DEVELOPMENT OF RISK BASED APPROACH TO SPARE PART INVENTORY MANAGEMENT FOR SUGAR FACTORIES: A CASE STUDY OF CHEMELIL SUGAR COMPANY.

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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 work to my wife Nelly and children Anita, Brian and Clare.

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ABSTRACT

Risk-based approach in spare part inventory management and plant maintenance is essential for ensuring asset integrity in a process facility. The sugar industry in Kenya has been a victim of inefficient spare part inventory management resulting to unscheduled factory stoppages, factory breakdowns, obsolescence of plant and equipment whose maintenance costs are very high. This has been compounded by high maintenance costs and expensive spares which are also difficult to find and procure. In this regard the purpose of the current study was to develop a risk based approach to spare part inventory management in order to improve the performance of the sugar factories. The study sought to achieve the following objectives: To identify the risk due to unavailability of spare part in the sugar factory, to asses spare part criticality using fault mode and effect analysis (FMEA) in the sugar factory and to determine spare part inventory risk mitigation strategies to be used in the sugar factory. In order to achieve the objectives the study employed a case study research design. This study targeted spare parts inventory records and plant maintenance records inventoried for the past one year in Chemelil Sugar Company. Document analysis was employed as the main tools for collecting secondary data. Data was analyzed by use of descriptive statistic using Excel. From the Pareto analysis of boiler, pre mills, mills and juice treatment downtime was used as a spare part risk identification technique. It was established that boiler, pre mills, mills and juice treatment had a downtime of 315.51 hrs, 294.19 hrs, 111.13hrs and 82.3 hrs respectively. Besides that, spare parts failure frequency ranging from 2 to 756 times a year was also used to identify spare part risk. Critical spare parts were the motors, water pump and the gears with a criticality index ranging between 8 to 25 based on downtime, lead time and availability in the market. The study established Reorder points (24, 16, 75), Lead time demand (13,4,30) and Safety stock (12,13,45) for motors, water pump and the gears respectively to determine the risk mitigation strategies for the critical spare parts for Chemelil sugar factory. In conclusion the factory should evaluate their spare parts inventory critically owing to their effect on the downtime and implementation of risk based approach to spare part inventory management. The findings of this study widens interest in the use of Risk based approach to a number of other stakeholders including operators, maintenance personnel, regulators and insurance companies and other industries to potentiate plant availability.

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ABBREVIATIONS AND ACRONYMS

COMESA	Common Market for Eastern and Southern Africa
EOQ	Economic Order Quantity
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode Effects and Criticality Analysis
GDP	Gross Domestic Product
HAZOP	Hazard and Operability Study
KSB	Kenya Sugar Board
KSI	Kenya Sugar Industry
MRO	Maintenance, Repair and Operations
MTBF	Mean-Time-Between-Failures
PdM	Predictive maintenance
PM	Preventive maintenance
RCM	Reliability Centered Maintenance
RM	Reactive Maintenance
RPN	Risk Priority Number
KETS	Kenana Engineering and Technical Services
KNBS	Kenya National Bureau of Statistics
KNA	Kenya National Assembly
LCE	Life Cycle Engineering
PLC	Programmable Logic Controllers
S	Severity
O	Occurrence
D	Detection
CI	Criticality index

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Equipment downtime due to unavailability of spare parts has incurred challenges for the manufacturing industry in managing the inventory globally (Kamal, Jafni, and Zulkifli, 2015). Consequently spare parts unavailability has led to poor plant performance which eventually affects financial performance. This is underpinned by Ogbo, Onekanma, & Ukpere, (2014) who argued that, inventory management has the largest impact towards maintenance and plant performance. Improper spare part inventory management results in stunted maintenance process and ultimately unexpected downtimes and irreparable loss for a company. One way to achieve high operational readiness of a plant is to acquire enough spare parts through a risk based approach (Kamal et al., 2015).

Risk-based approach in spare part inventory management and plant maintenance is basic for guaranteeing resource respectability in a procedure office (Khan & Haddara, 2004). Risk is the blend of the likelihood of a stock out and its outcome (Bharadwaj, Silberschmidt, and Wintle, 2011). Spare parts stock out results to disappointment, creation of misfortune, mishaps, extended downtime, administrative punishment and unexpected outcome (Bharadwaj et al., 2011). A risk based approach to spare parts inventory management helps in successful distribution of limited assets (Jakiul, Faisal and Mainul, 2012). However, this calls for vital obtainment approach to guarantee spare parts accessibility. In result the risk level can be limited and plant accessibility can be amplified inside the money related limitation. In risk based approach of inventory management, assets are apportioned to the most basic parts and accordingly expanded accessibility and reduce risk (Fisher, Hammond, Obermeyer, and Raman, 1994). In view of this, it is essential to incorporate risk perspective into the decision making in spare part inventory management.

There are four fundamental capacities to manage risk - risk identification, risk quantification, risk probability and risk response. The initial three; identification, quantification and probability are assembled together under Risk Analysis or Risk Assessment (Bharadwaj et al., 2011). A portion of the methods utilized are Failure Modes, Effects, Criticality Analysis (FMECA) and Hazard and Operability Studies (HAZOPs) (Kamal et al., 2015). These systems end up quantitative when outcomes and disappointment likelihood esteems are evaluated in numerical terms. In this circumstance, the goal is to maintain the level of spare parts about the probability of an inability to take care of the demand for an extra related to the results of the inability to take care of that demand (Kamal et al., 2015). This risk profile is then used to locate the ideal dimension of inventory with the end goal that budgetary advantage is boosted given a distinguished satisfactory risk level. Consequently, the objective is to keep up the dimension of spare parts which gives least warehousing and postpone costs on one side, while ensuring an abnormal state of accessibility of extra parts then again (Bharadwaj et al., 2011). The discontinuous or dubious interest, the vast quantities of extra parts and the risk of extra parts out of date quality may cause the spare parts not meeting the supply chain points.

It can therefore be inferred that inventory management has the largest impact towards plant and organization performance. This position is corroborated by Kamal et al., (2016) who argue that the risk associated with the value of spare parts shortage and excess in inventory have potential impact on the operation of the plant thus compromising on its performance. In United States about $ 300 billion has been utilized with the end goal of spare part inventory, plant maintenance and operation (Dhillion, 2002). Malaysia industry likewise is no special case to this issue where in construction industry alone, the management spent 12% of the yearly spending plan for the expense of support (Heng et al., 2009). Furthermore, Krishnasamy et al., (2005) has found that manufacturing company spent about 80% of its activity cost to address issue on gear disappointments and damage to individuals. These issues really host drawn reaction among different parties of business ventures to investigate spare part inventory management and maintenance management seriously (Liyanage & Kumar, 2003).

The Kenyan sugar industry has performed below its capacity at 59.535% which is credited to unscheduled processing plant stoppages, industrial facility breakdowns other than absence of cane for crushing by the sugar production lines (Kenya Sugar Board, 1998 – 2013). In consequence this has impaired its contribution to the economy as an attendant consequence of unscheduled factory stoppages, factory breakdowns. Technology adoption in the Kenya sugar industry is slow resulting in the operations of obsolete plant and equipment whose maintenance costs are very high and procurement of spares expensive and difficult to find leading to a drop in factory time efficiency (Mwanaongoro and Imbambi, 2014). However, there is no evidence that a research has been done on the relationship of risk based approach to spare part inventory management on the performance of the Kenyan sugar industry**,** though poor factory performance is mentioned generally in some of the studies carried out (Kaumbutho et al., 1991; Otieno, Kegode et al., 2003). This has informed the need for the current study on risk based approach to spare part inventory management in the Kenyan sugar factories to fill in the existing gap in literature.

1.2 Sugar manufacturing firms in Kenya

From a global perspective 78% of sugar in the world is extracted mainly from sugarcane and the balance from sugar beet. Sugarcane growing was introduced in Kenya in the early 1900s. The industry dates back to 1922 when Miwani Sugar Company was established followed by construction of various sugar factories namely: Ramisi (1927), Muhoroni (1966), Chemelil (1968), Mumias (1973), Nzoia (1978), South Nyanza (1979), West Kenya (1981), Soin (2006) and Kibos (2007). Other sugar firms such as Sukari Industries at Ndhiwa, Trans Mara Sugar, Opapo, Butali and Tana basin multi-projects have either been recently constructed or approved. Miwani and Ramisi collapsed, though Ramisi has been revived under a new name of Kwale Sugar Company Limited (Mwanaongoro and Imbambi, 2014).

However, the performance of the sugar industry in Kenya has been dismal. This position is justified by Otieno et al., (2003) and KSB, (2008) whose reports show that the problems affecting the millers are due to; inefficient factory operations, poor skills improvement, unrealistic company's Strategic Plans, poor maintenance policy and leadership, slow technology adoption, financial constraints, poor synchronization of cane availability and factory capacity (KNA, Third Session, March – 2015). These altogether explain the inconsistencies of the performance of the Kenya sugar sub-sector.

Economic liberalization and worldwide trade de-regulation present difficulties to the sugar industry sub-division of the Kenyan economy (Monroy et al., 2012). Multi-horizontal and local exchange arrangements, explicitly those related with (Common Market for Eastern and Southern Africa) COMESA, (East African Community) EAC and (World Trade Organization) WTO have encouraged the importation of sugar into Kenya at negligible or Zero taxes from producer member states. What's more, the sugar imported is by and large vigorously sponsored by its source Government (KSB, 2006). This has adversely affected the marketability of privately created sugar, which on account of its high production cost courtesy of inappropriate technologies with its attendant consequences of expensive and difficult to find spare parts. Hence Kenyan sugar industries cannot compete head to head with foreign sugar in the domestic and foreign markets.

LMC Worldwide Survey (2005) as cited in Mwanaongoro and Imbambi, (2014) established that all public sugar companies in Kenya with the exception of Mumias Sugar Company produced sugar at a cost higher than 150% of the world average as depicted in table 1.1 below:

Table 1. 1 Sugar production cost (US $ per ton)

World Average	Mumias	Sony Sugar	Nzoia	Chemelil	Muhoroni
263	314	436	455	486	526

Source: LMC Worldwide Survey on Sugar Production Costs, 2005 as cited in Mwanaongoro and Imbambi, (2014)

The above scenario can be ascribed to the use of obsolete machinery which cannot perform at the expected levels found in some factories. The resulting inefficiency at factory level due to constant breakdowns and prolonged down time as a result of poor spare part inventory contributes vigorously towards the high cost of privately made sugar. It is evaluated that Kenyan customers pay up to multiple times the world cost for household sugar (Mwanaongoro & Imbambi, 2014). Sugar in Kenya is evaluated to take care of the creation expenses of the slightest effective makers. In fine the measure of sugar created by such organizations is beneath market request, costly and barely ready to adequately contend with less expensive imports. This begs the question on what the effect of risk based approach spare part inventory management on the performance of sugar industries in Kenya.

1.3 Problem environment

The Kenyan sugar industry has performed below its capacity at 59.535% which is attributed to unscheduled factory stoppages, factory breakdowns besides lack of cane for grinding by the sugar factories (KSB, 1998 – 2013). This is aggravated by very high maintenance costs and expensive spares which are also difficult to find and procure culminating into drop in factory time efficiency from79.58% in 2006 to 74.91% in 2008 in comparison to the international set standard of 92% (Mwanaongoro & Imbambi, 2014). The consequence of this is low contribution of the sugar industry at 15% to the national economy against the aspirations of Kenyan Vision 2030 which stipulates that the sector should account for 20% of the GDP (KNBS, 2015).

Kenyan sugar is a victim of high sugar prices which are attributed to the high cost of production, which is above that of all East African Community and Common Market for Eastern and Southern Africa member countries. A 2014 study submitted to the Kenya Sugar Board (KSB) by Kenana Engineering and Technical Services (KETS, 2013) says the high cost of the sweetener is due to low cane yields, capacity under utilization and lack of regular factory maintenance programmes. Besides the sugar industry is constrained by low production capacities, lack of clear harvesting schedules, huge debts, managerial inefficiency, cane poaching, unreliable and fluctuating weather conditions, outdated technology, equipment and machinery (KETS, 2013)

1.4 Problem statement

There is a low contribution of the sugar industry at 15% to the national economy against the aspirations of Kenyan Vision 2030 which stipulates that the sector should account for 20% of the GDP. The poor performance of the Kenyan sugar industry is attributed to unscheduled factory stoppages, factory breakdowns besides lack of cane for grinding by the sugar factories. This situation has been further compounded by very high maintenance costs and expensive spares which are also difficult to find and procure culminating into drop in factory time efficiency from international set standard. To operate efficiently and effectively, the sugar industry need to ensure no disruption due to equipment breakdown, stoppages and failure through effective maintenance courtesy of risk based approach to spare part inventory management.

Risk based approach to spare part inventory management helps to spare support that upgrades equipment adequacy and reduces downtime. Accessibility of basic spares will stimulate the commitment of administrators to accomplish zero breakdowns, zero stoppages and a more secure workplace. However, there is no evidence that a research has been done on the risk based approach to spare part inventory management in the Kenyan sugar industry. This altogether has motivated the need for the current study on developing a risk based approach to spare part inventory management for sugar factories to fill in the existing gap in literature.

1.5 Main objective

To develop a risk based approach to spare part inventory management for sugar factories.

1.5.1 Specific objectives

The study was guided by the following specific objectives;

i. To identify the risk due to unavailability of spare part in the sugar factory;

ii. To asses spare part criticality using FMEA in the sugar factory;

iii. To determine spare part inventory risk mitigation strategies to be used in the sugar factory.

1.6 Significance of the study

It is hoped that the findings of the study will provide empirical evidence on the decline in the performance of the sugar industry and will provide a platform through which the policy makers can assist to resuscitate the industry. The management of Chemelil Sugar Company could use the findings of this study to improve in the management of spare parts with an aim of ensuring continuous production of sugar to meet the demand for sugar in the market. It is also believed that the data generated will constitute part of the knowledge pool from which future research can borrow and form a basis for further related research.

1.7 Delimitation of the study

The study focused on spare parts inventory management by the factory maintenance and planning teams in the sugar industry. Secondary data from Chemelil sugar factory was used to make inferences. The study was conducted in 2016/2017 financial year.

1.8 Limitations of the study

The study was conducted in Chemelil which may not allow generalizability to other Sugar factories with modern equipment/machines. This can be mitigated by recommending similar studies to be carried out in other sugar factories. There is an impediment with putting together the examination with respect to historical information with regards to new things with either short or no chronicled interest. In the other extreme, there are old items with a lot of recorded information however whose utilization is beginning to vanish as they might be supplanted by progressively present day equipment.

There are chances of existence of duplicates in the system. The duplicates occur due to the inaccuracies which allude to inconsistency between the recorded inventory amount and the genuine inventory amount physically accessible on the track. Duplication was corrected by sorting out the data base.

1.9 Assumptions of the study

The study made assumptions that:

i. Spare parts inventory management does affect performance of sugar factories in Kenya.

ii. Data collected was representative for making reliable inferences.

iii. The recommendations made after the findings are helpful in alleviating performance problems which could be related to spare part inventory management.

