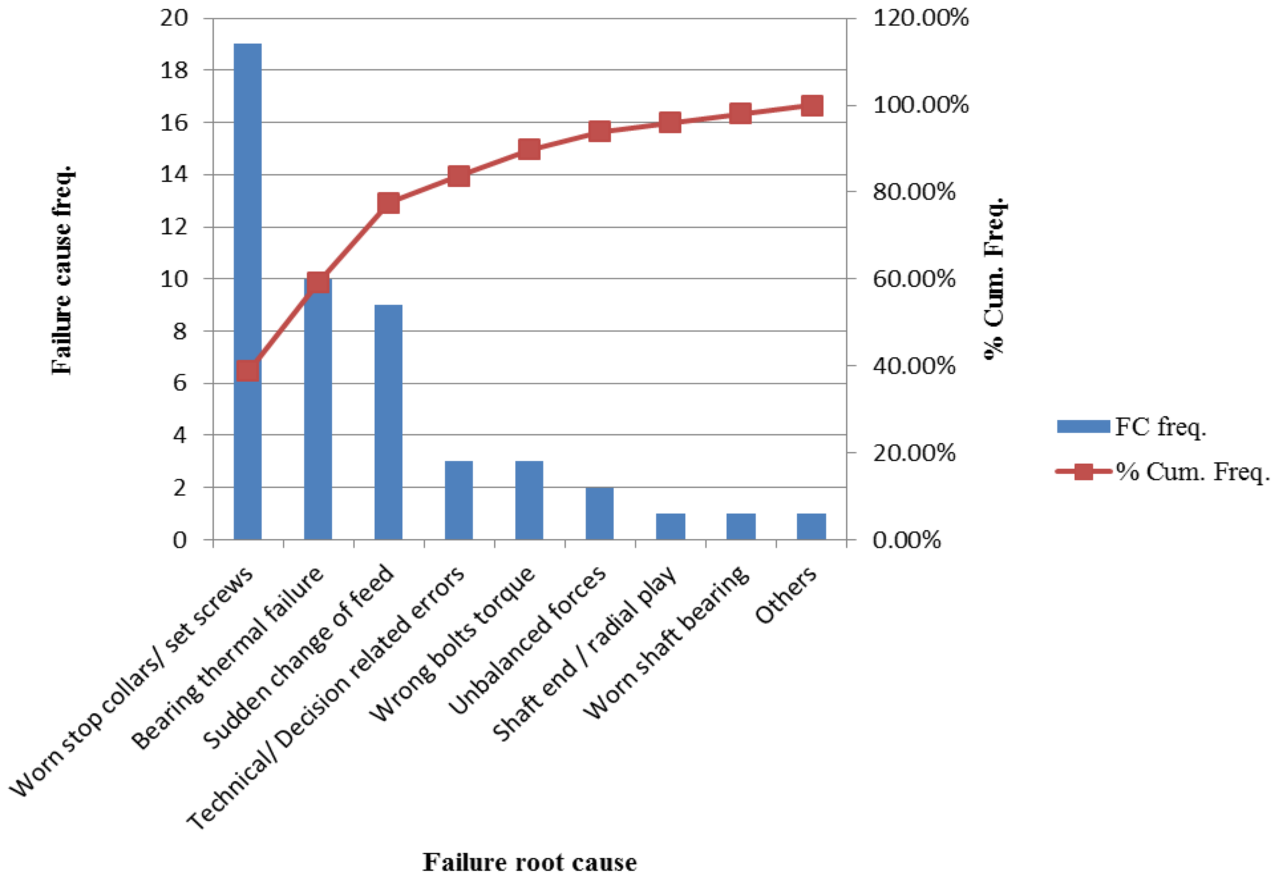

Figure 0.18: *Pareto analysis for RM Vibration Root Causes*

From fig. 4.18, Worn stop collars and set screws were identified as the main FC of RM vibration contributing 38.78% of the total sub-system FRCs. Bearing thermal failure and sudden change of feed were the second critical FCs with 20.41% and 18.37% of the total FCs respectively. Worn shaft bearing and shaft end/ radial play made the least contribution to FCs, each registering 2.04% of the total FRCs.

b. Degermer FRCs Pareto analysis

The degermer sub-system again had two critical failure modes, failure of degerming plates and blades and degermer screens failure. FRCs Pareto analysis was done for each of the two failure modes to identify the most critical potential failure root causes.

This analysis was done by quantitatively evaluating the collected field operating failure frequency data and the results are graphically presented in figures 4.19 and 4.20.

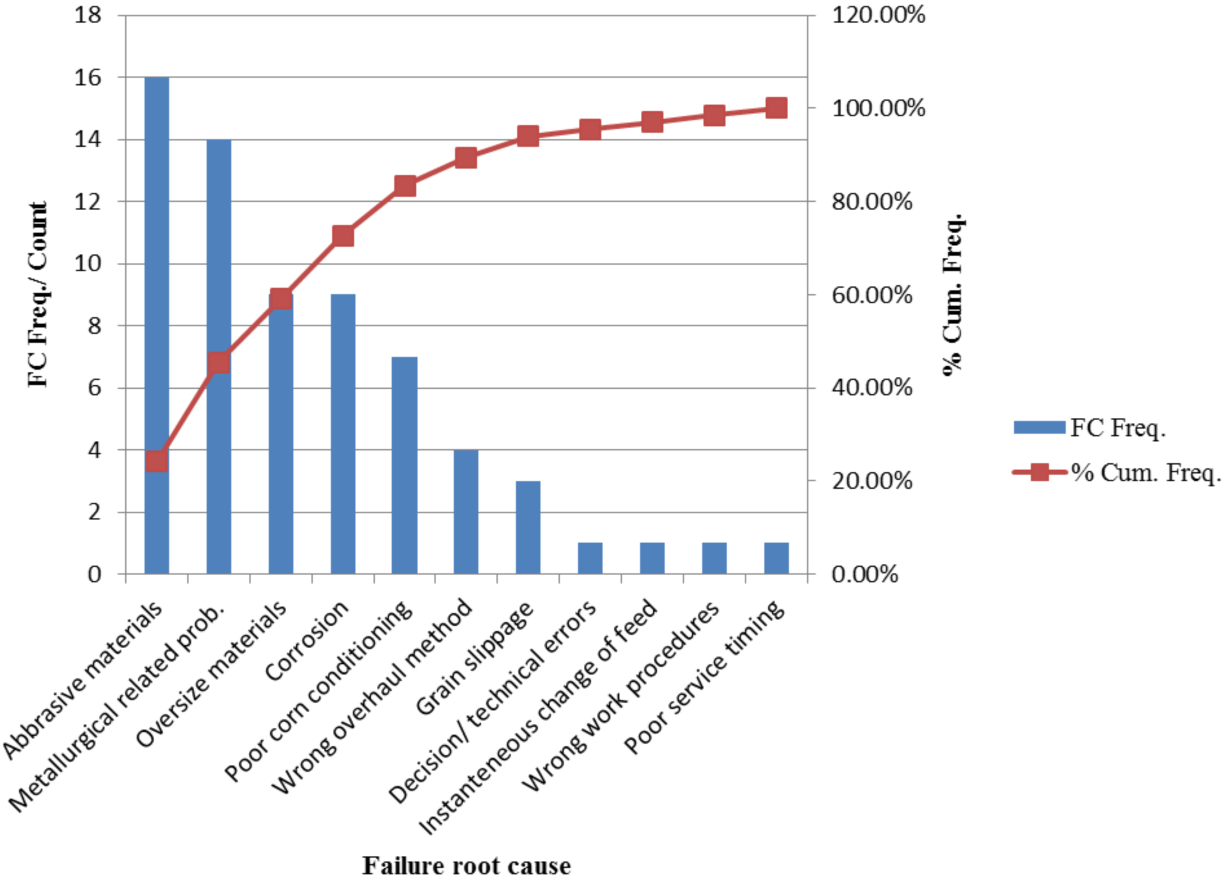

Figure 0.19 : *Pareto analysis for Degermer plates and blades Failure Root Causes*

From fig. 4.19, abrasive materials were the most critical FRCs for this sub-system registering 24.24% of the total sub-system FRCs. This was followed by metallurgical related problems, over size materials and corossion with % FRC contributions of 21.21%, 13.64% and 13.64% respectively of the total unit FRCs.

The least FRCs for degermer plates were instanteneous change of feed, wrong work procedures and poor service timing which registered 1.52% each of the total FC witnessed.