1.10 Operational definition of terms

Performance: A function of the production process efficiency and effectiveness which can be compromised by lack of spare parts required for maintenance (Obamwonyi & Gregory, 2010).

Risk based approach: Inventory management approach in which risk associated with the value of spare parts shortage and excess in inventory is consider red while stocking the spare parts (Kevin, 2017).

Risk mitigation: Reducing the probability of the risk happening (using existing technology instead of new technology) or reducing the consequence of the risk or some combination of both (Arunraj & Maiti, 2007).

Risk: Combination of the probability of a stock out event and its consequence, where a stock out is an event when a spare is not available on demand (Bharadwaj et al., 2011).

Spare part: Machines changeable parts, tools, equipment and supporting parts which are needed to keep the machines reliability above the desired level (Ablay, 2013).

Spare part criticality: On-availability of spare parts that affects plant productivity (Bacchetti & Saccani, 2012).

Spare part Inventory: Is the sum of spares held in a store or any other place at a specific time (Boylan & Syntetos , 2009).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents the concept of risk management, concept of performance of factories, empirical literature review and the research gap.

2.2 Concept of risk management

According to ISO 31000:2009, a risk is an impact of vulnerability on objectives while risk management is characterized as composed exercises to direct and control an association with respect to risk. Without risk taking there is no reward or advancement, thus risks ought to be overseen viably inside an association so that open doors can be amplified and the dangers limited. Risk is about vulnerability or all the more significantly the impact of vulnerability on the accomplishment of goals (Kevin, 2010). ISO 31000:2009 sets out standards, a structure and a procedure for the management of risk that is pertinent to an association. It doesn't order a one size fit for all to approach but instead underlines the way that the management of risk must be customized to the explicit needs and structure of the specific organization.

According to ISO 31000:2009, the management of risk must create and protect value by contributing to the achievement of objectives hence improved organizational performance. Risk management should be an integral part of organizational processes; from the setting of organizational objectives to strategic planning, project management and operational activities. The ISO 31000:2009 suggests that risk management should be an integral part of the decision-making process, so that decisions are the right ones and can be managed to a successful outcome. The risk management should explicitly address 'uncertainty,' systematically, structured and timely. Risk management should be based on the best available information, any data limitations, organization's risk profile and risk appetite for given situations. In addition risk management team should recognize the impact of the human, cultural and environmental paradigms of the organization on the achievement of objectives. Finally, the risk managers must address the perceptions of stakeholders not just company management, be dynamic and responsive to change and take account of new or emerging risks and be continually improving as the organization matures (Hopkin, 2010).

2.2.1 Risk management process

According to ISO 31000:2009, the risk management process ought to be; an essential piece of management, installed in the way of life and practices custom fitted to the business procedures of the organization.

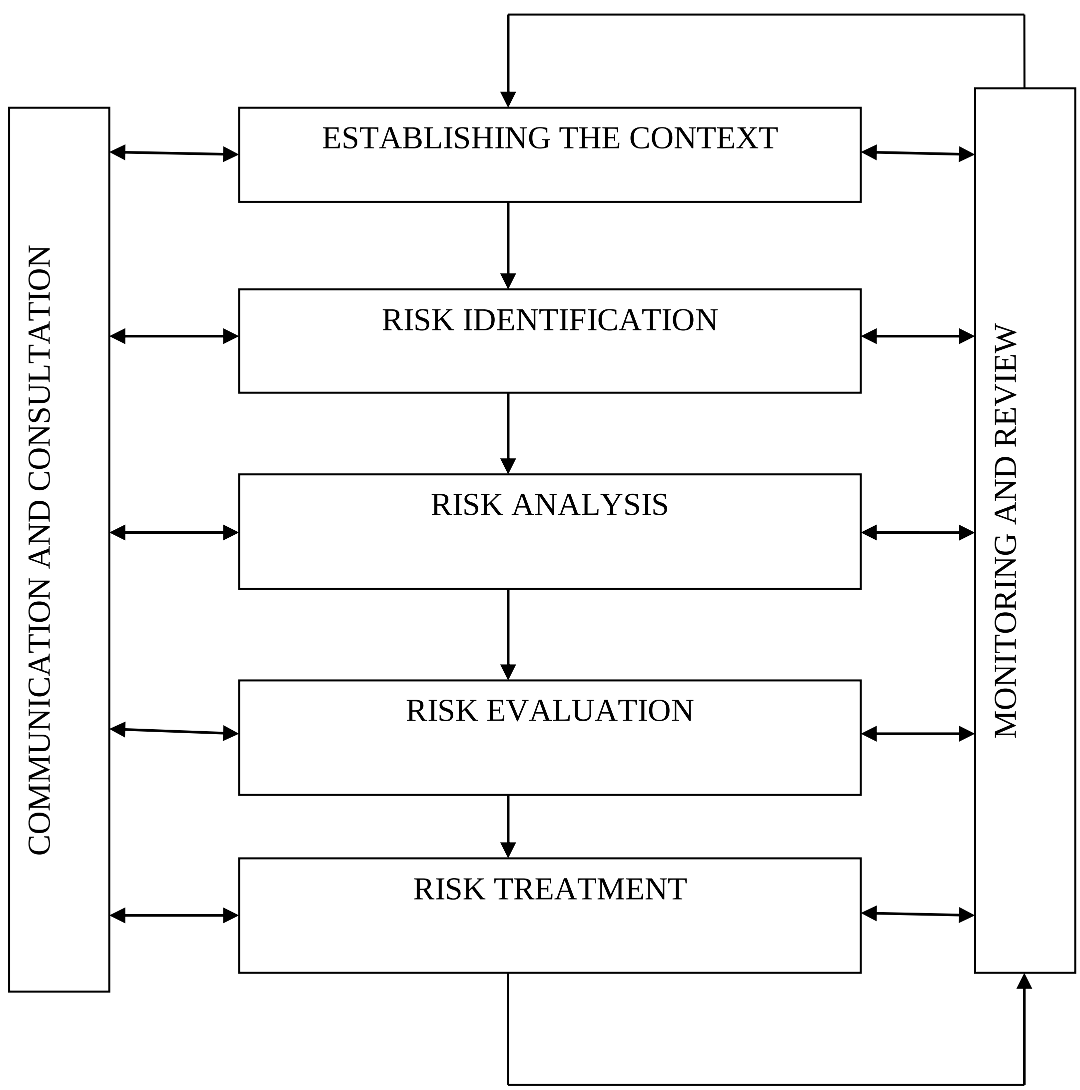

Figure 2. 1 Risk management process (ISO 31000:2009)

According to ISO 31000:2009, setting up the risk management process will differ as per the structure and the necessities of the association. It will incorporate exercises like defining objectives and destinations for risk management and characterizing the obligations, extension, profundity and broadness of the procedure. This is a fundamentally critical advance in the process since it will guarantee that the risk management approach is proper to the association, its risks and targets. It additionally incorporates point by point investigation of the internal and external partners, condition and key drivers and patterns that affect the destinations of the association.

According to Curtis and Carey (2012), risk assessment is the general procedure of risk detection, investigation and assessment. Recognizing risk incorporates understanding the source of risk, regions of effect, occasions and their causes and potential results. The objective is to make a thorough rundown of risks, including risks that might be related with botched chances and risks out of the immediate control of the association. A complete survey permits a full thought of potential impacts of risk upon the association (Curtis & Carey, 2012).

According to Tsakatikas and Kaisarlis (2007), FMECA is a widely established methodology used for identifying and analyzing all potential failure modes of a system. Through the FMECA application the mechanisms driving failure appearance as well as the failure effects and consequences of each individual case are examined. This takes place through a structured methodology which results in the assessment and quantification of the Criticality of a certain component.

In general as stated in Tsakatikas & Kaisarlis, (2007) three factors are used for defining criticality: First *Severity* (S) which defines the consequences of a failure occurrence and its calculation may be based on the consequences severity induced in qualitative terms (e.g. catastrophic, fatal, severe), or quantitatively (e.g. hours of downtime). Secondly, the *Occurrence* (O) which defines the frequency and illustrates the possibility - likelihood that a failure will occur. It may be based on a failure rate (λ) measurement or simply on the number of occurrences over a specified time interval (e.g. six months, one year). Finally, *Detection* (D) which defines the likelihood that symptom of a potential failure may be detected before having the actual failure occurrence. This factor is not given equal importance and even omitted in some studies of FMECA, especially those aimed most on process-based FMECA. Criticality for each component is evaluated as the product of these three terms which forms the Risk Priority Number (RPN).

RPN = S x O x D………………………………………………………………….(i)

Another method used to prioritize the critical spare part is by classifying into three categories: Vital (group V), Essential (group E) and Desirable (group D). According to (Bošnjaković, 2010), it could be noticed that four points of view ought to be mulled over. These are: generation, supply, safety and stock.

a) Criticality related with generation

For the upkeep work force, fundamental objective of their activity is to accomplish the accessibility and reliability of equipment to guarantee the production process. Only one out of every odd equipment has a similar impact to the framework. The production would not be influenced if in lack of some extra spare parts. Be that as it may, for other extra parts, the deficiency would result in the intrusion of activity of the general production. For one spare part, regardless of whether it is or not on the stock does not have a similar significance. The criticality of spare part is basically molded by criticality of hardware in which the spare part is utilized. Some extra parts are utilized just in one machine, while some are utilized broadly in numerous machines (Bošnjaković, 2010).

b) Criticality related with supply

Each spare part possesses it's time for acquiring. The lead time for obtaining could be over 4 months, under about fourteen days or in between. The lead time characterization could be subjective (Bošnjaković, 2010).

c) Criticality related with safety

It is critical to assess the security factor of each spare part. Absence of spare part could cause environmental calamity, risk to person, or effect on the sheltered activity of different machines. While for some spare parts, its disappointment does not have incredible impact to different machines, environment or human-being (Bošnjaković, 2010).

d) Criticality related with inventory

Some spare parts in the long run lose their quality or ease of use and might be basic for inventory (storage). In the event that the spare parts have huge measurements and weight, it might cause some pragmatic trouble for the support work force. In this regard if the spare part is exceptionally basic, its attractive quality is not exactly the same as the one with ordinary measurement and weight (Bošnjaković, 2010)

According to Fuchs, Kamenicky, Saska, Valis, & Zajicek, (2001), Hazard and Operability Analysis (HAZOP) is an organized and methodical procedure for framework examination and risk management. The HAZOP method was at first created to dissect concoction process systems, yet has later been stretched out to different sorts of systems and furthermore to complex tasks and to software systems.

HAZOP depends on a hypothesis that accept risk occasions are caused by deviations from structure or working expectations. Recognizable proof of such deviations is encouraged by utilizing sets of "direct words" as an orderly rundown of deviation points of view. This methodology is a one of a kind component of the HAZOP procedure that invigorates the creative ability of colleagues while investigating potential deviations. The HAZOP is a subjective strategy dependent on guide-words and is completed by a multi-disciplinary group (HAZOP group) amid a lot of meetings (Fuchs et al., 2001). In the sugar industry the HAZOP team consists of representatives from the following departments; electrical, mechanical, Process, laboratory, planning, civil and building.

The quantity of real misfortunes and expensive breakdown because of inaccessibility of spare parts in sugar factories has presented difficulties for upkeep, planning, creation and stock control. Besides this issue it has prompted breakdown of the equipment which in the long run effect organization's execution (Jafni et al., 2015). The reason for breaking down risk is to comprehend everything conceivable about risks, including the causes and sources, results and probability of event. Existing controls and their adequacy and effectiveness are likewise considered (ISO 31000:2009). The motivation behind risk assessment is to audit the examination, criteria and resilience of risks so as to organize and pick suitable risk treatment techniques. An association's lawful and administrative condition in its internal and external setting ought to likewise be considered at this stage. The assessment procedure enables associations to settle on proper choices about whether and how to treat risks (Parkinson and Finger, 2010).

Risk treatment includes choosing at least one choices for alleviating risks and executing those alternatives. Risk treatment is a repeating procedure that evaluates a risk, decides if the residual risk is at a middle of the road level and if not, which extra treatments should be actualized and surveying the adequacy of treatments (ISO 31000:2009). Communication and consultation must happen all through the procedure and ought to incorporate both internal and external partners. Risk management will fail if consultation and commitment of partners in the process isn't done (ISO 31000:2009). Observing and audit is basic to the risk treatment process since it guarantees that controls are viable, exercises are found out, risks fittingly tended to and the association is flexible and prepared for change. (Curtis and Carey, 2012).

2.2.2 Spare part inventory management

Spare parts inventory management is a total strategic service management process that organizations use to guarantee that correct spare part and assets are at the ideal place and the opportune time. Spare parts inventories are unique in relation to different sorts of inventories in organizations. According to Grondys (2013), in a manufacturing organization the spare parts essentially contrast from inventory of creation raw materials, work in progress and finished items. Firstly, inventories of generation raw materials and work in progress are maintained in request to diminish inconsistencies that may happen during creation. These varieties may result from changes that have happened in the structure of the item, equipment disappointments or value contrasts for transport services and vitality supply. Furthermore, inventory of finished items are an immediate wellspring of supply to final clients and they are put away in request to shield from irregularities occurring on market. The job of spare parts inventories in manufacturing process is to guarantee help and maintain full readiness of equipment and machine to work. Spare parts inventories are not intermediates and final items sold to the client on the final market (Kennedy et al., 2002).

Muckstadt (2004), have pointed out some imperative factors in the management of these inventories: Customers have rising desires concerning nature of related items and services. The event of disappointment is as of now a worry and the deferral in repairing because of absence of spare parts declines customers' negative observation; Some things have popularity (parts with extraordinary wearing and those identified with preventive maintenance), yet the incredible larger part has intermittent interest. The increasing multifaceted nature of items and the existence cycles decrease create an increase on the measure of dynamic codes and risk of obsolescence. Initially, it is imperative to distinguish expendable parts from repairable ones.

Spare parts are incredibly costly in a few portions and their fixation/repair (instead of disposing of) is plausible; harmed units can be supplanted either by new units or by fixed ones. For this situation, the inventory control models ought to likewise consider the expenses and fix time. Sherbrooke, (2004), talks about the instance of repairable parts. Another component of the inventory control is related with the presence of single or different areas inventories (Kennedy et al., 2002). Request forecasting is utilized to evaluate the inventory control parameters and at times additionally to choose the amount to order at the renewal time (Hemeimat et al., 2016).

At that point, a few techniques for item classification are amended in request to set up the inventory control regarding the sort of control, service level and related expenses. The angles typically considered in these orders contain esteem, criticality, request, and the item's stage in the existence cycle. The existence cycle of spare parts is related with the existence cycle of the final items which use them (Fortuin & Martin, 1999). Their interest is influenced by a few elements: size and age of the "populace" of final items (deals, running armada, installed base, and so on.); maintenance qualities of these items (preventive, restorative, and so on.) and attributes of the parts and their imperfections (wear, mishap, aging, and so forth.).

Fortuin, (1980) divides the life cycle of parts in three phases: initial, normal or repetitive and final. All through these stages, distinctive choices must be taken: to hold inventory or not: demands which are low in the beginning of the existence cycle (just as in the end) lead the supervisor to address whether parts ought to be put away or not (Li & Kuo, 2008). For some things, the demand is low to the point that the choice of not storing, meeting the demand by chance after its event might be the best choice; initial requests: uncertainty about the demand development hampers the planning of the initial requests; inventory control: after deciding that the part should be put away, an inventory recharging routine is vital, considering distinctive objectives (costs as well as service level) and demand conduct (patterns and regularity) and; final requests: high generation and maintenance expenses of the beneficial procedures related with low demands and expected life expectancy of items lead organizations to interrupt the creation of parts at a given time. At times, the last creation clump is increased to give extra spare parts final inventory (Kennedy et al., 2002).

To successfully oversee spare part inventories, the following advances are required; spare part inventory management strategy, spare part criticality and inventory risk alleviation (Eman et al., 2012). Basic spares management is one of the Key Performance Indicators (KPI's) of maintenance spares inventory management (Dewald, 2011). Deciding to stock or not to stock a spare part should concentrate on the criticality of the part to the sustained task of equipment resources for the generation office (Wally, 2010). Finally, spare part criticality remains a vital viewpoint in spare parts management as not every single spare part are similarly vital and ought to be overseen accordingly to improve execution of the plant. Spare part criticality can be estimated by utilization of disappointment recurrence, accessibility in the market, down time and lead time (Eman et al., 2012).

2.2.3 Risk based approaches in spare part inventory management

The inventory level to be maintained will rely on the need of such parts in back to back time intervals or inventory cycles to fulfill the maintenance necessities with an adequate risk level (Anwar et al., 1991). The trade-off involves the expense of stocking spare parts from one perspective and the expense of not meeting a demand for a section (stock out) on the other. Risk based methodologies, rather than numerous different methodologies, give administrators some adaptability in the management of their advantages while meeting similar destinations (Bharadwaj et al, 2011). Subjective risk examination comprehensively covers techniques that utilization engineering judgment and experience as the reason for the investigation of probabilities and results. Failure Modes, Effects, and Criticality Analysis (FMECA) and Hazard and Operability Studies (HAZOPs) are instances of subjective risk examination (Bharadwaj et al., 2011). Brown and May, (2003) suggested the implementation of regular inspection activity for the high risk spare part in order to avoid the potential failure and achieving appropriate risk toleration.

Khan and Haddara, (2004) used the risk matrix to define the risk and consequences. Besides that, (Balemans, 1947) developed checklist for chemical industry and (Rogers, 2000) used the check list for listing the possible risk that is related to plant hazard in operation. Assessing risk is crucial because the decision to maintain equipment can affect cost (Arunraj & Maiti, 2007). Consequently, spare parts have incredible influence on a wide range of maintenance exercises and the accessibility of process plant. For the instance of basic equipment this could prompt extreme results like unreasonable downtime costs, inert labor cost, etc. Maintenance regularly relies upon the spare parts accessibility and along these lines; the ampleness of parts in stock directly affects the operability of the framework. It could without much of a stretch be accomplished by storing a satisfactory amount of spares in the inventory. Hassan et al., (2012) built up a risk-based methodology for spare parts demand figure and spare parts inventory management for compelling designation of constrained assets. Adams, (2004) utilized improvement system to determine the best technique to anticipate initial stock necessities and evaluate the risk.

According to Flint (2006), the commercial aviation industry has as much as $30 billion worth of spare engines on stock. This is expensive in terms of holding cost and capital. The funds used to stock the spare parts could have been used in production hence increasing the profits.

The spare parts breakdown led to a loss in the production of the industry. For example, in the semiconductor industry alone, the loss of generation because of breakdown issues evaluated at a huge number of Euros every hour (Kranenburg, 2006). Dhillion, (2002) concurred that by eliminating certain risk in maintenance; the operating expense can be decreased by around 40-60%. Then again, spare parts accessibility playing a critical job in maintenance system (Ibrahim et al., 2015). According to Sullivan et al., (2010) spare part inventory management has the biggest effect towards maintenance productivity. Inappropriate spare part inventory management results in hindered maintenance process and eventually prompted the issue of organization opportunity misfortune (Ibrahim et al., 2015). There is a growing worry to address the issue of spare part inventory dependent on the potential risks presented by the inaccessibility of the spare parts to the equipment and machines in the sugar plant.

Hence, the problem of spare parts inventory is critical and the issues in spare parts management need to be solved accordingly. Risk-based approach is one of the techniques that are commonly used to deal with issues of uncertainties in executing management choices. This approach helps decision makers to formulate strategic options and decisions to assess various impacts and implications (Zsidisin, 2003). Specifically, risk perspective in plant maintenance is essential for ensuring asset integrity in a process facility (Hassan et al., 2012).

2.3 Concept of performance of factories

Performance is a function of the production process efficiency and effectiveness which can be compromised by lack of spare parts required for maintenance (Obamwonyi & Gregory, 2010). It is essential to have the spare parts available to maintain your equipment and plant (Wally, 2010). Effective spare parts inventory management guarantees availability of maintenance resources which dictates the ability of maintenance organization to match the maintenance workload aimed at achieving and sustaining optimum availability of production facility (Wireman, 1990). Effective Spare parts inventory management will engender maximum production and ensuring equipment availability at a lower cost with higher quality besides optimizing availability of spare parts hence high manufacturing performance. It can therefore be inferred that effective inventory control and management of spare parts remains essential for many companies as it enables them to achieve high service levels without unnecessary high inventory cost that would affect their performance.

According to Georgopoulos and Tannenbaum, 1957 cited in (Corina et al., 2011) organizational performance is the extent to which organizations, viewed as a social system fulfilling their objectives. In this study, factory performance indicators as non financial measures will be used as a measure of organization performance. These measures will include Equipment availability, downtime, production, health, safety and environment (HSE) and Factory time efficiency (Mwanaongoro & Imbambi, 2014).

2.4 Empirical literature review

2.4.1 Spare part risk identification techniques

The dimension of spares in an inventory has an immediate bearing on machine accessibility subsequently a precursor of risks. The accessibility of a machine is a component of the interim to address a disappointment, which in turn relies on, an opportunity to obtain a spare (to lead fixes) or a substitution (Bharadwaj et al., 2011). Choices within resource integrity management that include choices regarding inspection, fix, maintenance, substitution and the stocking of spares have generally been founded on a scope of works on including the prescriptive time sensitive (rule-based) approach, the condition-based methodology, Reliability Centered Maintenance (RCM) and Reactive Maintenance (RM) (Craig, 2010).

All companies should have a critical equipment verification program, where documentation, design and specification of the critical spares of equipment are independently reviewed to ensure they are fit for service therefore, spare part risks are reduced. The program should include regular reviews during the lifetime of the items, especially when standards change in terms of deterioration in condition, down time and changes in service conditions. Extreme value analysis to assess degradation out with the inspection regions, refinement of inspection intervals and locations when updated regularly results to reduction in the risk of unplanned failure (Craig, 2010). Maintaining an inventory at an ideal dimension depending on the risk profile of the spares in which the probability of an inability to take care of the demand for a spare is considered. The ideal dimension is with the end goal that financial advantages are upgraded, given risk-related constraints (Bharadwaj et al., 2011).

Over all issues that are identified with maintenance risk, there is a need to install a proper inventory strategy that can address the issue of maintenance (Adeyemi & Salami, 2010). Dhillion, (2002) concurred that by eliminating certain risk in maintenance; the operating expense can be diminished of around 40-60%. Materials and equipment's accessibility plays a huge job in maintenance procedure. According to Sullivan et al., (2010) inventory management has the biggest effect towards maintenance productivity. In this circumstance there are two main factors that can be centered around, which are the recurrence of equipment breakdown and recurrence of spare parts substitution. The dimension of the risk esteem will be relied upon the definition procedure and arrangements from the quantity of spare parts required and the recurrence of substitution (Jafni et al., 2015).

2.4.2 Spare parts criticality

Spare parts criticality is concerned with the consequence(s) of a part failure on the asset level which translates to plant performance. Spare part criticality can be measured in terms of the effects of its absence on production, lead time and failure frequency (Wally, 2011). There are a few components involved in determining the status of repair parts in a Maintenance, Repair and Operations (MRO) inventory. A portion of these parts are fundamental to the activity of generation equipment in a manufacturing plant and different parts don't have such an extreme effect on the procedure (Eaves and Kingsman, 2004). To determine what parts should be hung nearby as basic or an insurance spare, a criticality investigation of the maintainable resources is directed to rank the likelihood of effect on the generation procedure or worker security if the equipment were to come up short. In numerous instances the criticality investigation uncovers that the likely disappointment of the equipment under survey would directly affect representative security, condition or the capacity of the creation procedure to run successfully. According to Tsakatikas & Kaisarlis, (2007), stated that Failure Mode Effect and Criticality Analysis (FMECA) is a methodology used for identifying and analyzing all potential failure modes of a system. The criticality of the spare parts will be defined by the severity(S), Occurrence (O) and Detection (D) of the failure which will be used to determine the Risk Priority Number (PRN) (Tsakatikas & Kaisarlis,2007).

According to Fuchs et al., (2001), Hazard and Operability Analysis (HAZOP) is an organized and precise strategy for framework examination and risk management. A cross-useful group made out of workers from Operations, Maintenance, Engineering, Materials Management and Safety leads the primary period of a criticality examination (Regattieri, 2005). The investigation takes a look at the effect equipment disappointment would have on client orders, time to production interruption, worker security, condition, the capacity to segregate the fizzled equipment, equipment history of Mean-Time-Between-Failures (MTBF), PM/PdM history and the general consistency of disappointment. Every one of these components is looked into and given a weighted score somewhere in the range of zero and 100 that changes over into a section criticality ranking (Tsakatikas et al., 2008).

The scores are isolated into classes which indicate the seriousness of disappointment from disastrous to significant or insignificant. A disastrous rating would indicate a item or section or gathering which must be held in the inventory; it is a critical part for a critical resource/asset (Tsakatikas et al., 2008). A significant rating would indicate the part is for a non-basic resource and would most likely fall into the classification of an ordinary MRO consumable thing. The insignificant rating would indicate that the part was a non-basic thing and not a security concern on the resource/asset.

The second period of the criticality investigation is to determine if the thing will be hung nearby as a piece of the MRO inventory or assigned as a non-stock, arrange on demand basic spare. Parts held in the MRO inventory are an investment to guarantee generation isn't interrupted and security of the representatives and condition are not traded off (Fortuin & Martin, 1999). These parts that are obtained and held as a component of the inventory have an ongoing expense related with their management. A spare part held in the inventory, regardless of whether basic or non-basic has a handling or yearly carrying expense of 17 to 25% of the expense of the thing in the normal MRO inventory. In five years the related carrying cost has multiplied the cost of the spare part five times (Eaves & Kingsman, 2004).

A risk investigation that assesses the lead time from the time the request is put with the provider until receipt of the thing on location is additionally a factor that influences the choice to stock the spare part as a feature of the inventory (Muckstadt, 2004). The unwavering quality of the provider to meet the normal lead time for the part ought to likewise be a piece of the risk examination. Providers providing basic spare parts ought to experience an accreditation procedure and be under contract to moderate unforeseen lost generation time and deferred conveyances. A few sections must be obtained from a single provider. In the event that spare parts accessibility is restricted to a single provider, the inquiry should be solicited, "What is the financial status from this provider?" If there is a probability that the provider could leave business because of a pushed monetary condition, the choice may be to purchase what is accessible and hold the spare parts in inventory to relieve that risk (Gomes & Wanke, 2008). In the event that parts are out of date or the producer is never again producing these explicit parts, the choice may again be to buy the accessible parts and hold them in inventory as a fence against conceivable equipment disappointment.

The basic spare part adds to the significant misfortunes in the generation because of delayed down time and diminished effectiveness. According to Ibrahim et al., (2015), the quantity of significant misfortunes and equipment breakdown because of inaccessibility of basic spare parts prompts expensive downtime due to lost production time and unutilized labor.

2.4.3 Spare part risk mitigation strategies

The spare part risk mitigation is the prevention of losses due to unavailability of spare part. Spare part risk mitigation is the process in which risk level is minimized and plant availability is maximized within the financial constraint (Jaikul et al., 2012). This is measured by total stock cost, total risk value and probability of stock out (Arts, 2013). These measures include Frequency of failure, Availability, Downtime and lead time (Mwanaongoro & Imbambi, 2014).

The proposed strategy for risk mitigation will be based on the risk category. These categories are: Most critical spare part, Semi critical spare part and Non critical spare part. To begin with the most critical spare part the strategy is to order before the stock is depleted. The item used from the store will be ordered to replace it. The re-order point will be determined through constant evaluation of the inventory. The demand forecasting on spare parts will be accurately determined to establish the stock levels taking into consideration the desired service level (Eman et al., 2012). The maintenance and planning department in the sugar industry make an order of the same amount used during maintenance to replace the baseline, to keep the inventory position constant (Harris, 1990). Secondly, the semi critical spare part will be stocked based on the projected need. According to Hanson et al., (2015) a perpetual inventory control process audits inventory status day by day to determine inventory renewal needs. To use never-ending audit, precise tracking of all Stock-Keeping Units is vital. Interminable survey will be executed to re-arrange the re order point and ordered amount done daily. Finally, the non critical spare part according to Harris, (1990) on Economic Order Quantity (EOQ) the Continuous Review (R, Q) display the inventory is continuously checked and when the re order point "R" is achieved a great deal size of "Q" (monetary request amount) is put. Under this arrangement, the sugar industry will pay for the spare part with amount rebate or quantity discount.

A Proactive and efficient spare parts inventory management policies remains very basic since maintenance parts stock outs may prompt noteworthy generation misfortunes, as well as intangible cost, for example, increased risk to operating faculty (Gu, 2013).

Different categories of spares call for different replenishment policies. In this study spare parts inventory management policies are measured using Continuous Review and periodic review policies (Hanson et al., 2015). Spare parts which are essential to the operation of production equipment in a manufacturing plant and other parts do not have such a severe impact on the process (Eaves & Kingsman, 2004).

The objective of effective compelling spare part inventory management strategy being a piece of inventory control are: to relate spare part stock and store amounts to demand; to stay away from misfortunes because of decay, pilferage and out of date quality; to obtain the best turnover rate on all spare part things by considering both the expense of acquisitions and assets; to decrease stretched out downtime because of un-deliverability of the spare part (Markeset, 2011).

2.5 Research gap

The Risk Based approach to Spare part Inventory Management presented in this study is consistent with risk based decision making approaches used in maintenance and inspection planning within the process industry. However from the empirical review there were some research gaps.