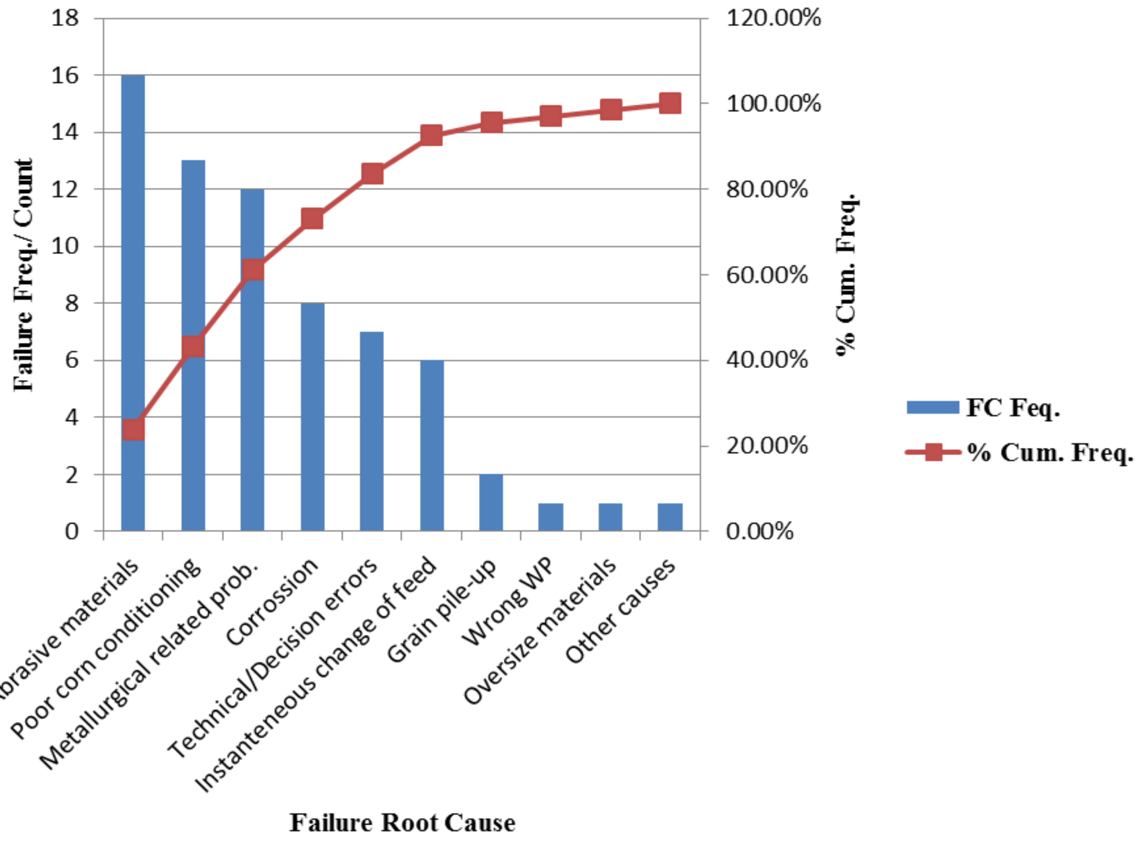

Figure 0.20: *Pareto analysis for Degermer Screens Failure Root Causes*

From fig. 4.20, abrasive materials were identified to be the most critical FRCs for degermer screens registering 23.88% of the total FRCs. Poor corn conditioning, metallurgical related problems and corrosion followed with 19.40%, 17.91% and 11.94% respectively. Grain pile-up, wrong WP and over-size materials came last in the list contributing only 1.49% of all the FRCs recorded for DS over the period of study.

Abrasive materials and metallurgical related problems were noted to be common FRCs for the two sub-system failure modes.

c. *Drive motor FRCs Pareto analysis*

Winding failure for DM sub-system was considered to be the most critical failure mode. Pareto FRC analysis was done for this failure mode to identify the potential failure root causes. The results are presented in figure 4.21.

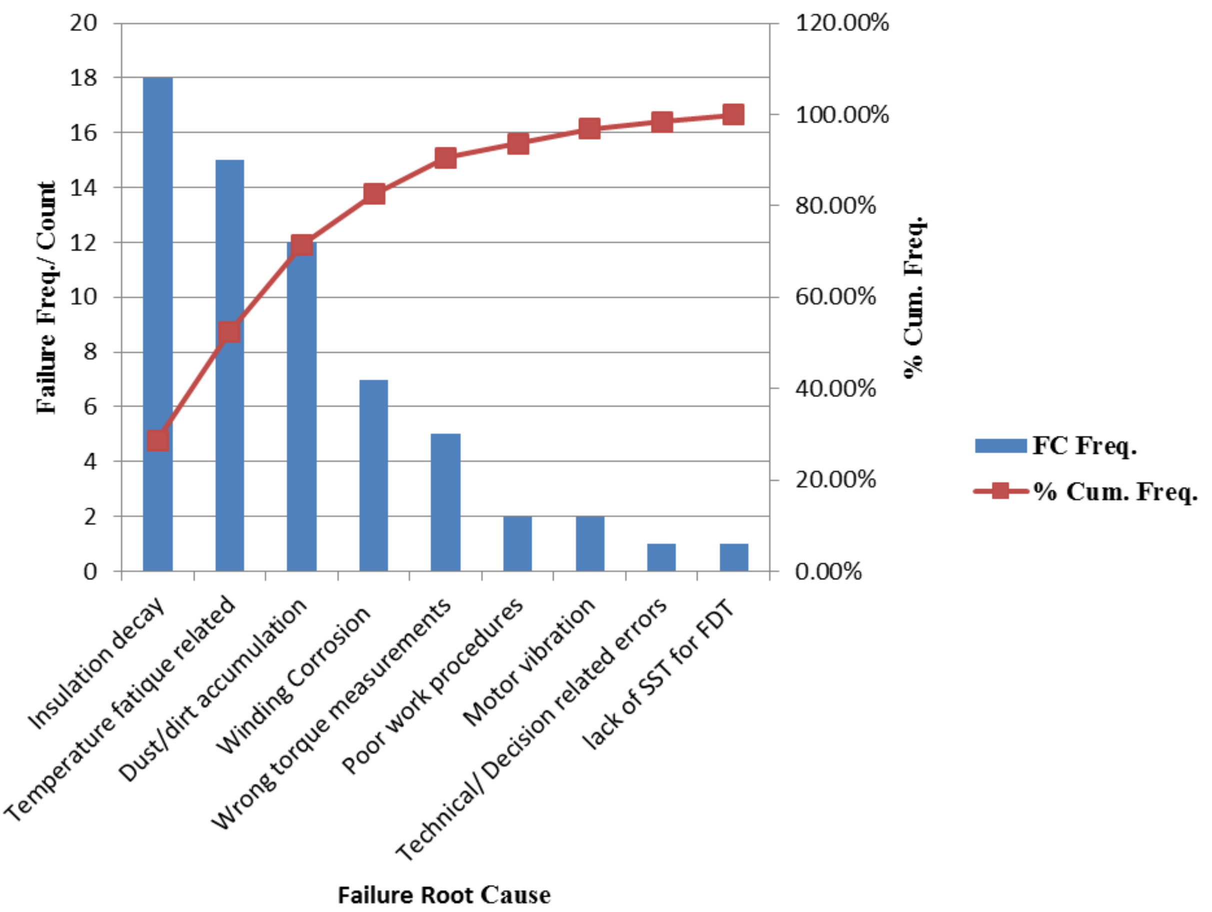

Figure 0.21: *Pareto analysis for DM Winding Failure Root Causes*

Fig. 4.21 shows DM winding FRCs. From the Pareto analysis, insulation decay was noted to be the most critical failure cause for DM winding failure with % FC of 28.57% of the total DM FRCs identified. This was followed by temperature fatique related problems, dust or dirt accumulation and winding corrosion at 23.81%, 19.05% and 11.11% respectively.

Poor work procedures, motor vibration, technical and decision related errors and lack of SST for drive motor FDT made the least contribution to FCs registering 3.17%, 3.17%, 1.59% and 1.59% respectively.

4.2.7 Deductions from Pareto analysis on Failure modes and Failure RCs

Deductions made from the Pareto analysis on the failure modes and their associated potential FRCs for the prioritised MMP critical sub-systems failure modes are as summarised in Table 4.12.

Table 0.12: *Summary of Pareto analysis for failure modes and potential failure RCs*

S/No.	MMP Sub-systems	Sub-System critical failure modes	Potential Failure Root Cause/s
1.	Roller mill	Milling surface failure	1. Lack of rolls tram/ parallelism 2. Abrasive materials 3. Metallurgical related problems
		RM vibration	1. Worn stop collars/ set screws 2. Bearing thermal failure 3. Sudden change of feed
2.	Degermer	Degermer plates and blades failure	1. Abrasive materials 2. Metallurgical related problems 3. Oversize materials
		Degermer screens failure	1. Abrasive materials 2. Poor corn conditioning 3. Metallurgical related problems
3.	Drive motor	DM windings failure	1. Insulation decay 2. Temperature fatique related 3. Dust/ dirt accumulation

The research also established that every critical failure mode identified had its failure effect to the milling plant production process. This is as summarised in Table 4.13;

Table 0.13: *Summary of failure mode, FC and failure effect on production process*

Failure Mode	***Failure Root Cause***	***Production process failure effect***
Milling surface failure	Lack of rolls tram/ parallelism	Processed material drifts to the open ends
		Processed material pile-up on rolls nip
		Poor quality throughput
		Out of balance thrust forces exerted on rolls and rolls bearing
	Abrasive materials	Mechanical effect (wearing) on rolls corrugation
		Poor quality throughput
		Inability of rolls to pull material being processed into the rolls
		Increased/ reduced throughput
	Metallurgical related problems	Accelerated wearing (Reduced service life and increased DT)
		Poor quality throughput
		Reduced TBF
		DT effect during time of re-corrugation or replacement
RM vibration	Worn stop collars/ set screws	RM shaft axial/ end play
	Bearing thermal failure	RM shaft radial play
		RM shaft vibration
		Reduced throughput
		Effect on roll adjustment units
	Sudden change of feed	Sudden load to rolls drive mechanism
		Processed material pile-up on rolls nip
		Reduced throughput
Degermer plates and blades failure	Abrasive materials	Mechanical effect (wearing) on plates and blades
		Poorly degermed corn
		Poor quality throughput
	Metallurgical related problems	Accelerated plates and blades wearing
		Poor quality throughput
		Reduced TBF
		DT effect during time of plates and blades replacement
	Over-size materials	Increased abrasion on plates and blades
		Accelerated plates and blades wearing
		Effect to rolls adjustment unit
Degermer screens failure	Abrasive materials	Mechanical effect (wearing) on screens due to excessive abrasion
		Poor quality throughput
		Reduced TBF
DM winding failure	Temperature fatique	Insulation decay
		Current leakage
		Winding Short circuiting
		Poor/ reduced cooling
	Dust/ dirt accumulation	Insulation decay

4.2.8 Discussion of results from Pareto analysis on Failure Modes and Failure RCs

Considering analysis done using Pareto, cause and effect diagram (or FBD) and 5Ms production process control parameters, most of the FCs for the sub-systems are interrelated in terms of causal factors. This means that a remedy for one failure cause translates to remedy of another failure cause.

From Pareto analysis of FRCs, It is observed that the main failure cause for RM milling surface failure was the inability to maintain rolls tram or parallelism. This fault was caused by lack of special service tools, (SST) for precision setting of the rolls clearance and lack of torque wrench for setting of bolts torque while fixing RM on the table. It was noted that when the rolls are not in tram or parallel, the material being processed "drifts" to the nip of the rolls towards the open end(s). This excess material over time begins to "pile up" in the nip of the rolls and caused accelerated wearing.

Failure to detect this accumulation on the rolls nip again slowly affected the quality of throughput. The research established that operating out of tram or parallelism and trying to make a fine grind or thin flakes caused the close ends of the rolls to actually make metal to metal contact, thus accelerating the rate of wearing. Abrasive material was noted to be another common critical FC for RM milling surface failure, degermer plates and blades failure and degermer screens. It also emerged that abrasive material came first as the main FC for degermer plates and blades and degermer screens with % failure rate of 24.24% and 23.88% respectively.