Bharadwaj et al., (2011) conducted a study on Risk based life management of offshore structures and equipment. This study was limited to the maintenance actions in the industry to ensure asset integrity in the offshore structures and equipment. The current study relied on secondary data on spare part inventory and maintenance in the sugar factory to determine spare part criticality.

Craig, (2010) assessed how predictive analytics helps improve Critical Equipment Reliability. The study was a desk research which relied on technical notes. The study concluded that Predictive Analytics helps increase revenue, reduce maintenance costs, and improve safety through reduction of equipment failure. The limitation of the study is that it emphasized on a specific equipment/machine leaving other parts of the plant. The current study looked at the spare parts that are used in the four sections of the sugar factory.

Adeyemi & Salami, (2010) Inventory Management: A Tool of Optimizing Resources in a Manufacturing Industry; a case study of Coca-Cola Bottling Company, Ilorin Plant. In their study they acknowledged the fact that there is a need to install an appropriate inventory technique that can address the issue of maintenance to reduce maintenance risks. Their findings indicated that inventory management is a must for the continuity and survival of any goal focused manufacturing organization. The limitation of this study is that it didn’t address spare parts inventory management.

Inventory Management: A Tool of Optimizing Resources in a Manufacturing Industry; A Case Study of Coca-Cola Bottling Company, Ilorin Plant. In their examination they recognized the way that there is a need to install a suitable inventory procedure that can address the issue of maintenance to diminish maintenance risks. Their findings indicated that inventory management is an unquestionable requirement for the continuity and survival of any objective centered manufacturing association. The impediment of this investigation is that it didn't address spare parts inventory management.

Jakiul et al., (2012) contemplated a risk based way to deal with non repairable spare parts inventory in Canada. The examination concentrated mainly on risk based spare parts criticality ranking, forecasting, and compelling risk decrease through key acquirement arrangement to guarantee spare parts accessibility. The paper proposed a risk based approach that utilized conjugate dissemination strategy with the ability to incorporate authentic disappointment rate just as master judgment to assess the future spare demand through back demand conveyance. The methodology continuously refreshes the earlier circulation with latest perception to give back demand conveyance. Hence the approach is unique in its kind. This study was limited to non repairable spare parts inventory leaving the consumable spare parts. In the current study, all spare parts that are being utilized by the sugar factory were all considered.

Kamal et al., (2016) in their study on spare parts inventory risk for decision making in plant maintenance. This paper describes the development of risk technique for plant maintenance decision making purposes using the Shortage and Excess Impact Table. It also used the Breakdown Probability Table to quantify the risk for the spare part failure. However the paper concluded that Equipment breakdown due to unavailability of spare parts is really disastrous in plant maintenance. The failure increases the cost of repair and production downtime. It is imperative to comprehend the maintenance and inventory works in request to guarantee the plant work accordingly. In addition, it is fundamental for the plant maintenance to adjust the issue of lack and overabundance of inventory in plant maintenance. This study was limited to the stocking levels of the spare parts by analyzing the risk using the shortage and excess impact table. The current study the researcher used the lead time, frequency of failure, availability in the market and down time to determine the spare part criticality.

The question of how many spares parts to stock has been addressed by numerous researchers. However, there are irregularities in findings caused by factors such as changes in product mix, differences in equipment breakdowns, differences in machine production rates, maintenance policies and difference between processes and material handling and gap between capacity and demand and other well established production problems and different contexts. The current study also concentrated on all classes of criticality of spare parts having operational consequences which is a dispatch from the previous studies which only concentrated only on complex and expensive spare parts leaving cheaper and frequently used spare parts with low associated shortages. This compromises on the generalizability of these studies providing a research gap invoking the need for more research to be done on development of risk based approach to spare part inventory management for sugar factories in the context of Chemelil sugar factory.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the research design, study area, data collection instruments and procedures and finally, data analysis per objective.

3.2 Research design

The research design entails in-depth study of a particular research problem rather than a sweeping statistical survey (Creswell, 2012). In this research the case study research design was adopted. Case study research excels at bringing us to an understanding of a complex issue or object and can extend experience or add strength to what is already known through previous research (Dooley, 2002). Here, the researcher performs in-depth investigation of Sugar factory maintenance and inventory of spare parts with view of developing a risk based approach to spare part inventory management. The case study narrows down from a broad field of research problems into one or a few easily researchable problems. The case study enabled the researcher gain insight of the equipment failure and spare part inventory and their relationships. The design can extend experience or add strength to what is already known through previous research, providing a detailed description of specific and rare cases.

3.3 Data collection

The Data was collected using document analysis of the factory maintenance and spare part inventory (spare part store) records in 2016/2017 financial year which included, lead time (time to delivery of spare part), availability in the market, frequency of failure and down time from the spare parts inventory records . The plant maintenance records in the four sections (Pre mills, Mills, Boiler and Juice treatment) of the sugar factory in 2016/2017 financial year were recorded. Secondary data was collected from spare inventory and maintenance section of Chemelil Sugar Company. Secondary data was used because it was found to be objective, allow for greater validity and more generalizable findings (Smith, et al, 2011). The study employed purposive sampling to select participants from the factory employees. This implies that all employees in the procurement, planning and maintenance department of Chemelil Sugar Company participated in the study.

3.4 Data analysis

Data analysis involves inspecting, transforming, and modeling data with the objective of highlighting valuable information, suggesting ends and supporting basic decision making (Adèr, 2008). Failure Modes, Effects and Criticality Analysis (FMECA) were utilized for failure mode and impacts analysis. It includes a criticality analysis, which is utilized to graph the likelihood of failure modes against the seriousness of their results (Silvestri et al., 2012). Criticality analysis is a quantitative analysis of events and the ranking of these in request of the reality of their results. Pareto analysis was done to concentrate on the materials whose supply takes higher positions in all out estimation of material utilization and all out estimation of turnover in the organization. Break down data was exhibited by utilization of tables and charts. The data was investigated by utilization of SPSS Version 21 and Excel.

3.4.1 Risk identification due to unavailability of spare part

This entailed identification of the down time due to unavailability of spare parts for repairs by the maintenance team. The failure mode to be addressed and the frequency of the spare parts used in one year were analyzed. Data was presented by use of histogram to aid in risk identification in the factory. Pareto analysis was used to analyze for parts of the plant which suffered the highest down time in the factory and root causes of downtime.

3.4.2 Assessment of spare part criticality using FMEA

For each of the spare part; the lead time, availability in the market, down time, frequency of failure and detect ability were extracted. The risk was calculated as follows:

3.4.2.1 Risk based on the lead time

Risk (Criticality index) = Lead time (Severity) X Frequency of failure (Occurrence)… (ii)

Where; lead time- time required in ordering, transporting and receiving the spare part

Frequency of failure (Occurrence) - Number of times the part failed in the period of study.

Risk Priority Number (RPN) = Severity(S) X Occurrence (O) X Detection (D)……. (iii)

Where; Severity - Lead time

Occurrence - Frequency of failure

Detection – ability to detect the failure

The criticality index calculated and the spare parts categorized as critical, semi critical and non critical and presented on a risk matrix table. A histogram was used to compare the criticality index and the risk priority number of the spare parts considered in the study.

3.4.2.2 Risk based on the availability

Risk(Criticality index) =Availability (Severity) x Frequency of failure (Occurrence). (iv)

Where; Availability – Availability in the market

Frequency of failure (Occurrence) - Number of times the part failed in the period of study.

Risk Priority Number (RPN) = Severity(S) X Occurrence (O) X Detection (D)…… (v)

Where; Severity - Availability

Occurrence - Frequency of failure

Detection – Ability to detect the failure

The criticality index calculated and the spare parts categorized as critical, semi critical and non critical using the risk matrix.

A histogram was used to compare the criticality index and the risk priority number of the spare parts considered in the study.

3.4.2.3 Risk based on the down time

Risk (Criticality index) = Down time (Severity) X Frequency of failure (Occurrence). (vi)

Where; Down time – Time that the equipment is out of use due to failure

Frequency of failure (Occurrence) - Number of times the part failed in the period of study.

Risk Priority Number (RPN) = Severity(S) X Occurrence (O) X Detection (D)…….. (vii)

Where; Severity - Down time

Occurrence - Frequency of failure

Detection – ability to detect the failure

The criticality index calculated and the spare parts categorized as critical, semi critical and non critical using the risk matrix.

A histogram was drawn to compare the criticality index and the risk priority number of the spare parts considered in the study.

3.4.3 Determination of inventory risk mitigation strategies

In this section, the researcher calculated the safety stock, reorder point as compared to the lead time to decide on the appropriate risk mitigation strategies based on their criticalities as shown in equation (viii), (ix) and (x).

Reorder point = Lead time demand + safety stock……………………………… (viii)

Lead time demand = Lead time in months x Average monthly usage ………….. (ix)

Safety stock = (Maximum monthly usage x Maximum Lead time) – (Average monthly usage x Average monthly lead time)……………………………………………….. (x)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the data presentation and discussion. The study established the risk based approach to spare part inventory management for sugar factories: A case study of Chemelil Sugar Company. The chapter is divided into three sections that address the three research objectives. The first section discuses the process of risk identification by using the spare parts consumed within the research period in the factory by the maintenance team. The results were collaborated by the use of Pareto analysis from the down time experienced in the four sections; Pre mills, Mills, Boiler and Juice treatment section due to insufficient spare parts. The second section will discuss the results of spare part criticality analysis and risk evaluation identified using FMEA, the risk matrix and Pareto analysis. Lastly, the third section will discuss the spare part inventory risk mitigation strategies to be adopted in order to reduce risk.

4.2 Risk identification due to unavailability of spare part

After the computation of the total down time from the four sections; Pre mills, Mills, Boiler and Juice treatment, the researcher was able to get the most critical section in the factory as seen from Figure 4.1 below. The x-axis represents the section in the factory, y-axis represents the down time in hours. From the Pareto analysis of the four sections it was established that the boiler, pre mills, mills and juice treatment had a downtime of 315.51 hrs, 294.19 hrs, 111.13hrs and 82.3 hrs respectively. It can be inferred that the boiler, pre mills, suffered the highest down time in the factory. Down time is an index of failure of spare parts which amounts to risks calling for risk vigilance (Slater, 2018). This argument gives credence to the use of downtime for purposes of risk identification. It can be observed that the downtimes experienced by the factory for a period of one year caused by spare part unavailabilty was exceptionally high due to the interdependence of the four sections in the factory.

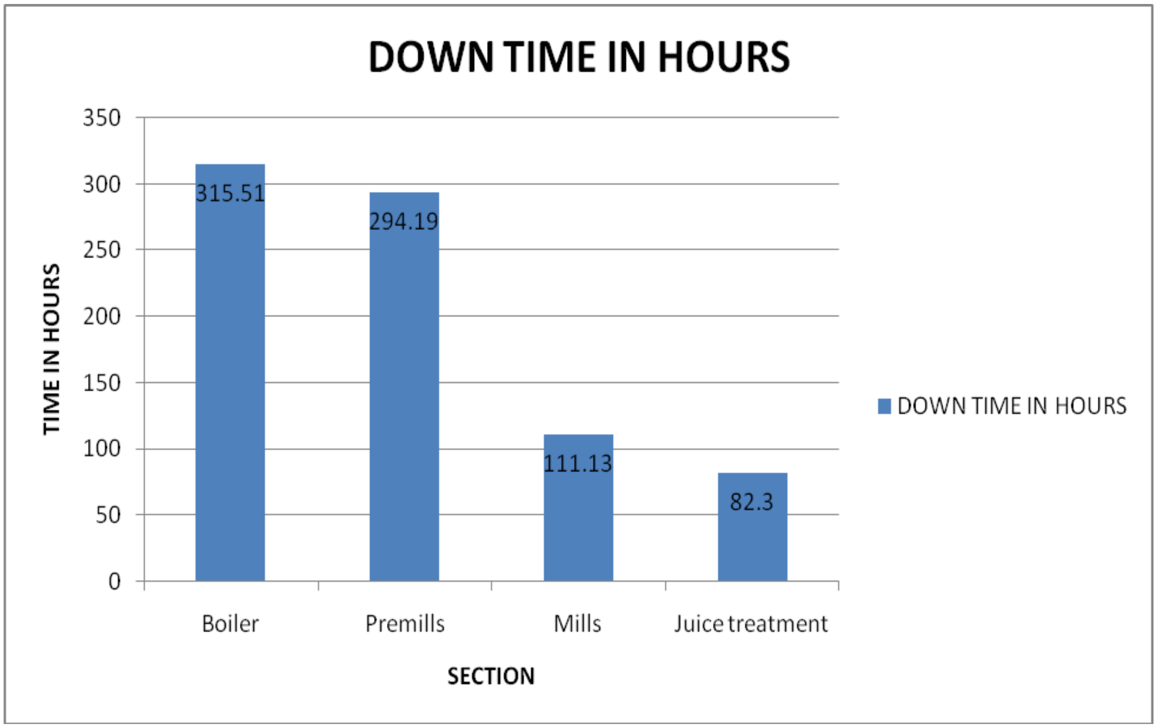

Figure 4. 1 Downtime in the four sections (Pre mills, Mills, Boiler and Juice treatment) for a period of one year (2016/2017)

The root causes of the risks are the frequency of failure and unavailability of the spare parts consumed in the factory sections highlighted in Figure 4.2. 20 spare parts that caused the failure in the factory four sections were analyzed as shown in figure 4.2 based on their frequency of failure. It was realized that the spare parts used occasioned risk occurrence ranging from 2 to 756 times a year. All this spares remain a source of down time as they are applied in all the four sections of the factory. From Figure 4.1 and Figure 4.2 the study identified that the extended down time in the four sections could be probably adduced to spare part frequency of failure.

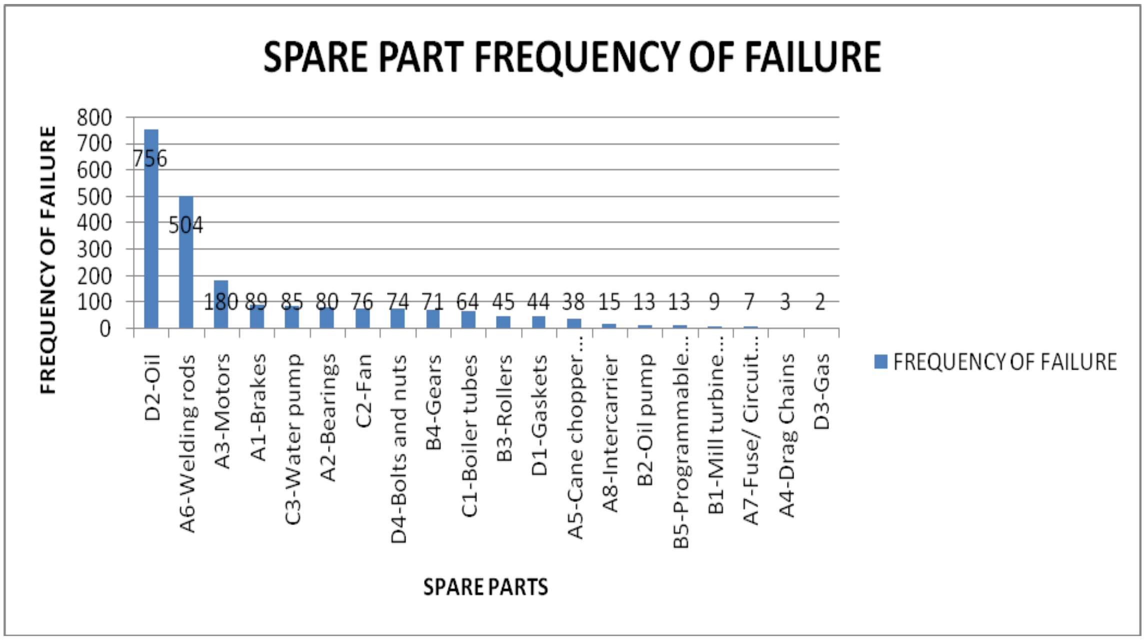

Figure 4. 2 Spare parts against risk occurrence for a period of one year (2016/2017)

4.3 Assessment of spare part criticality using FMEA

Each spare part purchased by the factory is a way of mitigating the consequence of failure of the part in operation. This calls for risk analysis and evaluation. In this study the Lead time, availability in the market, down time, frequency of failure and detect ability were used to analyze and evaluate the risk.

4.3.1 Risk analysis on the lead time

For the four sections whose down time was analyzed in Figure 4.1, the extended down time was due to unavailability of the spare part due to extended lead time as shown in Figure 4.3. From Table 4.1 and the risk matrix shown in Table 4.2, the twenty spare parts considered in the analysis were categorized based on the criticality index. The high risk (critical) spare parts were the Motors, Water pumps and the gears which had a criticality index of 8 and above, which was considered as according to the risk assessment matrix adapted from (Roberts, 2007).

The semi critical spare parts as depicted in Table 4.1 had a rating of 3-6 according to the risk matrix indicated in Table 4.2. The semi critical spare parts were: Welding rods, Mill turbine governor, Oil pump, Bearings, Rollers, Programmable Logic Controllers (PLC), Oil, Brakes, Intercarrier, Boiler tubes and Fan.

The non critical spare part indicated in Table 4.1 and Table 4.2 has criticality index of 1 to 2. These spare parts were: Drag Chains, Bolts and nuts, Cane chopper and knife, Fuse/ Circuit breakers, Gaskets and Gas. These findings are further corroborated in Figure 4.3.

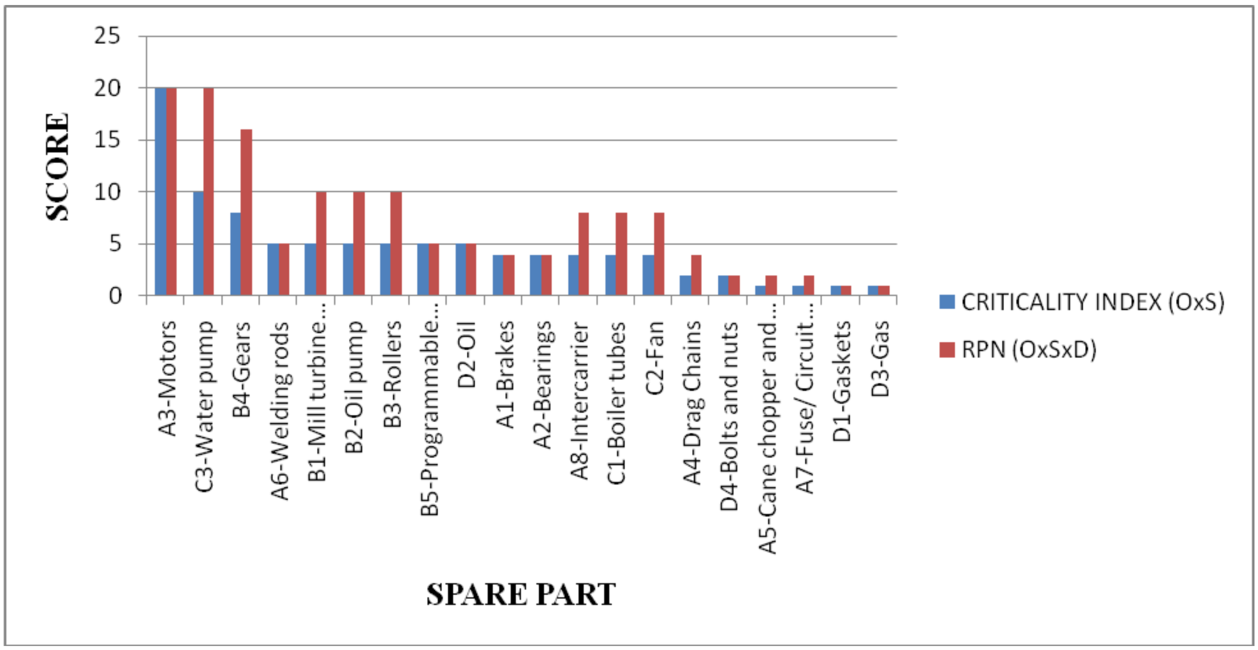

Figure 4. 3 Risk Priority Number compared with the criticality index of the spare parts based on the lead time for a period of one year (2016/2017)

Table 4. 1 Risk based on lead time for a period of one year (2016/2017)

SPARE PART	OCCURRENCE (O)	SEVERITY (S) (Based on lead time)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
A3-Motors	4	5	20	1	20
C3-Water pump	2	5	10	2	20
B4-Gears	2	4	8	2	16
A6-Welding rods	5	1	5	1	5
B1-Mill turbine governor	1	5	5	2	10
B2-Oil pump	1	5	5	2	10
B3-Rollers	1	5	5	2	10
B5-Programmable Logic Controllers(PLC)	1	5	5	1	5
D2-Oil	5	1	5	1	5
A1-Brakes	2	2	4	1	4
A2-Bearings	2	2	4	1	4
A8-Intercarrier	1	4	4	2	8
C1-Boiler tubes	2	2	4	2	8
C2-Fan	2	2	4	2	8
A4-Drag Chains	1	2	2	2	4
D4-Bolts and nuts	2	1	2	1	2
A5-Cane chopper and knife	1	1	1	2	2
A7-Fuse/ Circuit breakers	1	1	1	2	2
D1-Gaskets	1	1	1	1	1
D3-Gas	1	1	1	1	1

Table 4. 2 Risk matrix (Criticality Index)

		Severity				
		1	2	3	4	5
Frequency of failure	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Key

Criticality	Criticality index range
High Risk(Critical)	8≤CI≤25
Medium Risk(Semi critical)	3≤CI≤7
Low Risk(Non critical)	1≤CI≤2

Source: Author

From the graph in Figure 4.3, the critical spare parts has got the highest RPN (20 for the motors and water pump while 16 for the gears). The water pump and the gears are very risky since the failure occurred undetected because the risk priority number is twice their criticality index. The RPN is simply the multiplication of the occurrence, severity and detection ratings and its magnitude indicates the priority for corrective action (Roberts, 2007). It can therefore be argued that having this spares would reduce downtime.

The semi critical spare parts have an RPN between 4 and 10. The Mill turbine governor, Oil pump, Rollers, Intercarrier, Boiler tubes and Fan failures cannot be detected their RPN was between 8 and 10 while the Bearings, Programmable Logic Controllers (PLC), Oil, Brakes and Welding rods whose failure was detected before it occurred their RPN was between 4 and 5. Quantities of spare parts should be synchronized with the maintenance activities carried out in the factory (Alexander & Adam, 2011).

From table 4.1 and figure 4.3, the non critical spare parts had the RPN between 1 and 4. The Drag Chains had the highest RPN of 4 since its failure was undetected and had a criticality index of 2. The Bolts and nuts, Fuse/ Circuit breakers, Cane chopper and knife their RPN was 2. Finally, the Gaskets and Gas had an RPN of 1 each. For the Non critical spare parts the company considered partnering with the supplier or vendor to keep the spare part on consignment in their (supplier/vendor) inventory to avoid or reduce the inventory holding costs. These spare parts were recommended to be purchased when need arise since they have a very low lead time (Valmet, 2018).

4.3.2 Risk based on the availability

From Table 4.3, it revealed that the motors and water pumps were the critical spare parts with criticality index of 16 and 8 respectively. The severity was based on the availability in the market. Both spare parts were imported therefore, they required several days to be transported to the factory once they were ordered. Spare parts availability is influenced by availability of a single supplier, parts availability, lead time, supplier’s reliability, supplier’s financial status and supplier going out of business which would in turn affects the criticality index of the spare part (Wally , 2011). Figure 4.4, shows that motors risk priority number and criticality index were equal since the failure could be detected before it happened, on the other hand the water pumps risk priority number was double its criticality index, this because of the undetected failure in the pumps while being used in the factory.

The semi critical spare parts were Boiler tubes, Welding rods, Mill turbine governor, Rollers, Oil, Bearings, Oil pump, Gears, Programmable Logic Controllers (PLC), Fan and the Intercarrier as shown in Table 4.3. The Programmable Logic Controllers (PLC), Rollers, Oil pump and Mill turbine governor are all imported with criticality index of 4, 5, 4 and 5 respectively but with very low frequency of failure (Occurrence) as shown in Table 4.3. The oil and welding rods qualified to be semi critical based on the frequency of failure (Occurrence) of the rating of 5, their severity was 1 since they are available in the local market. Consequences (or severity) of the failure and the likelihood (or probability) that it will happen influences criticality index (LCE, 2016). This underpins the fact that The Boiler tubes, Bearings, Gears, Fan and Intercarrier had a low failure frequency (Occurrence) and available hence medium risk of 3 and 6.

The semi critical spare parts from Figure 4.4, the Boiler tubes, Mill turbine governor, Rollers, Oil pump, Gears, Fan and the Intercarrier has a higher risk priority number as compared to the criticality index due to undetected failure. On the other hand the Programmable Logic Controllers (PLC), Oil, Bearings and Welding rods their risk priority number was equal to the criticality index due to detected failure.

The Non critical spare parts; Brakes, Drag Chains, Bolts and nuts, Cane chopper and knife, Fuse/ Circuit breakers, Gaskets and Gas had low failure frequency and were procured locally hence low severity because they are locally available. Their criticality index was between 1 and 2 as shown in Table 4.3. The spare part failure has no impact on production and locally available which explains its non criticality (Catarina & Isabel, 2017). Figure 4.4 showed that the Cane chopper and knife, Drag Chains and Fuse/ Circuit breakers failures were not easily detected, hence the higher risk priority number in the non critical spare parts. The Brakes, Bolts and nuts, Gaskets and Gas failure was detected before it occurred.

Table 4. 3 Risk based on the availability for a period of one year (2016/2017)

SPARE PART	OCCURRENCE (O)	SEVERITY (S) (based on availability)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
A3-Motors	4	4	16	1	16
C3-Water pump	2	4	8	2	16
C1-Boiler tubes	2	3	6	2	12
A6-Welding rods	5	1	5	1	5
B1-Mill turbine governor	1	5	5	2	10
B3-Rollers	1	5	5	2	10
D2-Oil	5	1	5	1	5
A2-Bearings	2	2	4	1	4
B2-Oil pump	1	4	4	2	8
B4-Gears	2	2	4	2	8
B5-Programmable Logic Controllers(PLC)	1	4	4	1	4
C2-Fan	2	2	4	2	8
A8-Intercarrier	1	3	3	2	6
A1-Brakes	2	1	2	1	2
A4-Drag Chains	1	2	2	2	4
D4-Bolts and nuts	2	1	2	1	2
A5-Cane chopper and knife	1	1	1	2	2
A7-Fuse/ Circuit breakers	1	1	1	2	2
D1-Gaskets	1	1	1	1	1
D3-Gas	1	1	1	1	1

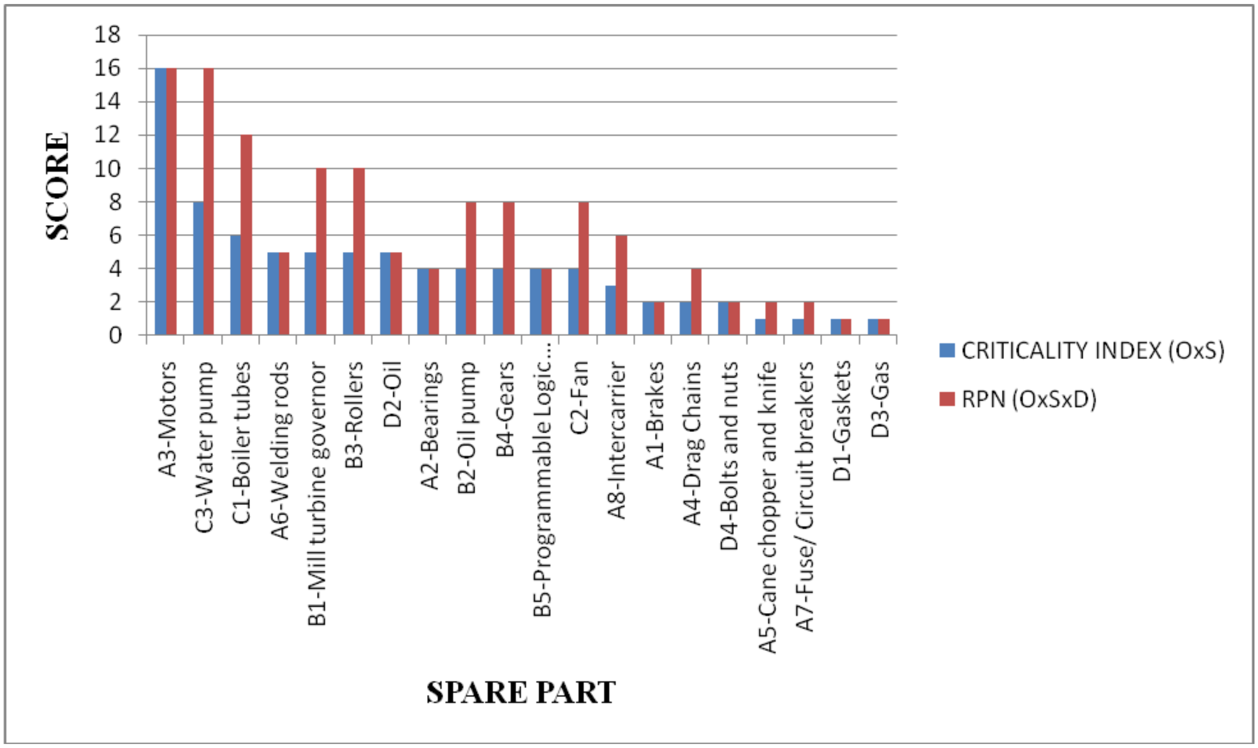

Figure 4. 4 Risk Priority Number compared with the criticality index of the spare parts based on Compatible spare parts and availability for a period of one year (2016/2017)

4.3.3 Risk based on the down time

From Table 4.4 and Table 4.2 it was deduced that the critical spare part due to the extended down time caused by their failure were; Welding rods, Oil, Motors, Brakes, Bearings, Gears, Boiler tubes, Fan, Water pump, Bolts and nuts. The criticality index for each critical spare part indicated in Table 4.4 was between 10 and 25. The frequency of failure (occurrence) for the welding rods, oil and motors were 5, 5 and 4 respectively. The other critical spare parts; Brakes, Bearings, Gears, Boiler tubes, Fan, Water pump, Bolts and nuts had a failure frequency (occurrence) of 2 each. It was therefore realized that lack of attention towards the critical equipment spares could threaten the availability of the plant through prolonged down time (Hassan et al., 2012).