For RM milling surface failure, abrasive material came second after rolls tram and parallelism with FC contribution of 21.43%. Metallurgical related problems emerged also to be another critical FC for the prioritized MMP sub-systems under study. It came out to be the second failure contributor for degermer plates and blades with % FC of 21.21%, and third FC for degermer screen and RM milling surface failure with % FC of 17.91% and 14.29% respectively. The research also identified other FCs that appeared common for degermer plates and blades failures, RM milling surface failure, degermer screens failure were also affected by oversize materials, grain pile-up, technical and decision related errors, instantaneous change of feed and wrong WPs, which made FC contribution of between 7% to 19% of all the respective FRCs witnessed. Most of these failure causes are related and thus addressing a FC on one sub-system will ultimately address the same or another FRC on another sub-system.

Under the cause and effect analysis, insulation decay, temperature fatique and dirt or dust accumulation were identified to be the most critical FC for DM winding failure with FC contribution of 28.51%, 23.81% and 19.05% respectively. Again, considering RCA and FB diagram, lack of proper maintenance documentation, poor service timing or schedule, lack of modern SST for maintenance action and FDT also emerged to be a common FC for MPP equipment under study.

4.3 Survey results and discussions

4.3.1 Introduction

This section gives analysis of survey results and interpretations from the milling plant visited during this research work. The survey tool used in the research was aimed at establishing the type of maintenance policy and practices used in corn milling plants, the level of maintenance optimization and milling plant equipment utilization (availability and reliability levels). The data collected was analysed and presented in form of frequency tables and descriptive statistics in tabular form.

4.3.2 Response rate

A total of 55 questionnaires were given out and administered to a total of 67 workers from the milling firm, out of which, 42 questionnaires were returned. This represented a response rate of 76.36%. Out of the 42 questionnaires, 4 had some question items not responded to and thus, were declared incomplete and invalid and not considered during analysis. A total of 38 questionnaires were thus complete and considered validly filled for analysis.

4.3.3 Survey results analysis

The research sought to establish the level of education of the respondents. It was noted that 11 (28.95%) had KCSE certificates only, 15 (39.47%) had certificate level trainings in different fields, 8 (21.05%) had diploma level trainings also in different fields, 3 (7.89%) had degree certificates and only 1(2.63%) was pursuing postgraduate training. Table 4.14 gives the analysis.

Table 0.14: *Summary of academic qualifications of the milling plant respondents*

	Academic Qualifications			
	Level of education			
		Frequency	%	% Cum.
Level	Masters (On-going)	1	2.63	2.63
	Bachelor’s degree	3	7.89	10.52
	Diploma certificate	8	21.05	31.57
	Craft/ grade test certificate	15	39.47	71.04
	KCSE	11	28.95	100
	Total	**38**	**100**	

It is seen in Table 4.14 that 71.04% of the respondents had at least a professional training and this is an indicator of good survey results from the respondents. The research sought to establish the period of service of the respondents in the milling industry. This was important since the subject under study required that the respondents be relatively familiar with the maintenance management in milling industry. Table 4.15 gives the summary.

Table 0.15: *Respondents years of experience in milling industry*

Duration in years working with milling organization

	No. of yrs	**Frequency**	**%**	**Cumulative %**
Valid	Less than 1yr	4	10.53	10.53
	1-3 yrs	18	47.37	57.90
	4-6 yrs	15	39.47	97.37
	More than 6 yrs	1	2.63	100.00
	Total	**38**	**100**	

It is seen that 4 respondents (10.53%) had served for less than 1 year, 18 respondents (47.37%) had served between 1 and 3 years, 15 (39.47%) had served between 4 and 6 years and 1 (2.63%) had more than 6 years working experience in milling plants. Overall, the results showed that 89.47% of the respondents had served for at least one year in the organization. This meant that the responses obtained from the respondents were valid since they were drawn based on experience and informed decisions of the respondents in the milling industry.

The research sought again to establish the existing maintenance policy used in corn milling industry (Table 4.16). From the respondents, 23 (60.53%) indicated that FBM was the most commonly used maintenance policy employed to address critical milling plant sub-system failures. 8 (21.05%) indicated use of TBM/ UBM, 5 (13.16%) indicated application of CBM whereas 1 (2.63%) indicated use of either OBM or DOM policies.

Table 0.16: *Maintenance policies used to solve milling plant critical sub-system failures*

Maintenance policy used in milling plant critical failure modes	Frequency	Percentage	Cumulative %
FBM	23	60.53	60.53
TBM/ UBM	8	21.05	81.58
CBM	5	13.16	94.74
OBM	1	2.63	97.37
DOM	1	2.63	100
Total	**38**	**100**	

It was seen that milling plant critical equipment which required close condition monitoring were run to failure (RTF) and thus FBM was the commonly used maintenance policy to address the failure occurrence crisis. This was noted at 60.53% from the respondents and this is what occasioned the frequent and prolonged down times (extended TTR). It emerged that predictive maintenance measures were not in place to predict potential failures and address them before occurrence. The research established that the organization lacked condition monitoring techniques and or expertise and tools/ equipment that could predict potential failures and address them before occurrence. The research also revealed that there were no proper work procedures and critical sub-system maintenance or service schedules that could be used by the maintenance team to address future failures.

The research again sought to establish the level of application of job cards in maintenance operations (Table 4.17). From the respondents, it came out that 13 (34.21%) indicated that job cards were not used in maintenance operations, 7 (18.42%) indicated that job cards were used but on case to case basis, 1 (2.63%) stated that job cards were generated for every maintenance activity and 15 (39.47%) indicated that job cards were rarely used with 2 (5.26%) indicating use of job cards only on milling plant critical failures.

Table 0.17: *Level of application of job cards in corn milling industry.*

Use of job cards in maintenance operations	Frequency	Percentage	Cumulative %
Not used	13	34.21	34.21
Used on case to case basis	7	18.42	52.63
Generated for every maintenance activity	1	2.63	55.26
Rarely used	15	39.47	94.73
Used only on critical failures	2	5.26	100.00
Total	**38**	**100**	

From the analysis on Table 4.17, it was noted that job cards were not properly being utilized in the milling industry. The management of the organization was not concerned with application of job cards during maintenance activities. This implied that the organization was not keen on time taken to perform a specific maintenance activity and comparison made to the standard operating procedures for such a maintenance activity and the materials (spare parts) used. This was evident from poor maintenance records witnessed during time of data collection.

Again the research sought to establish the key objectives pursued by maintenance function in the corn milling industry. This was necessary since the research wanted to establish the level of attention and support milling firms attached to the maintenance function. The results are given in Table 4.18;

Table 0.18: *Key objective pursued by maintenance function in corn milling industry*

Key objectives pursued by maintenance function in corn milling industry	Frequency	Percentage	Cumulative %
Equipment availability	7	18.42	28.95
Staff and equipment safety	2	5.26	34.21
Cost effectiveness	6	15.79	50.00
Production targets	12	31.58	81.58
Product quality	11	28.95	100.00
Total	**38**	**100**	

From the survey results, it emerged that **maintenance management** was just but another **secondary function** in the milling organization. From the survey analysis, it was noted that the key objective pursued by maintenance in corn milling industry was to meet production targets at 12 (31.58%) of the respondents. This was followed by product quality at 11 (28.95%), equipment availability came third with only 7 (18.42%), cost effectiveness at 6 (15.79%) and lastly staff and equipment safety at 2 (5.26%).

This implied that lack of adequate attention and support to milling plant maintenance management to ensure equipment availability is what triggered milling plant sub-system frequent failures and thus leading to plant shut downs.

Again, the research wanted to establish the main causes of production process delays in corn milling industry. The results are as in Table 4.19

Table 0.19: *Main cause of production process delays in corn milling industry*

Causes of prolonged Production process delays	Frequency	Percentage	Cumulative %
Unplanned down time or equipment failure	18	47.37	47.37
Set ups or adjustments	5	13.16	60.53
Parts change	1	2.63	63.16
Loading or start-ups	1	2.63	65.79
Minor stoppages	9	23.68	89.47
Reduced speed or cycle time	4	10.53	100.00
Total	**38**	**100**	

The results indicated that, unplanned down time or equipment failure was the main cause of prolonged production process delays. This was as indicated by the respondents at 18 (47.37%) of the total causes. This was followed by minor stoppages at 9 (23.68%), then set-ups or adjustments at 5 (13.16%). This implied that there was a need to institute mechanisms that could control or minimize unplanned down times in corn milling plants. Production delays caused by parts change, loading and reduced speed or cycle time were negligible and thus not significant for consideration.

The research again sought to establish when milling plant sub-systems are serviced, repaired and or overhauled and what triggers these maintenance actions.

The results are given in Table 4.20.

Table 0.20: *When are Milling plant equipment serviced and or overhauled and what triggers these maintenance actions.*

	Frequency	Percentage	Cumulative %
Upon failure (Case to case basis)	17	44.74	44.74
According to OEMs specifications	2	5.26	50.00
As a production strategy to meet production targets	16	42.11	92.11
Due to reduced equipment efficiency	3	7.89	100.00
Total	**38**	**100**	

From the results, it was noted that milling plant sub- systems maintenance actions were mostly triggered by failure with a survey response rate of 17 (44.74 %) of the total causes. This was followed by a production strategy to meet production targets and reduced equipment efficiency at 3 (7.89%) and 2 (5.26%) respectively.

To establish the level of milling plant equipment utilization, personnel competence and whether there were training and skills gaps in handling the maintenance function, the research used a 5-point Likert scale of “strongly disagree” to “strongly agree” and the respondents were to respond to the question items in the questionnaire.

The research wanted to establish whether there is a well- trained maintenance team in the organization to handle maintenance activities. The results from the respondents are given in Table 4.21;

Table 0.21: *There is a well-trained maintenance team in the organization to handle maintenance activities.*

		Frequency	Percentage		Cumulative %
Valid	**Strongly disagree**	7	18.42		18.42
	Disagree	14	36.84	55.26	55.26
	Nor agree nor disagree	1	2.63	2.63	57.89
	Agree	10	26.32		84.21
	Strongly agree	6	15.79	42.11	100.00
	Total	**38**	**100**		

The findings showed that 55.26% of the respondents disagreed with the fact that the organization had well trained maintenance team to handle maintenance activities. They expressed dissatisfaction with the competence of the personnel that handles maintenance. This was attributed to the fact that there was no maintenance team dedicated purposely to handle maintenance activities but production line millers doubled as maintenance officers. Only 42.11% of the respondents agreeing with the fact that the organization has well-trained maintenance team to handle maintenance activities with 2.63% of the respondents remaining neutral on the issue.