The risk priority number and criticality index for six critical spare parts (Welding rods, Oil, Motors, Brakes, Bearings, Bolts and nuts) were equal since their failure was easily detected. On the other hand the other four critical spare parts (Gears, Boiler tubes, Fan and Water pump) their RPN doubles the criticality index since their failure was undetected as shown in Figure 4.5. Risk detection and management assessment allowed plant managers and the maintenance team to spot problems before they happened and put solutions in place to reduce the potential for unplanned and prolonged downtime (Kevin, 2017).

After the analysis shown in Table 4.4, the semi critical spare parts were; Cane chopper and knife, Fuse/Circuit breakers, Intercarrier, Mill turbine governor, Programmable Logic Controllers (PLC) and Gaskets whose criticality index was between 4 and 5. Finally, Oil pump and Gas down time had criticality index of 3. The frequency of failure (occurrence) for the semi critical spare parts was 1 (one).

From Figure 4.5, the semi critical spare part who's RPN doubles the criticality index were Cane chopper and knife, Fuse/ Circuit breakers, Intercarrier, Mill turbine governor, Rollers and Oil pump. On the other hand, the Programmable Logic Controllers (PLC), Gaskets and Gas their RPN was equal to criticality index since their failure was easily detected. Continuous monitoring of plant equipment by use of sensors assisted in recognizing the breakdown and disappointments before they happen hence minimizes interruptions (Ellacott, 2017).

The non critical spare part based on the down time was the drag chain whose criticality index was 2 as shown in Table 4.4. From Figure 4.5 the drag chain had a doubled RPN as compared to the criticality index due to its undetected failure.

Table 4. 4 Risk based on the down time for a period of one year (2016/2017)

SPARE PART	OCCURRENCE (O)	SEVERITY (S) (Based on the down time)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
A6-Welding rods	5	5	25	1	25
D2-Oil	5	5	25	1	25
A3-Motors	4	5	20	1	20
A1-Brakes	2	5	10	1	10
A2-Bearings	2	5	10	1	10
B4-Gears	2	5	10	2	20
C1-Boiler tubes	2	5	10	2	20
C2-Fan	2	5	10	2	20
C3-Water pump	2	5	10	2	20
D4-Bolts and nuts	2	5	10	1	10
A5-Cane chopper and knife	1	5	5	2	10
A7-Fuse/ Circuit breakers	1	5	5	2	10
A8-Intercarrier	1	5	5	2	10
B1-Mill turbine governor	1	5	5	2	10
B5- PLC	1	5	5	1	5
D1-Gaskets	1	5	5	1	5
B3-Rollers	1	4	4	2	8
B2-Oil pump	1	3	3	2	15
D3-Gas	1	3	3	1	3
A4-Drag Chains	1	2	2	2	4

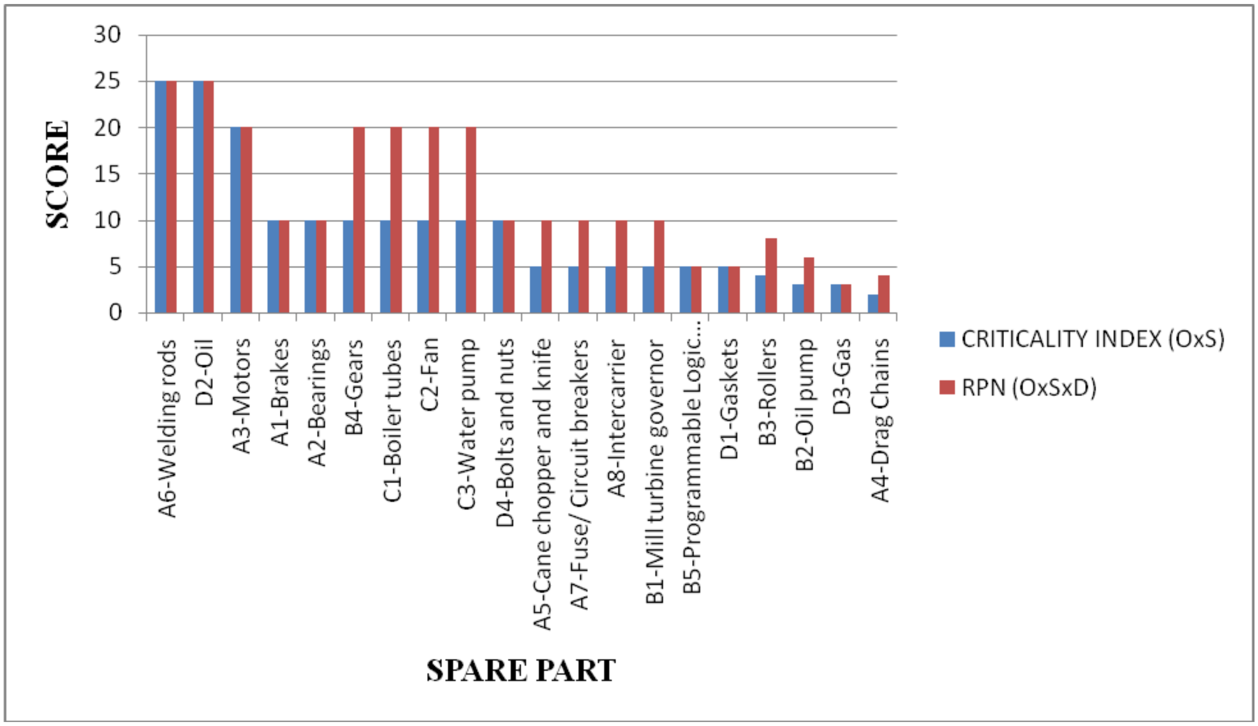

Figure 4. 5 Risk Priority Number compared with the criticality index of the spare parts based on down time for a period of one year (2016/2017)

4.3.4 Summary for the risk analysis and evaluation

Criticality examination is the apparatus to utilize on the off chance that you need to enhance unwavering quality and oversee plant resources dependent on risk instead of recognition (LCE, 2016). From Table 4.5 the three factors considered in criticality analysis and evaluation were tabulated and therefore it was discovered that the critical spare parts were the motors, water pump and the gears. They all had criticality index between 8 and 25 from the three factors considered (Wally, 2011).

The semi critical spare parts were; Oil, Welding rods, Brakes, Bearings, Boiler tubes, Fan, Intercarrier, Programmable Logic Controllers (PLC), Oil pump, Rollers and Mill turbine governor. They all have a criticality index between 3 and 6 for the lead time and availability as shown in Table 4.5 and Table 4.2. Semi critical spares are the ones which breakdown may result in loss of production but where invariable production loss can be recovered or made up (Gopalakrishnan, 2013).

The non critical spare parts were; Bolts and nuts, Cane chopper and knife, Drag Chains, Gaskets, Gas and Fuse/ Circuit breakers. Non critical spares are spare parts whose breakdown doesn't affect production (Gopalakrishnan, 2013). The criticality index was between 1 and 2 in at least two factors considered as shown in Table 4.5.

Finally, the main determinant in the criticality assessment was the lead time, down time and availability in the market. The extended down time was due to unavailability of the spare part during maintenance while the extended lead time was due to the unavailability in the market (Schroeder, 2015).

Table 4. 5 Table on the criticality index based on the lead time, availability and down time for a period of one year (2016/2017).

SPARE PART	CRITICALITY INDEX (OxS) - DOWN TIME	CRITICALITY INDEX (OxS) - LEAD TIME	CRITICALITY INDEX (OxS) - AVAILABILITY
A6-Welding rods	25	5	5
D2-Oil	25	5	5
A3-Motors	20	20	16
A1-Brakes	10	4	2
A2-Bearings	10	4	4
B4-Gears	10	8	4
C1-Boiler tubes	10	4	6
C2-Fan	10	4	4
C3-Water pump	10	10	8
D4-Bolts and nuts	10	2	2
A5-Cane chopper and knife	5	1	1
A7-Fuse/ Circuit breakers	5	1	1
A8-Intercarrier	5	4	3
B1-Mill turbine governor	5	5	5
B5-Programmable Logic Controllers(PLC)	5	5	4
D1-Gaskets	5	1	1
B3-Rollers	4	5	5
B2-Oil pump	3	5	4
D3-Gas	3	1	1
A4-Drag Chains	2	2	2

The critical spare parts are 3 spare parts as shown in Table 4.6. From Figure 4.6 the researcher realized that the critical spare parts had a highest percentage of 60.9 % in the lead time since they were not locally available. They were contributing a failure frequency of 38.5%, 37.1% down time and 38.5% number of spare parts consumed as shown in Figure 4.6.

The semi critical spare parts are 11 spare parts as shown in Table 4.8 which contributed a failure frequency of 51.9%, 47.5% down time and 51.9% number of spare parts consumed as shown in Figure 4.6. These parts were locally available hence a percentage lead time of 35.3% as shown in Figure 4.6.

The non critical spare parts were 6 in number as shown in Table 4.10. The lead time was very low at a percentage of 3.8% as shown in Figure 4.6. They were contributing a failure frequency of 9.6%, 15.4% down time and 9.6% number of spare parts consumed as shown in Figure 4.6.

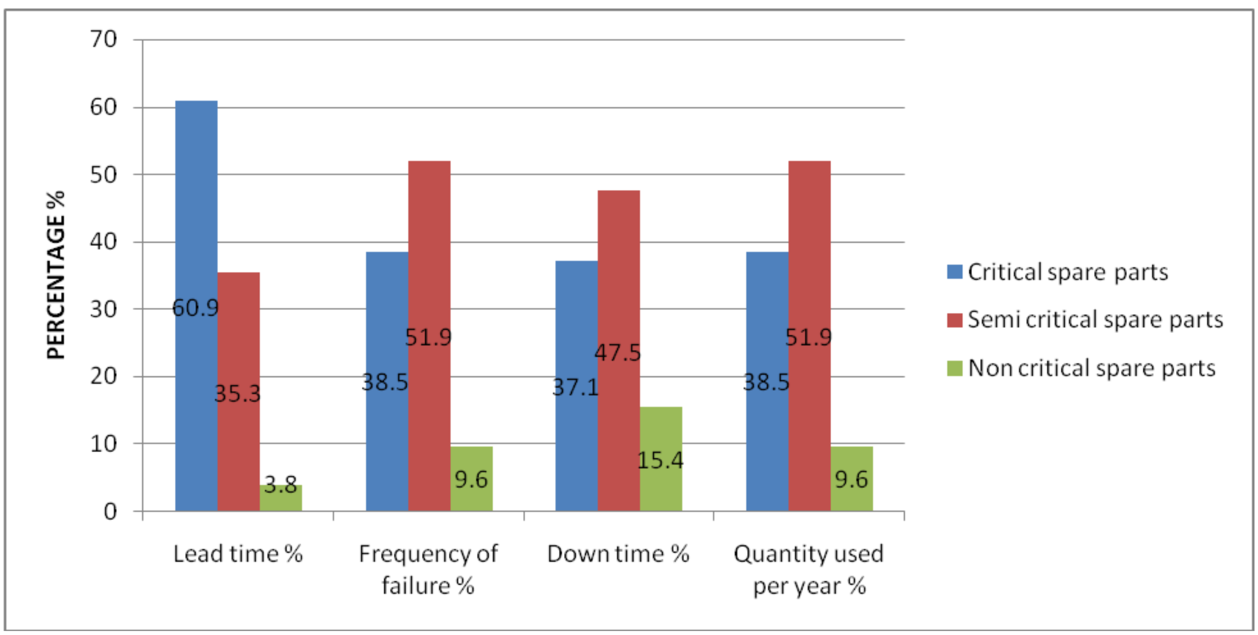

Figure 4. 6 Comparing the percentages of lead time, frequency of failure, down time and quantity of spare part consumed for a period of one year (2016/2017)

4.4 To determine inventory risk mitigation strategies

The researcher developed strategies of ordering spare parts based on their criticality. The risk mitigation strategies provided a solution to the expensive down time and reduced the wastage of the labor. The risk mitigation strategies adopted were classified depending on the criticality of the spare part.

4.4.1 Strategy of ordering critical spare parts

From Table 4.6, motors, water pump and gears were found to be critical spares based on their lead times, down time and availability. This implies that spare parts used from the store should be replaced. The re-order point was determined through constant evaluation of the inventory which was found to be 17 pumps, 75 Gears, and 25 motors as shown in Table 4.7. The maintenance team must use the detectors to assist in detecting the equipment failure before it happens. The strategic direction is that maintenance and planning department in the sugar industry optimize their spare part inventory during maintenance. This argument is in line with Harris, (1990) who opined that the inventory replacement baseline during maintenance should keep the inventory position constant. Besides, critical spare parts call for a stocking policy where some of the stock is reserved for critical demand (Rooij, 1998). However the stocking policy should pay attention to financial, safety, and environmental implications of having the spare part and what the equipment failure might induce in the stock out of the spare part.

Table 4. 6 Critical spare parts for a period of one year (2016/2017)

S/no	Critical spare parts	Lead time in days	Frequency of failure	Down time(hrs)	Quantity used per year
1.	Motors	96	180	81.03	48
2.	Water pump	96	85	93.82	12
3.	Gears	24	71	12.36	180

According to equations (viii), (ix) and (x) to calculate the reorder points, lead time demand and safety stock respectively. The organization was able to determine the risk mitigation strategies that ensured the down time is drastically reduced.

Table 4. 7 Reorder points, Lead time demand and Safety stock for critical spare parts for a period of one year (2016/2017)

SPARE PARTS	Lead time demand	Safety stock	Reorder point
Motors	13	12	25
Water pumps	4	13	17
Gears	30	45	75

4.4.2 Strategy of ordering semi critical spare parts

To mitigate the risk of extended down time due to unavailability of semi critical spare parts, they were stocked based on the need, lead time and frequency of failure. From Table 4.8, it was observed that the lead times of the semi critical spare parts was an average of 1 to 96 days calling perpetual inventory control as a strategic approach of optimizing the stock levels. According to Hanson et al., (2015) an unending inventory control process surveys inventory status day by day to determine inventory renewal needs. To use unending audit, exact tracking of all Stock-Keeping Units is vital. Interminable audit will be executed through a re-arrange point and request amount that will be done on a daily basis. Reorder points for Oil, Welding rods, Brakes, Bearings, Boiler tubes, Fan, Intercarrier, PLC, Oil pump, Rollers and Mill turbine governor were 123, 98, 12, 125, 5, 7, 7, 21, 11, 11 and 11 respectively as shown in Table 4.9. This implies that inventory must be updated in real time to take care of high frequencies of failures associated with semi critical spares.

Table 4. 8 Semi critical spare parts for a period of one year (2016/2017)

S/no	Semi critical spare parts	Lead time in days	Frequency of failure	Down time(hrs)	Quantity used per year
1.	Oil	3	756	416.835	1224
2.	Welding rods	1	504	277.89	923
3.	Brakes	12	89	16.36	99
4.	Bearings	12	80	15.4	1250
5.	Boiler tubes	12	64	54.29	24
6.	Fan	12	76	16.68	76
7.	Intercarrier	24	15	23.01	5
8.	Programmable Logic Controllers (PLC)	96	13	20.33	15
9.	Oil pump	96	13	6.92	11
10.	Rollers	96	45	10.13	8
11.	Mill turbine governor	96	9	20.13	11

Table 4. 9 Reorder points, Lead time demand and Safety stock for semi critical spare parts for a period of one year (2016/2017)

SPARE PARTS	Lead time demand	Safety stock	Reorder point
Oil	11	112	123
Welding rods	3	95	98
Brakes	4	8	12
Bearings	42	83	125
Boiler tubes	1	4	5
Fan	2	5	7
Intercarrier	4	3	7
PLC	7	14	21
Oil pump	4	7	11
Rollers	4	7	11
Mill turbine governor	4	7	11

4.4.3 Strategy of ordering non critical spare parts

From Table 4.10, essentially the annualized cost of stocking these spare parts could be higher than the annualized cost of not stocking them, there is no critical need for stocking them in large quantities. This argument is propounded by the findings in table 4.10 which depicts the non critical spares as having the shortest lead times low frequency of failure and low down time as compared to critical and semi critical spares. This implies that when stocking them the reorder points should be observed as illustrated in Table 4.11 for Bolts and nuts, Cane chopper and knife, Drag Chains, Gaskets, Gas and Fuse/Circuit breakers at 120, 7, 5, 21, 5 and 13 respectively. However this should be coupled with the principles of Economic order quantity and view of environmental equipment failure they may induce.

From the findings the non critical spare parts portend, low downtime, low frequencies of failure and locally available. According to Sigma, (2017) when spares parts are associated with low downtime and can be acquired quickly and easily they can be left out of a stocking plan. This implies that there is need to optimize stocking of non critical spares.

Table 4. 10 Non critical spare parts in a period of one year (2016/2017)

S/no	Non critical spare parts	Lead time in days	Frequency of failure	Down time(hrs)	Quantity used per year
1.	Bolts and nuts	3	74	22.8	1074
2.	Cane chopper and knife	3	38	50.3	42
3.	Drag Chains	12	3	5.96	2
4.	Gaskets	3	44	23.55	144
5.	Gas	3	2	6.04	23
6.	Fuse/ Circuit breakers.	3	7	46.13	102

Table 4. 11 Reorder points, Lead time demand and Safety stock for non critical spare parts in a period of one year (2016/2017)

SPARE PARTS	Lead time demand	Safety stock	Reorder point
Bolts and nuts	9	111	120
Cane chopper and knife	1	6	7
Drag Chains	1	4	5
Gaskets	2	19	21
Gas	1	4	5
Fuse/ Circuit breakers.	1	12	13

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Overview

The main objective of this study was to develop a risk based approach to spare part inventory management in order to improve the performance of the sugar factories. The study investigated risk due to unavailability of spare part in the sugar factory; Assessed spare part criticality using FMEA in the sugar factory and determined spare part inventory risk mitigation strategies to be used in the sugar factory. In the background of this study it was established that spare part inventory management affects the performance of sugar factories .This position is corroborated by the findings of this study

5.2 Key findings

5.2.1 Risk due to unavailability of spare part in the sugar factory.

The study revealed a prolonged down time in the sugar factory four sections (Boiler, Pre mills, Mills and Juice treatment). On the other hand it was realized from the study that the spare parts failure contributed to the frequent down time experience in the factory. It can be inferred that the boiler and pre mills suffered the highest down time in the factory. The downtime occasioned by the spare part failure was found to be exceptionally high due to the interdependence of the four sections in the factory. The root causes of the risks were found to be frequency of failure and unavailability of the spare parts consumed in the aforementioned factory sections.

5.2.2 Spare part criticality using FMEA in the sugar factory.

The criticality of the spare parts in the study was determined by using the frequency of failure (occurrence) and Severity which was classified in terms of lead time, availability and downtime. From the spare part criticality analysis it was realized that the critical spare parts had a longest lead time as compared to the semi critical spare parts and non critical spare parts lead times.

The study revealed that the risk priority number doubled criticality index in the spare parts whose failure cannot be detected. On the other hand the criticality index and the risk priority number were equal for spare parts whose failure was detected before it happened. The critical spare parts had the longest lead time hence the highest production and human capital losses. The Semi critical and non critical spares parts have a long and the shortest lead time respectively hence production loss can be recovered or made up.

On the criticality based on the availability the spare parts whose supply depends on the original equipment manufacturer (OEM) were the most critical since they were not available in the local market. The spare parts which were available in the local markets are semi critical and non critical.

Finally, from the study, the spare parts whose failure led to extended down time are the most critical. Risk detection and management assessment allowed plant managers and the maintenance team to spot problems before they happened and put solutions in place to reduce the potential for unplanned and prolonged downtime.

5.2.3 Inventory risk mitigation strategies to be used in the sugar factory.

Lastly, the risk mitigation strategies were classified based on the three levels of criticality: Critical, Semi critical and Non critical. Motors, water pump and gears were found to be critical spares based on their lead times, down time and availability. This implies that spare parts used from the store should be replaced. The re-order point was determined through constant evaluation of the inventory. The maintenance team must use the detectors to assist in detecting the equipment failure before it happens. The strategic direction is that maintenance and planning department in the sugar industry optimize their spare part inventory during maintenance. The stocking policy should also pay attention to financial, safety, and environmental implications of having the spare part and what the equipment failure might induce in the stock out of the spare part

The Semi critical spare part, a perpetual inventory control process was adopted. The daily inventory status was determined to establish the replenishment needs. Since the semi critical spare parts were locally available, an order was raised depending on the lead time and the safety stock. For the semi critical spares there is always a need for utilization of perpetual review, accurate tracking of all Stock-Keeping Units was necessary as a risk mitigation strategy. Perpetual review should be implemented through a re-order point and order quantity that will be done on a daily basis.

The Non critical spare parts there was no critical need for stocking them in large quantities since they had the shortest lead times, low frequency of failure and low down time as compared to critical and semi critical spares. Their annualized cost of stocking could be higher than the annualized cost of not stocking them, there was no critical need for stocking them in large quantities. This argument is propounded by the findings of this study which depicts the non critical spares as having the shortest lead times low frequency of failure and low down time as compared to critical and semi critical spares. However this should be coupled with the principles of Economic order quantity and view of environmental equipment failure they may induce as a risk mitigation strategy. From the findings the non critical spare parts portend, low downtime, low frequencies of failure and locally available.

5.3 Conclusion

It can be concluded that the downtimes experienced by the factory in a period of one year courtesy of spare part failure is exceptionally high due to the interdependence of the four sections in the factory. This calls for strategies to mitigate downtime and guarantee its reduction as it has a considerable effect in improving productivity and is a prerequisite for a profitable and flexible production. Down time and spare part frequency of failure are the risk identification strategies embraced by the the sugar factories and other manufacturing plants. The use of down time is justified by the length of time that the mills, premills, boilers and juice treatment remain unoperational due to spare part related issues. Reducing downtime increases machine availability which in turn increases throughput. Minimizing downtime also reduces order lead times and increases customer satisfaction. This study focused on downtime occasioned by unavailability of spares. The findings therefore should provide a window of addressing the spare parts crisis which is critical for downtime by ensuring regular tracking and attacking spare part failures which was found to be exceptionally high.

Plant reliability relies on plant maintenance and critical operation of spare parts inventory. This calls for a keen interest on investment and proper management of critical spares as it guarantees plant uptime. The study submits that criticality of spare parts are dictated by downtime, lead time and availability in the market. This informs the need to observe these three aspects in Chemelil Sugar Company in spare part inventory management to reduce risks of plant unavailability. That is, adequate spare part criticality assessment through the factors used for defining criticality such as Lead time, availability in the market, down time, frequency of failure and detect ability. However the focal point in criticality assessment should remain the impact of environment, safety besides downtime or impact on production. In this regard Chemelil Sugar Company should prioritize on evaluation of their stocking strategy other than being triggered by stock out. This will guarantee availability of spare parts upon demand which would in turn increase the utilization of the plant and consequently optimal uptime.

Spare part risk mitigation strategies remain the most effective means of guaranteeing reduced down time and spare part unavailability risks. Checking on the reorder point, safety stock and lead time of the spare parts based on the criticality provides a very effective risk mitigation strategy. However from the findings reorder point remains the most cardinal risk mitigation strategy as it guarantees safety stock and spare part availability hence continued plant operation. Effective implementation of spare part risk mitigation strategies in spare part inventory management reduces time loss, thus, enhanced sugar factories performance. It is prudent to acknowledge the fact that demand of spares and inventory management depends on issues like failure rate of the component over a period of time and the consequence of their unavailability. Economic order quantity, view of environmental equipment failure, perpetual inventory control process, financial and safety review remains the cornerstone for spare part risk mitigation depending on the criticality of the spare part in question.

5.4 Recommendations

From the key findings, conclusions and the direction from the literature review, it was clear that Risk Based Approach to Spare Part Inventory Management has a significant effect on the performance of sugar industries. The study, therefore, suggests the following recommendation to enhance sugar industries performance;

The factory should effectively implement risk based approach to spare part inventory management for reduced failure frequencies, tone and time loss due to stoppages. Besides a comprehensive spare part inventory system data clean-up effort is required to address issues of under stocking and overstocking of spare parts for effective spare part optimization.

The factory needs to adopt a compelling spare part planning as a major aspect of inventory control by relating spare part stock and store amounts to demand; avoiding misfortunes because of waste, pilferage and out of date quality; obtaining the best turnover rate on all spare part items by considering both the expense of acquisitions and assets; reducing stretched out downtime because of un deliverability of the spare part

The factory should consider the criticality of segments as a vital issue and use criticality of spare parts to determine the initial sufficient amount of spares to be put away to execute maintenance adequately. Other than a risk-based system aiming to expand the accessibility of a machine by maintaining a certain dimension of spare parts in the inventory ought to be received.

The sugar industry stakeholders such as The Government of Kenya (GoK), The Kenya Sugar Board (KSB), Kenya Sugar Research Foundation (KESREF), Millers, Cane Transporters, Cane Growers/ Out grower's institutions should encourage and ensure effective adoption of Risk Based Approach to Spare Part Inventory Management as this is the best approach to ensure improved performance to sugar industries as stated in Kenya Vision 2030 and sustainable development goals.

5.5 Research contributions

The research has contributed two aspects in the theory field. First, it classified the criticality in three aspects; lead time, availability in the market and down time. Secondly, the use of the Failure Mode and Effect Analysis (FMEA) with the risk matrix to classify the criticality of the spare parts. Finally, establishing an ordering policy of spare parts based on their criticality.

Contribution to the practice, the research developed a general methodology that can be adapted to various fields and industries to order and stock the spare parts based on their criticality. The spare parts inventory holders to work with the maintenance team to establish what to stock, when to order and the quantity to order based on their criticality.

5.6 Suggestions for further studies

The researcher suggests the following for further areas of research;

Future research should look in to the effect of risk based approach of spare part inventory management on plant performance.

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APPENDICES

Appendix I

Risk matrix (Criticality Index)

		Severity				
		1	2	3	4	5
Frequency of failure	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

KEY

Criticality	Criticality index range
High Risk(Critical)	$8 \leq CI \leq 25$
Medium Risk(Semi critical)	$3 \leq CI \leq 7$
Low Risk(Non critical)	$1 \leq CI \leq 2$

Source: Author

Risk assessment matrix

		Impact			
		None	Small	Moderate	High
Frequency	Very High		High	Very High	Very High
	High		Moderate	High	Very High
	Moderate		Low	Moderate	High
	Low		Low	Low	Moderate
	None	No Risk			

Source: Roberts, (2007)

Appendix II

Occurrence – Failure frequency

Mean failure frequency per year	Score
1-50	1
51-100	2
101-150	3
151-200	4
Above 200	5

Source: Author

Detection

Ability to detect failure of parts	Score
Detecting failure before it happens	1
Not able to detect failure	2

Source: Author

Severity – Down time

Down time (Hours)	Criticality Scoring
0-2	1
3-5	2
6-8	3
9-11	4
12 and above	5

Source: Author

Appendix III

Severity – Lead time

Lead time	Severity(S) Score
1 day to 6 days	1
7 days to 12 days	2
13 days to 18 days	3
19 days to 24 days	4
Above 24 days	5

Source: Author

Severity – Availability

Compatible spare parts and availability	Criticality Scoring
Used in all sections and available in Kisumu/ Chemelil	1
Used in 2-5 sections and available in Nairobi/Mombasa	2
Used in one section and available in Nairobi/Mombasa	3
Special spare part used in more than one section with known supplier overseas	4
Special spare part used in one section with unknown supplier overseas	5

Source: Author

Appendix IV

Failure mode and effect analysis for spare parts – Lead time

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
1.	A1- Brakes for the cranes	Braking the cranes	-No brakes	-Delay in loading sugar cane	Sub standard brakes	Frequent replacement	2	2	4	1	4
2.	A2 – Bearings	Smooth movement of rotating part	-Wearing out	-Grinding the moving part	-Insufficient lubrication -Use of substandard lubricants	-Frequent lubrication -Checking the bearings frequently	2	2	4	1	4
3.	A3- Motors	Moving the cranes	-Burnt motor windings -Worn out brushes	- Delay in loading of sugar canes	-Overloading -Over current -Short circuit -Non replacement of brushes	-Not overloading -Use of rated circuit breakers -Frequent replacement of brushes	4	5	20	1	20
4.	A4-Drag chains	Moving the sugar cane on the feed table into the auxiliary cane carrier	-Broken chains	-No sugar cane crushed -Overloaded feed table	- Wear and tear -Ageing	-Frequent inspection of the chains	1	2	2	2	4

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
5.	A5- Cane chopper and knife	-Chopping the sugar cane -Cutting the sugar cane to smaller pieces	-Broken choppers/ knife	-The sugar cane are moved before being chopped/cut properly	-Foreign hard object breaking the choppers/knives - Wear and tear - Ageing	- Frequent inspection of the choppers/ knives -Feed the machine with clean sugar cane ie without foreign hard objects	1	1	1	2	2
6.	A6- Welding rods	-Joining metals	- Substandard welding rods	-Making weak joints	-Receiving substandard welding rods	-Order correct quality of welding rods -Check the quality of the supplied rods before receiving them	5	1	5	1	5