This implied that establishment of maintenance department headed and composed of competent personnel was necessary to handle maintenance function of milling plant equipment and address the sub-systems failure occurrences.

The research again sought to establish whether the industry performs adequate regular equipment checks and inspections to identify potential failures.

From Table 4.22, the results showed that 52.63% of the respondents felt that the industry was not conducting adequate regular equipment inspections to identify potential failures. 36.84% said that regular equipment inspections are done to identify potential failures and 10.53% didn't agree nor disagree. This implied that potential failures couldn't be noted and maintenance action instituted on time. The results agreed with earlier finding that FBM was commonly used to address most milling plant failures due to lack of failure prediction and detection techniques that could detect and identify potential failures before failure occurrence. CBM policy was not used. Regular equipment inspections are very vital since they identify potential failures and inform maintenance department when to institute maintenance control measures before failure occurrence.

Table 0.22: *The industry performs adequate regular equipment inspections to identify potential failures.*

		Frequency	Percentage		Cumulative %
Valid	**Strongly disagree**	9	23.68		23.68
	Disagree	11	28.95	52.63	52.63
	Nor agree nor disagree	4	10.53	10.53	63.16
	Agree	8	21.05		84.21
	Strongly agree	6	15.79	36.84	100.00
	Total	**38**	**100**		

The results indicated that 52.63% of the respondents felt that the industry was not conducting adequate regular equipment inspections to identify potential failures. 36.84% said that regular equipment inspections are done to identify potential failures. 10.53% didn't agree nor disagree. This implied that potential failures could not be detected on time and maintenance action and or policies instituted on time. The results agreed with finding that FBM policy was the commonly used MP to address most milling plant failures due to failure to institute early potential failure prediction and detection methods. CBM policy was not considered for application. Regular equipment checks and inspection for condition monitoring and potential failure detection are very vital since they identify potential failures and address them before occurrence.

Again, the research sought to establish whether the industry had adequate modern technology for equipment potential failure and failure diagnosis. The results showed that more than 50% of the respondents (65.79%) said that the industry had no adequate modern technology for equipment condition monitoring and failure diagnosis. 31.58% agreed that the industry had adequate technology for equipment condition monitoring and failure diagnosis, whereas 2.63% remained neutral on the issue.

This implied that the industry was least applying or not using modern technology (tools and techniques) for critical sub-system condition monitoring for potential failure detection and thus the maintenance team was unable to diagnose potential failures before occurrence. The need for condition monitoring for failure prediction is that CBM policy can be used to prevent or minimize potential failures before occurrence. The results are shown in Table 4.23.

Table 0.23: *There is adequate modern technology for equipment condition monitoring and failure diagnosis.*

		Frequency	Percentage		Cumulative %
	Strongly disagree	6	15.79		15.79
	Disagree	19	50.00	65.79	65.79
Valid	**Nor agree nor disagree**	1	2.63	2.63	68.42
	Agree	7	18.42		86.84
	Strongly agree	5	13.16	31.58	100.00
	Total	**38**	**100**		

The research again wanted to establish whether the maintenance team was adequately trained on failure detection and use of modern failure detection and diagnostic equipment. The results are as given in Table 4.24;

Table 0.24: *There is adequately trained maintenance team on failure detection and use of modern failure detection and diagnosis equipment.*

		Frequency	Percentage		Cumulative %
	Strongly disagree	7	18.42		18.42
	Disagree	18	47.37	65.79	65.79
Valid	**Nor agree nor disagree**	2	5.26	5.26	71.05
	Agree	6	15.79		86.84
	Strongly agree	5	13.16	28.95	100.00
	Total	**38**	**100**		

The results from the respondents, Table 4.24 showed 25 of the respondents translating to 65.79% didn’t agree with the idea that the milling plant had adequately trained maintenance team on failure detection and use of modern failure detection and diagnostic equipment. 28.95% agreed with the statement while 5.26% remained neutral on the issue.

This implied that combination of lack of modern equipment for condition monitoring and lack of adequately trained maintenance team on failure detection and use of modern failure detection and diagnosis equipment (Table 4.24) led to inability to predict potential failures on time and thus this contributed to the run to fail condition as commonly witnessed. The run to fail condition resulted to application of FBM policy as the only maintenance policy applicable to address most sub-system failures. This meant that there was a need to train the maintenance team on failure detection methods and use of modern failure detection and diagnosis equipment.

The research again wanted to establish whether the organization records and maintains an updated maintenance record and service schedules. The results are as shown in table 4.25 below;

Table 0.25: *The organization records and maintains updated maintenance records and service schedule.*

		Frequency	Percentage		Cumulative %
	Strongly disagree	4	10.53		10.53
	Disagree	14	36.84	47.37	47.37
Valid	**Nor agree nor disagree**	6	15.79	15.79	63.16
	Agree	10	26.32		89.48
	Strongly agree	4	10.53	36.85	100.00
	Total	**38**	**100**		

Results from the respondents, (Table 4.25) shows that 47.37% of the respondents did not agree with the idea that the organization records, updates its maintenance records and follows service schedules. 36.85% indicated that updated records are available with 15.79% being uncertain and remaining neutral on this issue.

This again agreed with what the research experienced during time of data collection where the records available were not up to date and poorly organised and took the researcher a lot of time piecing the data together. This implied that the organization was not keen on updating maintenance records and again not strict on milling plant sub-system service schedules. Failure to develop, maintain and update maintenance records and service schedules was a recipe for unplanned failures or downtimes due to poor maintenance timings.

The research also sought to establish whether the top management of milling industries valued maintenance as one of the very key functions towards achieving milling plant production targets. The results from the respondents are shown in Table 4.26;

Table 0.26: *The top management values maintenance as one of the very key functions towards achieving milling plant production targets*

		Frequency	Percentage		Cumulative %
Valid	**Strongly disagree**	6	15.79	44.74	15.79
	Disagree	11	28.95		44.74
	Nor agree nor disagree	5	13.16	13.16	57.9
	Agree	12	31.58	42.11	89.48
	Strongly agree	4	10.53		100.00
	Total	**38**	**100**		

From the respondents (Table 4.26), it emerged that 44.74% of the respondents expressed their disagreement that the top management of milling plants valued maintenance as one of the key functions towards achieving milling plant production targets. 42.11% confirmed that the organizations management valued maintenance as driving force towards production targets, with 13.16% being neutral on the issue. This implied that the top management was not very supportive towards ensuring milling plant critical sub-systems uptime. This is further confirmed or collaborated by failure to follow service schedules, poorly maintained maintenance records and lack of condition monitoring techniques and modern equipment for potential failure detection (PFD).

Lastly, the research wanted to establish whether the organization has well defined and monitored KPIs. The results are shown in Table 4.27.

Table 0.27: *The organization has well defined and monitored KPIs*

		Frequency	Percentage		Cumulative %
Valid	**Strongly disagree**	6	15.79	57.9	15.79
	Disagree	16	42.11		57.9
	Nor agree nor disagree	4	10.53	10.53	68.43
	Agree	7	18.42	31.58	86.85
	Strongly agree	5	13.16		100.00
	Total	**38**	**100**		

From the results, (Table 4.27), more than 50% of the respondents, 22, translating to 57.9% disagreed with the idea that the organization had well defined and monitored KPIs. 31.58% were positive on availability of KPIs with 10.53% remaining neutral on the issue.

This implied that the organization management was not again very keen on manufacturing performance indicators implementation. This is evident from the big percentage of the respondents who disagreed with the presence of well monitored KPIs.

4.4 Maintenance policy development

4.4.1 Introduction

The main purpose of maintenance engineering is to reduce the adverse effects of breakdown and to increase the availability at a low cost, in order to increase performance and improve the dependability level" (Simeu Abazi & Sassine, 2001). One of the methods of achieving this is through enhancing TTF or TBF and reducing TTR so that equipment remains available for production for long duration of time hence enhancing reliability level.

By definition, a maintenance policy (MP) is a policy that dictates which parameter triggers a maintenance action. In practice, selecting the right maintenance policy appears to be a difficult decision and especially in industrial set-ups where the CAPEX for plant set-up is high. Although MPS is considered to be a multiple criteria (multi-criterion) decision making process, it is necessary to incorporate a decision tree in the MPS process and to critically analyse all the potential failure root causes. In milling plants MPS, this will aid at arriving at the most feasible maintenance policy applicable to milling plants production process equipment.

4.4.2 Maintenance policy selection criteria for milling plant critical failures

This section discusses the criteria used for milling plant MPS with a view of arriving at the most optimal and appropriate maintenance policy (MP) applicable to milling plant sub-systems critical failure modes. The prioritised three (3) critical sub-systems and their corresponding five (5) failure modes and the FRCs were considered and the most feasible MP chosen with the aid of a decision tree. The criteria used considered the milling plant identified sub-systems together with their respective failure modes and the FR causes. Further, the maintenance policy selected was based on failure criticality or the risk of failure in terms of failure cost (DT and DTC) of the failure mode/s and reliability of maintenance policy that was considered to be most feasible to the failure mode/s.

A decision tree was used to narrow down the maintenance policies available and pick the most optimal maintenance policy or policies applicable to the failure mode/s.

4.4.3 Maintenance policy selection for maize milling plant sub-systems

i. **Roller mill**

Roller mill is one of the most critical milling plant sub-systems. Roller mill had two critical failure modes, RM milling surface failure and RM vibration.

a. MPS for Roller mill milling surface failure

FRCs for milling surface failure was identified to be lack of rolls tram or parallelism, presence of abrasive materials in the milling line and metallurgical related problems. From the decision tree used in MP selection for this failure mode, CBM together with development of the right processing procedures (right work procedures) and technology for milling surface condition monitoring was proposed as the most feasible maintenance policy.

Further, UBM and DOM were also feasible maintenance policies which could as well be considered for application. UBM proved to be viable since milling surface failure seemed predictable and displayed IFR behaviour (as noted from failure records). From the maintenance records and the milling team, UBM service/ maintenance schedules for the RM could easily be developed and made available and thus could as well be considered.

DOM although, proved to be feasible MP, the time and cost implication for ‘reprouting’ (Increase in texture and surface or case hardening) of the RM proved non effective in its application.

Due to criticality of this sub-system in the milling process, FBM which was triggered by unplanned DT proved to be very costly in terms of DT and DTC and thus not recommended for application.

b. MPS for Roller mill vibration

The second failure mode for RM was RM vibration which was caused by worn stop collars and or worn or loose set screws, bearing thermal failure or sudden change of feed or loading. Interview results showed that the maintenance team used CM to address failures resulting from RM vibration. Again the team lacked adequate knowledge and skills for potential failure detection and SST for vibration detection and testing. CBM was chosen to be most feasible MP since it was noted that the condition was detectable and a certain value (of vibration) could be established as the reference point for safe working condition/ limit beyond which, maintenance should be carried out.

UBM was also feasible since this failure mode displayed a predictable behaviour with IFR. Again, due to criticality of this sub-system, FBM was not recommended since the DT and its corresponding DTC was too high. DOM and TBM again were not feasible. It was noted that there was no existing procedures for RM condition monitoring, vibration monitoring and detection and thus a recommendation for development of condition monitoring and vibration detection technique together with tools for vibration detection was suggested. Overall, CBM and UBM were the recommended MPs feasible to address the two failure modes.

ii. Degermer

The research also identified two critical failure modes for degermer sub-system, degerming plates and blades failure and screens failure.

a. *MPS for degermer plates and blades failure*

Main FRCs of degermer plates and blades failure was due to abrasive materials in the milling line, metallurgical related problems and over size materials. On the other hand, Degermer screens failure was occasioned mainly by presence of abrasive material in the milling line, poor corn conditioning and metallurgical related problems. Interview results showed that the maintenance team over-relied on CM approach (a reactive maintenance strategy) and little on UBM to solve these failures.

It was noted that the failure condition was detectable and thus CBM policy together with procedures for measurements of failure detection was the most recommended maintenance policy. UBM could as well be considered since from maintenance records, the failure rate was predictable. It was noted that UBM tools and schedules were available but UBM service schedule were not available and hence a recommendation to develop UBM service schedules.

FBM could again be considered but was not economically feasible since unplanned shutdown resulting from failure to perform predictive or preventive maintenance could cost the milling plant DTC of US$ 34,005.66 for CM.

b. *MPS for degermer screens failure*

For degermer screens failure, the maintenance team used FBM. The disadvantage with this policy was that it resulted to production line plant shutdown during the time of screens failure maintenance. Since the screens failure behaviour was predictable and demonstrated an IFR pattern, UBM was considered to be the most appropriate MP. Moreover, Interview with the plant maintenance or milling team together with the failure records available, it showed that service schedule and procedures could be developed and thus UBM proved to be the most optimal maintenance policy.

It was noted that FCs for degermer plates and blades were related to FCs for the screens. Thus, OBM could also be used such that when an opportunity for overhaul of degermer sub-system to service or replace plates and blades, such an opportunity could be utilised to check the condition of degermer screens and if need be, replacement and or repair could be done during such an opportune time.

iii. Drive motor

For drive motor sub-system, the most critical failure mode was DM winding failure. The main FRCs included insulation decay, temperature fatique related problems and dust or dirt accumulation on the DM windings. Interview results showed that the maintenance team relied entirely on CM. FBM was not recommended since this led to unplanned production line or plant shutdown which led to high DTC. CBM was the most feasible maintenance policy since right operating condition parameters could be established and a threshold set. What was noted to be lacking was special service and test tools and procedures for DM potential failure detection.

Training on DM potential failure detection technology together with acquisition of SST and procedures for failure detection, FD (winding failure detection test, WFDT and vibration detection test, VDT) could enhance optimality of this policy and make it the most feasible MP for this failure mode, FM. UBM could also be used since again the failure behaviour was predictable. DOM, OBM and TBM could not be recommended since they were not feasible if adopted could lead to adverse effect to the production process.

4.4.4 MPS Summary

Table 4.21 gives summary of the optimal maintenance policies applicable to milling plant critical sub-systems failure modes. It is worth noting that, although manufacturing plants and or their sub-systems operate under different conditions, their maintenance challenges are unique and varying from one manufacturing plant to another or from one sub-system to another. Again, milling plant equipment failure modes and the corresponding failure root causes are different in nature and may require different maintenance actions and policies.

Industrial set-ups and their organography do not allow flexibility where the maintenance team can study and pilot or implement a maintenance policy towards addressing systems failure modes but instead, they more than often apply FBM policy when failure occurs many a times leading to unplanned plant shut down. This MP development and selection model or frame work can therefore, be adopted and used across the manufacturing and production sector where complex systems and sub-systems are used in production to assist the organization develop and select the most optimal maintenance policy applicable to the plant failure modes.

This model or frame work can as well be customized to suit different industrial operating conditions. The first important step is to identify and prioritise the industrial plant critical sub-systems. Then, use Pareto analysis or chart to quantitatively prioritise or rank the failure modes. After failure mode prioritization, the critical failure modes are subjected to root cause analysis (RCA) to establish failure root causes. Then with the use of a decision tree, develop a matrix of all feasible maintenance policies and select the most optimal maintenance policy that will best address the prioritized failure modes.

Table 4.28 gives summary of the feasible maintenance policies applicable to corn milling plant critical sub-system failure modes.

Table 0.28: *Selected feasible maintenance policies for milling plants critical failure modes*

Sub-system	***Failure mode***	***Failure root causes***	***Most feasible maint. Policy***
1. Roller mill	a. Milling surface failure	Lack of rolls tram or parallelism, abrasive materials, metallurgical related problems.	CBM (Rolls tram/ parallelism test), UBM + service schedule and procedures
	b. RM vibration	Worn stop collar or set screw, bearing thermal failure, sudden change of feed.	CBM (vibration analysis), UBM + training, service schedule and procedures
2. Degermer	a. Degermer plates and blades failure	Abrasive materials, metallurgical related problems, oversize materials.	CBM (Regular measurements), UBM + training, procedures and service schedule
	b. Degermer screens failure	Abrasive materials, poor corn conditioning, metallurgical related problems	OBM, CBM, UBM + procedures and service schedule
3. Drive motor	a. DM winding failure	Insulation decay, temperature fatique related problems, dust or dirt accumulation.	CBM (winding failure detection test), UBM+ Training, procedures and service schedule

4.5 Research findings

This research identified some vital findings on milling plant systems that were of essence to optimal functioning of maize milling plant equipment.

4.5.1 Failure modes prioritization

Based on the first objective, the research identified roller mill, degermer and drive motor as the most critical milling plant sub-systems. The sub-systems prioritization was guided by failure risk criticality which was informed by three failure parameters; Failure occurrence rate or frequency, which could also be known as failure count, DT and failure DT cost. Further, from Pareto analysis for roller mill sub-system, it was noted that the RM had two critical failure modes, namely;

- Failure or wearing of roller mill milling surface and
- Roller mill unit vibration.

From degermer sub-system failure Pareto analysis, it was noted that degermer sub-system had as well two critical failure modes; Failure of degermer blades and plates and the degermer screens failure.

For the drive motor sub-system, drive motor windings was identified to be the most critical failure mode.

Based on the second research objective, RCA was performed using the 5Ms model together with the cause and effect charting and Pareto analysis. Pareto analysis was used as a quantitative analysis tool for failure root cause prioritization. The research established three critical FRCs for roller mill sub-system milling surface failure mode. These were identified to be;

- Lack of rolls tram and or parallelism on the rolls or RM
- Abrasive materials and
- Metallurgical related problems

For roller mill sub-system vibration failure mode which was the second critical failure mode for this sub-system, the research established three main FRCs which included;

- Worn stop collars or set screws

- Bearing thermal failure and
- Sudden change of feed of the fluidized corn in to the milling production line.

For the degermer plates and blades failure mode, three critical FRCs were identified. These included;

- Abrasive materials
- Metallurgical related problems and
- Over size materials.

Degermer screens had also three critical FRCs namely;

- Abrasive materials
- Poor corn conditioning (Abrasive materials) and
- Metallurgical related problems

For the drive motor, the critical failure mode was identified to be failure of drive motor windings and was noted to be caused by the following FRCs;

- Insulation decay
- Temperature fatique related problems
- Dust or dirt accumulation and
- Winding corrosion

Based on the third objective, to develop the maintenance policy, a decision tree was chosen as the most appropriate tool to aid in the MP development and selection.

The research also showed that FBM, a reactive maintenance approach was the commonly used maintenance policy used to solve milling plant failure occurrences which did not guarantee optimal equipment availability.

4.5.2 Findings on milling plant failure root causes and maintenance management

Considering Cause and Effect diagram and Root Cause Analysis results for milling plants, the following vital findings were established;

- Lack of proper maintenance documentations, poor service timing or schedule, lack of modern SST for maintenance actions and lack of modern FD tools and equipment for sub-systems condition monitoring was noted to be a major contributor to milling plant frequent failures.

- It also emerged that unplanned down time or unplanned equipment failure was the main cause of prolonged down time. This meant that there was a need to institute mechanisms that could control or minimise unplanned down times in corn milling plants.

- Also noted was that the organizations failure to follow service schedules, poorly maintained maintenance records and lack of condition monitoring techniques together with lack of modern equipment for PF detection was noted to be a main contributor to frequent milling plant failures.

- Again the milling industry lacked adequately trained and competent maintenance team to undertake potential failure detection and use of modern failure detection and diagnosis equipment. It came out that the milling personnel who are not maintenance management experts were doubling as millers as well as maintenance personnel.

- The organizations management was not very keen on ensuring effective maintenance management by dedicating time and resources to the maintenance function.

- Most important was the observation that the critical milling plant equipment that required close condition monitoring where ***'run to failure'*** (RTF/ OTF), a condition that necessitated the application of FBM to solve the crisis.

- It also emerged that PF detection techniques and SST for potential failure detection where not available for application. Lack of proper service schedules and adequate maintenance and service documentation affected the quality of maintenance.

The milling plants have a lot of unorganised and unprocessed data and to organize and manage this data is a challenge to the milling plants. Milling plants do not apply CMMS for purposes of control, monitoring and ease of their operations.

Table 4.22 gives a Summary of the suggested remedies for milling plant sub-system failure modes. The results have been developed in line with the analysis results from the prioritised MP equipment failures modes. The results give the suggested feasible remedy for the milling plant FRCs.

Table 0.29: *FRCs and the suggested remedies for corn milling plant sub-system failure modes*

Failure Mode	**Failure Root Cause**	**FRC suggested remedy/ actions**
	Lack of rolls tram/ parallelism	-Test for rolls parallelism and tram regularly with metal feeler gauge. - Use traming plate to lay across rolls to test for tram. - Adjust tram by rising and lowering one or both ends of the rolls until proper tram is obtained.
	Abrasive materials	-Perform proper screening of the medium to be processed. -Install magnetic pole pieces to trap metallic pieces -Perform proper corn conditioning -Make best choice of rolls corrugation to achieve increased rolls life.
a. Milling surface failure	Metallurgical related problems	-Make best choice of engineering material -Ensure controlled condition temperatures to avoid temperature fatique. -Do lubrication where necessary.
b. RM vibration	Worn stop collars/ set screws	-Make good selection of genuine stop collars/set screws -Perform regular checks to ascertain good working condition. -Replace when necessary -Proper lubrication -Control operating temperature
	Bearing thermal failure	-Ensure the right bolts torque -Ensure correct internal clearance
	Sudden change of feed	-Provide surge hopper to the corn feed inlet -Provide controlled corn feeding
a. Degermer plates and blades failure	Abrasive materials	-Perform screening of the medium to be processed. -Install magnetic pole pieces to trap metallic pieces - Perform adequate corn conditioning -Good quality material for plates and blades
	Metallurgical related problems	-Best choice of engineering material -Control operating temperature -Good corn screening
	Over-size materials	-Elimination of foreign matter -Install scalping device to filter large sized materials -Good magnetic protection to attract any iron tramps -Perform screening of the medium to be processed
c. Degermer screens failure	Abrasive materials	- Install magnetic pole pieces to trap metallic pieces -Good quality material for screens
DM winding failure	Insulation decay Temperature fatique	-Perform FDT for motor winding -Control operating temperature -Minimise dust/ dirt accumulation on cooling fan and heater matrix/cooling fins

CHAPTER FIVE
CONCLUSION AND RECOMENDATIONS

This chapter presents key research findings, conclusion, contribution to theory and practice and recommendations for future research.

5.1. Key research findings

This research identified number of findings that were very critical to optimal functioning of milling plant equipment and maintenance Management;

One of the main contributing factor to milling plant critical sub-systems failure root causes was the inability of the millers or 'maintenance team' to undertake system performance audit through condition monitoring to predict or detect potential failures. Some milling plant sub-systems will ***Run to Failure, RTF or Operate to Failure, OTF*** because their failure will not have a serious failure effect or serious failure criticality, however, other milling plant sub-systems need preventive or predictive maintenance measures to prevent failure occurrence because of the associated failure risks. This research recommends that milling plant systems performance audit be conducted for condition monitoring to detect potential failures before occurrence.

Lack of proper maintenance documentations, poor service timing or schedule, lack of modern SST for maintenance actions and lack of modern FD tools and equipment for sub-systems condition monitoring was established to be a major contributor to milling plant frequent failures. This research showed that milling plants had no modern failure or potential failure detection tools, **FDT** for failure detection or condition monitoring which could ensure maintenance function becomes efficient.

This research also noted that there was a need for milling plant maintenance team to get adequate regular training on modern manufacturing technology especially on potential failure detection techniques, **PFDT** and use of SST for potential failure detection. This implied combination of skills gap and lack of PFDT equipment. Lack of proper service schedules and adequate maintenance and service documentation affected the quality of maintenance.

There was a dire need for milling plants to develop, maintain and update maintenance records and service schedules. Failure to accomplish this was a recipe for unplanned plant sub-system failures or DT due to poor maintenance timings. This was confirmed by poorly organised data as witnessed during data collection.

There was a need to enhance job cards application in maintenance function. Little or no use of job cards was evidenced by poor maintenance records witnessed during data collection.

There was a need for milling plants to establish well trained maintenance team to address all maintenance function in the milling plant. This was evidenced by results from plant management that their main objective is to meet production targets and quality products. Production targets and quality products are functions of equipment availability.

Lastly, this research noted that milling plants management team should not **"see"** ***maintenance function*** as just another ***costly secondary function*** in the milling process left solely to the plant millers but should get adequate support to ensure its effectiveness, efficiency and optimality. Key performance indicators need to be established which will be used as the standard measure towards achieving the organization's optimal performance and or production targets.

5.2. Conclusion

From the research, very vital findings were identified which are very key to optimal functioning of corn milling plant equipment and maintenance management optimization.

Based on the first objective, the research identified roller mill, degermer and drive motor as the most critical milling plant sub-systems. The sub-systems prioritization was guided by failure risk criticality which was informed by three failure parameters; Failure occurrence rate or frequency or failure count, DT and failure DT cost. Further, from Pareto analysis for roller mill sub-system, it was noted that the RM had two critical failure modes;

- Failure or wearing of roller mill milling surface and
- Roller mill unit vibration.

From degermer sub-system failure Pareto analysis, it was identified that degermer sub-system had as well two critical failure modes; Failure of degermer blades and plates and the degermer screens failure.

For the drive motor sub-system, drive motor windings was identified to be the most critical failure mode.

Based on the second research objective, results from RCA together with cause and effect charting, 5Ms potential failure causal parameters and Pareto analysis established three critical FRCs for roller mill sub-system milling surface failure mode. These were identified to be;

- Lack of rolls tram and or parallelism on the rolls or RM
- Abrasive materials and
- Metallurgical related problems

For roller mill sub-system vibration failure mode which was the second critical failure mode for this sub-system, the research established three critical FRCs which included;

- Worn stop collars or set screws
- Bearing thermal failure and
- Sudden change of feed of the fluidized corn in to the milling production line.

For the degermer plates and blades failure mode, three critical FRCs were identified. These included;

- Abrasive materials
- Metallurgical related problems and
- Over size materials.

Degermer screens had also three critical FRCs namely;

- Abrasive materials
- Poor corn conditioning (Abrasive materials) and
- Metallurgical related problems

For the drive motor, the critical failure mode was identified to be failure of drive motor windings and was noted to be caused by the following FRCs;

- Insulation decay
- Temperature fatique related problems
- Dust or dirt accumulation and

- Winding corrosion

Based on the third objective, a modified decision tree was developed that aided optimal maintenance policy selection to deal with milling plant critical failure mode root causes.

For the roller mill milling surface failure, CBM (rolls tram or parallelism test), UBM together with development of service schedules and right work procedures was recommended to provide optimal maintenance for this failure mode.

For roller mill vibration failure mode, CBM (vibration analysis test), UBM together with training, development of service schedule and right work procedures was recommended to offer optimal maintenance for this failure mode.

For the degermer plates and blades failure, CBM (regular measurements) UBM together with training, development of service schedule and right work procedures was recommended to offer optimal maintenance for this failure mode.

Degermer screens failure, OBM, CBM, UBM together with development of service schedule and right work procedures was recommended to offer optimal maintenance for this failure mode.

For drive motor winding failure, CBM (winding failure detection test), UBM together with training and development of service schedule and right work procedures was recommended to offer optimal maintenance for this failure mode.

From the above research findings, it came out that there is no any single particular maintenance policy that can address all milling plant recurrent sub-system failures, however, combination of optimal maintenance policies, (RCM) together with other maintenance policy parameters (Service schedules, proper work procedures, trainings….) can be applied to give the most optimal maintenance policy. Selection of the most optimal maintenance policy guided by a decision tree, a decision making tool to aid in the maintenance policy selection.

On the other hand, the research also showed that FBM, a reactive maintenance approach was the commonly used maintenance policy used to solve milling plant failure occurrences which did not guarantee optimal equipment availability.

5.3. Recommendations

One of the main contributing factor to milling plant critical sub-systems failure root causes was the inability of the millers or 'maintenance team' to undertake system performance audit through condition monitoring to predict or detect potential failures. Some milling plant sub-systems will ***Run to Failure, RTF or Operate to Failure, OTF*** because their failure will not have a serious failure effect or serious failure criticality, however, other milling plant sub-systems need preventive or predictive maintenance measures to prevent failure occurrence because of the associated failure risks. It is recommended that milling plant systems performance audit be conducted routinely for condition monitoring to detect potential failures before occurrence.

Lack of updated maintenance documentations, poor service timing or schedule, lack of modern SST for maintenance actions and lack of modern FD tools and equipment for sub-systems condition monitoring was established to be a major contributor to milling plant frequent failures. The research showed that milling plants had no modern failure or potential failure detection tools, **FDT** for failure detection or condition monitoring which could ensure maintenance function becomes efficient. It is recommended that updated maintenance documentations, service schedules together with SST for potential FD be established to improve on maintenance efficiency. Failure to accomplish this was noted to be a recipe for unplanned plant sub-system failures or DT due to poor maintenance timings. This was confirmed by poorly organised data as witnessed during data collection.

This research recommends a need to install metal detectors along the milling line with automatic detection ability, rejection, and attraction and removal mechanisms to eliminate any metal foreign matter or particles along the milling line. Milling sub-systems whose failure root cause was presence of abrasive material along the milling line will be guaranteed enhanced service life.

This research also recommends a need for milling plant maintenance team to get adequate regular training on modern manufacturing technology especially on potential failure detection techniques, **PFDT** and use of SST for potential failure detection. This implied combination of skills gap and lack of PFDT equipment. Lack of proper service schedules and adequate maintenance and service documentation affected the quality of maintenance.

This research also recommended adequate utilization of job cards in the maintenance function. Little or no use of job cards was evidenced by poor maintenance data track witnessed during data collection.

Lastly, this research further recommended change of ideology of the milling plants management team thus they should not **"see"** ***maintenance function*** as just another ***costly secondary function*** in the milling process left solely to the plant millers but should get adequate support to ensure its effectiveness, efficiency and optimality. Key performance indicators need to be established which will be used as the standard measure towards achieving the organization's optimal performance and or production targets.

5.4. Research contribution

In the context of research contribution to theory, from the findings of this research, it emerged that there is no single particular maintenance policy that can address all milling plant recurrent sub-system failures. This research therefore identified combination of maintenance policies and procedures for the purpose of arriving at the most optimal maintenance policy applicable for the various sub-systems failure modes.

Further, milling plants industrial set-up and the organizations organography do not allow innovations where the maintenance team can study and pilot or implement a maintenance policy towards addressing systems failure modes.

Again, most important was the observation made from the research that the critical milling plant equipment that required close condition monitoring where ***'run to failure'*** (RTF), a condition that necessitated the organization to apply FBM to solve the crisis.

In the context of contribution to practice, this research has developed a model or frame work for maintenance policy development that can be modified and applied in the manufacturing sector where complex multi- functional systems are used. The modification especially for the decision tree can be done to suit field operating conditions to assist the maintenance team and decision makers choose the most applicable and optimal maintenance policy.

Failure risk based FMEA methodology together with Pareto charting can be used to do failure mode identification and quantitatively perform failure risk prioritization. RCA and Pareto charting can further be applied for failure root cause analysis and prioritization. Then a **'customized'** decision tree based on field operating conditions then used to assist in development of an optimal maintenance policy that can as well be modified and applied in other production systems and or other manufacturing industrial system set-ups.

In conclusion, this research has developed a failure risk based FMEA methodology or frame work for prioritization of manufacturing process critical failure modes. After failure modes identification, the research subjected the failure modes to failure root cause analysis, RCA using the cause and effect diagram for failure root cause identification. Then Pareto charting was applied to quantitatively prioritise the failure root causes. Lastly, maintenance policy was developed using a decision tree that considered variety of the applicable maintenance policies and all associated technical, knowledge and skills based aspects as well as tools, procedures and schedules so as to arrive at the most optimal maintenance policy that can mitigate recurrent failures in corn flour milling plants.

5.5. Recommendations for future research

Corn milling plant milling operations and maintenance function efficiency is one of the interesting areas of industrial engineering research that is not fully exploited. Based on the findings from corn milling industry, it is recommended that more research be geared towards production process optimization optimization through simulation process so as to identify areas of concern that require process or system improvement.

Since this research did not perform maintenance model validation, it is one again recommended that simulation be done to validate the maintenance policy model developed by this research. This can be done by varying the input parameter variables and analysing the results. The simulation runs can be done repeatedly and for different plants to check on the consistency of the results.

Further research on corn milling plant production optimization can be carried out where the researcher can perform milling plant simulation to arrive at the most optimal working conditions.

Again, this research model or frame work developed can be applied to other manufacturing plant set-ups since the field failure data are different depending on real working conditions. A decision tree can then be used to aid in the development of the maintenance policy then comparison be done to compare similarities of the two models.

REFERENCES

Adewole, B. (Ed.) (2008). Nigeria's flour milling industry: *An analyst's perspective*. Nigeria: Lead Capital Ltd.

Affonso, L. O. A. (2013). Machinery Failure Analysis Handbook: *Sustain your operations and Maximize uptime*, Elsevier.

Bloch Mercier, S. (2002). A preventive maintenance policy with sequential checking procedure for a Markov deteriorating system. *European Journal of Operational Research*, Vol. *142*(3), pp 548-576.

Bloch, H.P and Geitner, F.K. (2006). *Maximizing Machinery Uptime*, Elsevier, MA, USA.

Chen, C. C. (2013). A developed autonomous preventive maintenance programme using RCA and FMEA. *International Journal of Production Research*, *51*(18), 5404-5412.

David, F.R. (1997). "Strategic Management" Francis Marion University, 239.

Dhillon, B.S. (2002). *Engineering Maintenance*, CRC Press, Boca Raton, USA.

Dhillon, B.S. (2011). Medical equipment reliability: A review, Analysis methods and improvement strategies. *International Journal of Reliability, Quality and Safety Engineering*, *18*(04), 391-403.

Dudushki, I. (2009). "Modelling the process of management of the maintenance of the agricultural machinery", *Trakia Journal of Sciences*, Vol. 7, Suppl. 2, pp. 45-48.

Gandhare, B. S., Akarte, M. M., and Patil, P. P. (2018). Maintenance performance measurement: A case of the sugar industry. *Journal of Quality in Maintenance Engineering*, *24*(1), 79-100.

Gitau, R., Mburu, S., Mathenge, M. K., and Smale, M. (2011). *Trade and Agricultural competitiveness for growth, food security and poverty reduction: A case of wheat and rice production in Kenya* (No. 680-2016-46757).

Jonsson, P., and Lesshammar, M. (1999). Evaluation and improvement of manufacturing performance measurement systems: The role of OEE. *International Journal of Operations and Production Management*, *19*(1), 55-78.

Kumar, U., and Parida, A. (2006). Maintenance performance measurement: The need of the hour for the mechanized mining industry. In *Asian Mining Congress: 16/01/2006-18/01/2006* (Vol. 1). The Mining, Geological and Metallurgical Institute of India.

Lofchie, M. F. (1989). The Policy Factor: Agricultural Performance in Kenya and Tanzania. Nairobi: Heinemann, Kenya Ltd.

Monroe, D.J. (2010). *Juran's quality handbook: The complete guide to performance excellence* (6th edition). [Electronic] Editors: Juran, J.M and Defeo J.A. McGraw-Hill Professional.

Muchiri, P., Pintelon, L., and Gelders, L. (2011). Development of maintenance function Performance measurement framework indicators. *International Journal of Production Economics*, Vol.131 No.1, pp. 295-302.

Murthy, D. N. P., Atrens, A. and Eccleston, J. A. (2002). Strategic Maintenance Management. *Journal of Quality in Maintenance Engineering*, Vol.8 No.4, pp. 287 – 305.

Murthy, D.N. and Asgharizadeh, E. (1999). "*Optimal decision making in a maintenance service operation", European Journal of Operational Research*, Vol. 116 No. 2, pp. 259-73.

Murthy, D.N.P., Atrens, A. and Eccleston, J.A. (2002). "Strategic maintenance management", *Journal of Quality in Maintenance Engineering*, Vol. 8 No. 4, pp. 287-305.

Musyoka, L.W. (2011). Challenges of Strategy Implementation in Jomo Kenyatta Foundation. *International Journal of Current Research* 3 (11), 301-308.

Neely, A. (2005)."The evolution of performance measurement research: Developments in the Last decade and a research agenda for the next", *International Journal of Operations and Production Management*, Vol. 25 Iss: 12 pp. 1264 – 1277.

Neely, A., Gregory, M., and Platts, K. (1995). Performance measurement system design: A literature review and research agenda. *International journal of operations & production management*, *15*(4), 80-116.

Nowlan, F.S., and Heap, H.F. (1978). Reliability Centered Maintenance, *United Airlines Publications,* San Fransisco.

Pantazopoulos, G. and Tsinopoulos, G. (2005). “Process failure modes and effects analysis (PFMEA): A structured approach for quality improvement in the metal forming industry”, *Journal of Failure Analysis and Prevention,* Volume 5, Issue 2, pp.5-10.

Pinjala, S.K., Pintelon, L. and Vereecke, A. (2006). “An empirical investigation on the relationship between business and maintenance strategies”, *International Journal of Production Economics,* Vol. 104 No. 1, pp. 214-229.

Pintelon, L. and Waeyenbergh, G. (1999). “A practical approach to maintenance modelling”, in Flexible Automation and Intelligent Manufacturing, Begell House Inc, New York, NY, pp. 1109-1119.

Ramirez, E. C., Johnson, D. B., McAloon, A. J., Yee, W., and Singh, V. (2008). Engineering process and cost model for a conventional corn wet milling facility. *Industrial crops and products*, *27*(1), 91-97.

Robobank International (2012). *European flour milling industry.* Robobank industry note p. 328.

Rotich, K. J. (2011). Strategy Implementation Challenges at Unga Group Limited, Kenya. *Unpublished MBA Project, University of Nairobi*.

Sachdeva, A., Kumar, D., and Kumar, P. (2008). Planning and optimizing the maintenance of paper production systems in a paper plant. *Computers & Industrial Engineering*, volume *55* Issue 4, 817-829.

Saranga. H. (2004). Opportunistic Maintenance Using Genetic Algorithms. *Journal of Quality in*

Maintenance Engineering, Volume 10 Issue 1, pp. 66-74.

Sharma, A., Yadava, G. S., and Deshmukh, S. G. (2011). A literature review and future Perspectives on maintenance optimization. *Journal of Quality in Maintenance Engineering*, *17*(1), 5-25.

Sharma, R. K., and Sharma, P. (2010). "System failure behaviour and maintenance decision making using, RCA, FMEA and FM". *Journal of Quality in Maintenance Engineering*, Volume *16* issue 1, pp.64-88

Sharma, R. K., Kumar, D., and Kumar, P. (2005). "FLM to select suitable maintenance strategy in process industries using MISO model". *Journal of Quality in Maintenance Engineering*, volume 11, No. 4, pp. 359-374, 2005.

Shum, Y.S. and Gong, D.C. (2006). The Application of Genetic Algorithm in the Development of Preventive Maintenance Analytic Model. *The International Journal of Advanced Manufacturing Technology*. Vol. 32, pp.169-183.

Swanson, L. (1997). An empirical study of the relationship between production technology and maintenance management. *International Journal of Production Economics*, 53 (2), 191–207.

Swanson, L. (2001). Linking maintenance strategies to performance. *International Journal of Production Economics*. Vol. 70 (3), 237–244.

Tan, J.S. and Kramer, M.A. (1997). A General Framework for Preventive Maintenance Optimization in Chemical Process Operations. *Computers and Chemical Engineering*, 21(12), pp. 1451-1469.

Van Horenbeek, A. , Pintelon, L. and Muchiri, P. (2010). "Maintenance optimization models and criteria", *International Journal of System Assurance Engineering and Management*, Vol.1 No. 3, pp. 189-200.

Van Horenbeek, A., Pintelon, L., and Muchiri, P. (2010). Maintenance optimization models and criteria. *International Journal of System Assurance Engineering and Management*, *1*(3), 189-200.

Yin, R. K. (1984). *Case study research: Design and methods.* Newbury Park: Sage publications.

APPENDICES

Appendix I: Standard operating time for MMP critical equipment for major overhaul

S/No.	Subsystem/Equipment	Std. duration(Hrs)	Expected condition after service
1	Degermer	11	As Good As New, AGAN
2	Roller mill	24	As Good As New, AGAN
3	Elevator	4	As Good As New, AGAN
4	Drive motor	5	As Good As New, AGAN
5	Plansifter	2	As Good As New, AGAN
6	Screens	0.5	As Good As New, AGAN

Appendix II: Production specifications for Mwanzo Milling Plant, OEM, 2009

Equipment Name	**Corn Flour and Grits Milling Machine**
Capacity	28T
Products	Corn grits, flours, husks/ bran, germ
Yield	• Corn grits and flours 25-30%
	• Corn husks 20-25%
Total capacity	Corn grits and flour 75-80%
Corn Flours Fineness	40-2000 mesh (adjustable)
Sand content	＜0.02%
Magnetic metal content	＜0.003/kg
Moisture content	13.5-14.5%
Fat content	0.5-1%

Appendix III: Corn grits specification sheet, (Source, Mwanzo Milling plant, OEM).

Item	**Description**	**Allowable**	**ACTUAL**
1.	Moisture content Maximum	13.5%-Corn, 10.4% for flour and grits	12%
2.	Other Colour Corn	maximum 5% in yellow, 2% in white	ok
3.	Defective Corn Maximum	4%	ok
4.	Grits Size	1.0mm to 1.3mm	> 1.3mm
5.	Foreign Matter Maximum	0.5%	ok
6.	Filth, Dust, Soil Maximum	0.1%	ok
7.	Dead Weevils per kg Maximum	10%	ok
8.	Toxic Seeds Maximum	0.05%	ok
9.	Aflatoxin Total Maximum	4ppb (4 micrograms/kg)	ok

Specification sheet, Source, GMA, 2012

Appendix IV: Technical data/ specifications of existing MMPs

TYPE	POWER (KW)	POWER CONSUMPTION(KW/H)	CAPACITY (T/24H)	SIZE OF PROCESSING PLANT(L×W×H) meters
10t	32	52-54	10	7*5*5(line construction)
20t,25t,28t	47	40-45	20	8*5*5(line construction)
30t	54	40-45	30	8*5*5(line construction)
50t	70	40-45	50	10*5*5(line construction)
100t	100	40-45	100	12*5*7.5(line construction)

Source, OEM, 2012

Appendix V: Example of Data entry form for failure and effect on 28TPD production line

Sub-system	***Failure mode***	***Failure date***	***Time of Failure***	***Date of Return***	***Return time***	***TTR/ Unavailable time (Hrs)***	***Production DTC***
Degermer	Worn plates and blades leading to loss of process function	4/01/14	8:32am	5/01/14	07:54pm	29	33.8333T
Drive motor	Burnt windings	30/04/14	11:49pm	01/05/14	14:46pm	2.57hrs	2.9983T
Roller mill	Worn milling surface	26/05/14	7:32pm	27/03/14	11:32pm	28hrs	32.67T
Elevator	Conveyor system/ slack chain and sprocket for elevator	30/06/14	6:13 pm	30/06/14	07:29pm	1.2667hrs	1.4778 T

Appendix VI: List of Cereal milling industries in Kenya

Medium – Large Scale Milling Firms		
S/ No.	**Milling Firm**	**Location**
1	Uzuri Ltd	Nairobi
2	Capwell Industries Ltd	Thika
3	Kabansora Millers	Nairobi
4	United Millers	Eldoret
5	Mombasa Maize Millers	Nairobi
6	Mombasa Maize Millers	Mombasa
7	Eldoret Grains Ltd	Eldoret
8	Pembe Flour Mills	Nairobi
9	Mombasa Grain Milling	Mombasa
10	Chania Mills	Thika
11	Unga Group Ltd	Nairobi
12	United Millers Limited	Kisumu
13	Eldoret Grains	Kitale
14	Osho Grains	Nairobi
15	Kitale Industries	Kitale
16	Kitui Millers Ltd	Mombasa
17	Mwanzo millers Ltd	Masii
18	Mombasa Maize Millers	Kisumu
19	Maize Milling Company Ltd	Eldoret
20	Nairobi Flour Mills	Nairobi
21	TSS Grain Millers Ltd	Mombasa
22	Unga Ltd – Eldoret	Eldoret
23	Eastern Flour Mills	Machakos
24	Atta	Mombasa
25	Bakex	Thika
26	Maisha	Kiganjo
27	McNeel (closed business)	Thika
28	Milly Grains	Mombasa
29	Premier Flour Mills	Nairobi
30	Rafiki Millers Ltd	Nairobi
Small Scale Milling Firms		
31	Cateress Milling Ltd	Nairobi
32	Nakuru Flour Mills	Nakuru
33	Aberdare Maize Milling Ltd	Nyeri
34	Rosanne Investments Ltd	
35	Proctor & Allan EA Ltd	Nairobi
36	Beada Millers	
37	Besoko Millers	
38	Kapari Ltd	Nairobi
39	Meru Central Multi-Purpose	Meru
40	Grits Industries Ltd	Kitui

41	Bemar Ltd	
42	Muki Maize Millers	Nakuru
43	Karanda Millers	
44	Midland Millers	Kerugoya
45	Joli Millers	Matuu
46	Kalwa Maize House	
47	Centaur Milling Enterprise	
48	Organic Virgin	
49	Kifaru Maize Millers	Nairobi
50	Umoja Flour Mills	Thika
51	Mama Millers	Thika
52	Maycorn Kenya	Thika
53	Swaminarayan Industries	
54	Msafiri Flours Ltd	Athi River
55	AUM Maize Millers	
56	Meru Pendo Millers	
57	Kwest Millers	Thika
58	Batian Grain Millers	Nairobi
59	Sava Industries	
60	Katex Enterprises	
61	Pan African Grain Millers	
62	Sunrise Grain Millers	
63	Njora Food Products	
64	Sweet Meal Flour	
65	Valley Posho Mill	Nakuru
66	Mabrouk Flour Mills	
67	Daiga Millers	
68	Uchumi Grain Millers	
69	Summer Millers Ltd	
70	Range Food Products	
71	Snow Maize Millers	
72	Gakenge Maize Millers	
73	Nanyuki Grain Millers	Nanyuki
74	Savco Millers	
75	Embu Food Industries	

Appendix VII: Questionnaire

Introductory letter

Dear Respondent,

RE: <u>FILLING OF QUESTIONNAIRE</u>

I am a student at Dedan Kimathi University currently pursuing Master of Science Degree in Industrial Engineering and Management. As part of the programme requirement, I am currently carrying out a research on Development of a maintenance strategy that mitigates recurrent failures in corn milling plants in Kenya.

Am therefore kindly requesting you to objectively fill this questionnaire form attached.

Kindly note that the information that you provide will be treated with utmost confidentiality and will solely be used for academic purposes only and not any other.

Thanks in advance for your co-operation.

Yours faithfully,

ABROSE KIIA JOSIAH.
Industrial Engineering and Management,
Dedan Kimathi University of Technology.

Section A: Background Information

1. Please select the industrial section/ area that best describes where you work

Milling section [ ]

Plant maintenance and repair Section [ ]

Motor vehicle Service Section [ ]

Transport Section [ ]

Quality control Section [ ]

Loading section [ ]

Any other, please indicate..

2. Years of service and experience in milling industry

Less than a year	[ ]	1-3 years	[ ]	4-6 years	[ ]
7-9 years	[ ]	10-12years	[ ]	13 years and above	[ ]

3. Level of Academic/ Professional training, (Highest qualifications)

KCSE	[ ]	Certificate	[ ]	Diploma	[ ]
Undergraduate	[ ]	Postgraduate	[ ]		

Any other, please indicate...

Section B: Milling plant equipment maintenance management

4. Which maintenance policy does the industry use to address down times caused by milling plant sub-system failures? (Rank in order of priority; highest=1 and least=5)

Failure based maintenance (Corrective) [ ]

Time based/Use based maintenance (Preventive) [ ]

Condition based maintenance (Predictive) [ ]

Opportunity based maintenance (Passive) [ ]

Design out maintenance (Proactive) [ ]

5. Are maintenance job cards used in your industry when performing maintenance operations? (Rank in order of priority; highest=1 and least=5)

Not used [ ]

Rarely used [ ]

Generated for every maintenance activity [ ]

Used only on critical failures [ ]

Always used [ ]

6. What is the key objective pursued by maintenance function in the milling industry? (Rank in order of priority; highest=1 and least=5)

Equipment availability [ ]

Staff and equipment safety [ ]

Cost effectiveness [ ]

Production targets [ ]

Product quality [ ]

7. What level of importance does the milling plant management attach to maintenance functions? (Rank in order of priority, 1=Highest and Least= 5).

Maintenance is a key function of equipment availability [ ]

Maintenance is just a secondary function [ ]

Maintenance leads to time wastage [ ]

Maintenance improves productivity and profitability [ ]

Maintenance is a costly function is the milling firm [ ]

***8*. Which are the causes of production process delays in the milling industry?**

(Rank in order of priority, 1=Highest, 5= Least)

Unplanned down time/ equipment failure [ ]

Set up adjustments [ ]

Repairs or parts change [ ]

Loading or start-ups [ ]

Reduced speed, cycle time or capacity [ ]

9. When is milling plant equipment repaired or overhaul is done and what triggers these maintenance actions? (Rank in order of priority 1= highest, 5= Least)

Upon failure (Case to case basis) [ ]

Accordance to original equipment manufacturer's (OEM) specifications [ ]

As a production strategy [ ]

Due to reduced equipment efficiency [ ]

Due to reduced output [ ]

10. What triggers equipment service and or overhaul? (Rank in order of priority 1= highest, 5= Least)

Upon failure (Case to case basis) [ ]

Accordance to original equipment manufacturer's (OEM) specifications [ ]

As a production strategy [ ]

Due to reduced equipment efficiency [ ]

As a result of reduced efficiency [ ]

Section C: Milling Plant equipment utilization and productivity

Dear respondent, kindly mark your most applicable response.

S/No	Question	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
11.	There is well trained maintenance team in the organization to handle maintenance activities?					
12.	The industry performs adequate regular equipment inspections to identify potential failures					
13.	There is adequate modern technology for equipment condition monitoring and potential failure diagnosis					
14.	Maintenance personnel is adequately trained on failure detection and use of modern diagnostic equipment					
15.	Maintenance department records and maintains well updated maintenance records					
16.	The management values maintenance as one of the key functions of the organization towards achieving production targets					
17.	The organization has well defined and monitored KPI's					

Thank you for your patience and corporation