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
7.	A7- Fuse/ Circuit breakers	-Protection against over current	-Open circuit	-Single phasing	-Broken fuse -Circuit breaker OFF	-Replace broken fuses -Reset the circuit breaker	1	1	1	2	2
8.	A8- Intercarrier	- Moving the cut and chopped sugar cane into the mills. -Moving the bagasse to the boiler and the excess to the storage -Moving the bagasse to the boiler from storage	-Derailing -Broken -Stopped -Open circuit	-No milled sugar cane -Overloading -Lack of sufficient bagasse at the boiler	- Broken fuse -Circuit breaker OFF - Wear and tear - Ageing	-Replace broken fuses -Reset the circuit breaker -Replace the pulleys	1	4	4	2	8
9.	B1- Mill Turbine governor	-Speed regulation of the mill turbine	-High speed mill turbine -Low speed of the turbine	-Chocking the mill -Low juice extraction	- Wear and tear - Ageing	-Frequent inspection of the governor	1	5	5	2	10
10	B2- Oil pump	-Pumping lubrication oil	-In effective lubrication	-Rapid wear and tear of the moving parts	- Faulty impeller -Faulty motor -Open circuit	-Frequent inspection and servicing the pump and its accessories	1	5	5	2	10
11	B3- Rollers	-Juice extraction	-Extended tolerance -Worn out rollers	-In effective juice extraction	- Wear and tear - Ageing	-Adjust the roller tolerance - Frequent inspection of the roller to recommend replacement	1	5	5	2	10

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
12	B4- Gears	-Reducing the speed of the mills	-Slip out	-In effective speed reduction	- Wear and tear - Ageing	-Lubrication -Replacing the mill	2	4	8	2	16
13	B5- Programmable Logic Controllers (PLC)	- Controlling the motors	-Improper motor control	-Over feeding the mills -The motors runs with varied speed	-The PLC not well programmed -Burnt PLC	-Use the manufacture's manual to programe the PLC - Replace the PLC if worn-out - Frequent inspection of the PLC	1	5	5	1	5
14	C1- Boiler tubes	-Providing a bigger surface area for water heating	-Broken pipe	-Non production of enough steam to drive the machine -Most parts/sections will be closed down.	- Corrosion	- Frequent inspection of the pipes -Replacing the pipes -By passing the faulty boiler and utilize the other three.	2	2	4	2	8
15	C2- Fan	-Exhaust -Cooling -Oxygen for combustion	-Fan stops	-No exhaust -Overheating -Low temperature in the furnace	- Wear and tear - Ageing -Worn-out bearing	- Frequent inspection of the fan to recommend replacement	2	2	4	2	8
16	C3-Water pump	-Supply of water to the boiler	-Pump stops	-No water flow into the boiler tubes -Insufficient steam	- Faulty impeller -Faulty motor -Open circuit	-Frequent inspection and servicing the pump and its accessories	2	5	10	2	20

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
17	D1- Gaskets	-Sealing the manholes	-Leakage	-Loss of Sugar juice	-Worn-out -Improper fitting -Ageing	-Frequent inspection and replacement	1	1	1	1	1
18	D2- Oil	-Lubrication	-Noise produced on the moving parts -Metal particles on the moving parts	-The rollers stops -Broken bearing	-Substandard oil -Faulty oil pump -Lack of frequent oil replacement	- Frequent inspection of oil levels and replacement -Repair of faulty oil pump	5	1	5	1	5
19	D3- Gas	-Provision of heat when joining metals and sealing broken sections in the tanks	-Absence of gas	-No gas	-Delayed delivery of gas	-Frequent inspection of the gas cylinders -Replacing empty gas cylinders	1	1	1	1	1
20	D4- Bolts and nuts	-Fixing of two or more parts	-Shaking rotating systems	-Unstable moving system -Leakages -Vibrating machines	-Worn-out -Improper fitting/tightening -Ageing	-Frequent inspection of nuts and bolts and replacing the loose/broken	2	1	2	1	2

Appendix V

Failure mode and effect analysis for spare parts - Availability

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
1.	A1- Brakes for the cranes	Braking the cranes	-No brakes	-Delay in loading sugar cane	Sub standard brakes	Frequent replacement	2	1	2	1	2
2.	A2 – Bearings	Smooth movement of rotating part	-Wearing out	-Grinding the moving part	-Insufficient lubrication -Use of substandard lubricants	-Frequent lubrication -Checking the bearings frequently	2	2	4	1	4
3.	A3- Motors	Moving the cranes	-Burnt motor windings -Worn out brushes	- Delay in loading of sugar canes	-Overloading -Over current -Short circuit -Non replacement of brushes	-Not overloading -Use of rated circuit breakers -Frequent replacement of brushes	4	4	16	1	16
4.	A4-Drag chains	Moving the sugar cane on the feed table into the auxiliary cane carrier	-Broken chains	-No sugar cane crushed - Overloaded feed table	- Wear and tear -Ageing	-Frequent inspection of the chains	1	2	2	2	4

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
5.	A5- Cane chopper and knife	-Chopping the sugar cane -Cutting the sugar cane to smaller pieces	-Broken choppers/ knife	-The sugar cane are moved before being chopped/cut properly	-Foreign hard object breaking the choppers/knives - Wear and tear - Ageing	- Frequent inspection of the choppers/ knives -Feed the machine with clean sugar cane i.e. without foreign hard objects	1	1	1	2	2
6.	A6- Welding rods	-Joining metals	- Substandard welding rods	-Making weak joints	-Receiving substandard welding rods	-Order correct quality of welding rods -Check the quality of the supplied rods before receiving them	5	1	5	1	5
7.	A7- Fuse/ Circuit breakers	-Protection against over current	-Open circuit	-Single phasing	-Broken fuse -Circuit breaker OFF	-Replace broken fuses -Reset the circuit breaker	1	1	1	2	2
8.	A8- Intercarrier	- Moving the cut and chopped sugar cane into the mills. -Moving the bagasse to the boiler and the excess to the storage -Moving the bagasse to the boiler from storage	-Derailing -Broken -Stopped -Open circuit	-No milled sugar cane - Overloading -Lack of sufficient bagasse at the boiler	- Broken fuse -Circuit breaker OFF - Wear and tear - Ageing	-Replace broken fuses -Reset the circuit breaker -Replace the pulleys	1	3	3	2	6

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
9.	B1- Mill Turbine governor	-Speed regulation of the mill turbine	-High speed mill turbine -Low speed of the turbine	-Chocking the mill -Low juice extraction	- Wear and tear - Ageing	-Frequent inspection of the governor	1	5	5	2	10
10.	B2- Oil pump	-Pumping lubrication oil	-In effective lubrication	-Rapid wear and tear of the moving parts	- Faulty impeller -Faulty motor -Open circuit	-Frequent inspection and servicing the pump and its accessories	1	4	4	2	8
11.	B3- Rollers	-Juice extraction	-Extended tolerance -Worn out rollers	-In effective juice extraction	- Wear and tear - Ageing	-Adjust the roller tolerance - Frequent inspection of the roller to recommend replacement	1	5	5	2	10
12.	B4- Gears	-Reducing the speed of the mills	-Slip out	-In effective speed reduction	- Wear and tear - Ageing	-Lubrication -Replacing the mill	2	2	4	2	8

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
13	B5- Programmable Logic Controllers (PLC)	- Controlling the motors	-Improper motor control	-Over feeding the mills -The motors runs with varied speed	-The PLC not well programmed -Burnt PLC	-Use the manufacture's manual to progamme the PLC - Replace the PLC if worn-out - Frequent inspection of the PLC	1	4	4	1	4
14	C1- Boiler tubes	-Providing a bigger surface area for water heating	-Broken pipe	-Non production of enough steam to drive the machine -Most parts/sections will be closed down.	- Corrosion	- Frequent inspection of the pipes -Replacing the pipes -By passing the faulty boiler and utilize the other three.	2	3	6	2	12
15	C2- Fan	-Exhaust -Cooling -Oxygen for combustion	-Fan stops	-No exhaust -Overheating -Low temperature in the furnace	- Wear and tear - Ageing -Worn-out bearing	- Frequent inspection of the fan to recommend replacement	2	2	4	2	8
16	C3-Water pump	-Supply of water to the boiler	-Pump stops	-No water flow into the boiler tubes -Insufficient steam	- Faulty impeller -Faulty motor -Open circuit	-Frequent inspection and servicing the pump and its accessories	2	4	8	2	16

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
17	D1- Gaskets	-Sealing the manholes	-Leakage	-Loss of Sugar juice	-Worn-out -Improper fitting -Ageing	-Frequent inspection and replacement	1	1	1	1	1
18	D2- Oil	-Lubrication	-Noise produced on the moving parts -Metal particles on the moving parts	-The rollers stops -Broken bearing	-Substandard oil -Faulty oil pump -Lack of frequent oil replacement	- Frequent inspection of oil levels and replacement -Repair of faulty oil pump	5	1	5	1	5
19	D3- Gas	-Provision of heat when joining metals and sealing broken sections in the tanks	-Absence of gas	-No gas	-Delayed delivery of gas	-Frequent inspection of the gas cylinders -Replacing empty gas cylinders	1	1	1	1	1
20	D4- Bolts and nuts	-Fixing of two or more parts	-Shaking rotating systems	-Unstable moving system -Leakages -Vibrating machines	-Worn-out -Improper fitting/tightening -Ageing	-Frequent inspection of nuts and bolts and replacing the loose/broken	2	1	2	1	2

Appendix VI

Failure mode and effect analysis for spare parts - Down time

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
1.	A1- Brakes for the cranes	Braking the cranes	-No brakes	-Delay in loading sugar cane	Sub standard brakes	Frequent replacement	2	5	10	1	10
2.	A2 – Bearings	Smooth movement of rotating part	-Wearing out	-Grinding the moving part	-Insufficient lubrication -Use of substandard lubricants	-Frequent lubrication -Checking the bearings frequently	2	5	10	1	10
3.	A3- Motors	Moving the cranes	-Burnt motor windings -Worn out brushes	- Delay in loading of sugar canes	-Overloading -Over current -Short circuit -Non replacement of brushes	-Not overloading -Use of rated circuit breakers -Frequent replacement of brushes	4	5	20	1	20
4.	A4-Drag chains	Moving the sugar cane on the feed table into the auxiliary cane carrier	-Broken chains	-No sugar cane crushed -Overloaded feed table	- Wear and tear -Ageing	-Frequent inspection of the chains	1	2	2	2	4

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
5	A5- Cane chopper and knife	-Chopping the sugar cane -Cutting the sugar cane to smaller pieces	-Broken choppers/ knife	-The sugar cane are moved before being chopped/cut properly	-Foreign hard object breaking the choppers/knives - Wear and tear - Ageing	- Frequent inspection of the choppers/ knives -Feed the machine with clean sugar cane i.e. without foreign hard objects	1	5	5	2	10
6	A6- Welding rods	-Joining metals	-Substandard welding rods	-Making weak joints	-Receiving substandard welding rods	-Order correct quality of welding rods -Check the quality of the supplied rods before receiving them	5	5	25	1	25
7	A7- Fuse/ Circuit breakers	-Protection against over current	-Open circuit	-Single phasing	-Broken fuse -Circuit breaker OFF	-Replace broken fuses -Reset the circuit breaker	1	5	5	2	10
8	A8- Intercarrier	- Moving the cut and chopped sugar cane into the mills. -Moving the bagasse to the boiler and the excess to the storage -Moving the bagasse to the boiler from storage	-Derailing -Broken -Stopped -Open circuit	-No milled sugar cane -Overloading -Lack of sufficient bagasse at the boiler	- Broken fuse -Circuit breaker OFF - Wear and tear - Ageing	-Replace broken fuses -Reset the circuit breaker -Replace the pulleys	1	5	5	2	10

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
9.	B1- Mill Turbine governor	-Speed regulation of the mill turbine	-High speed mill turbine -Low speed of the turbine	-Chocking the mill -Low juice extraction	- Wear and tear - Ageing	-Frequent inspection of the governor	1	5	5	2	10
10	B2- Oil pump	-Pumping lubrication oil	-In effective lubrication	-Rapid wear and tear of the moving parts	- Faulty impeller -Faulty motor -Open circuit	-Frequent inspection and servicing the pump and its accessories	1	3	3	2	6
11	B3- Rollers	-Juice extraction	-Extended tolerance -Worn out rollers	-In effective juice extraction	- Wear and tear - Ageing	-Adjust the roller tolerance - Frequent inspection of the roller to recommend replacement	1	4	4	2	8
12	B4- Gears	-Reducing the speed of the mills	-Slip out	-In effective speed reduction	- Wear and tear - Ageing	-Lubrication -Replacing the mill	2	5	10	2	20
13	B5- Programmable Logic Controllers (PLC)	-Controlling the motors	-Improper motor control	-Over feeding the mills -The motors runs with varied speed	-The PLC not well programmed -Burnt PLC	-Use the manufacture's manual to progamme the PLC - Replace the PLC if worn-out - Frequent inspection of the PLC	1	5	5	1	5

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
14	C1- Boiler tubes	-Providing a bigger surface area for water heating	-Broken pipe	-Non production of enough steam to drive the machine -Most parts/sections will be closed down.	- Corrosion	- Frequent inspection of the pipes -Replacing the pipes -By passing the faulty boiler and utilize the other three.	2	5	10	2	20
15	C2- Fan	-Exhaust -Cooling -Oxygen for combustion	-Fan stops	-No exhaust -Overheating -Low temperature in the furnace	- Wear and tear - Ageing -Worn-out bearing	- Frequent inspection of the fan to recommend replacement	2	5	10	2	20
16	C3-Water pump	-Supply of water to the boiler	-Pump stops	-No water flow into the boiler tubes -Insufficient steam	- Faulty impeller -Faulty motor -Open circuit	-Frequent inspection and servicing the pump and its accessories	2	5	10	2	20
17	D1- Gaskets	-Sealing the manholes	-Leakage	-Loss of Sugar juice	-Worn-out -Improper fitting -Ageing	-Frequent inspection and replacement	1	5	5	1	5

ITEM	PART NUMBER/ NAME	FUNCTION	FAILURE MODE	EFFECT OF FAILURE	CAUSE OF FAILURE	CURRENT CONTOL	OCCURRENCE (O)	SEVERITY (S)	CRITICALITY INDEX (OxS)	DETECTION (D)	RPN (OxSxD)
18	D2- Oil	- Lubrication	-Noise produced on the moving parts -Metal particles on the moving parts	-The rollers stops -Broken bearing	-Substandard oil -Faulty oil pump -Lack of frequent oil replacement	- Frequent inspection of oil levels and replacement -Repair of faulty oil pump	5	5	25	1	25
19	D3- Gas	-Provision of heat when joining metals and sealing broken sections in the tanks	-Absence of gas	-No gas	-Delayed delivery of gas	-Frequent inspection of the gas cylinders -Replacing empty gas cylinders	1	3	3	1	3
20	D4- Bolts and nuts	-Fixing of two or more parts	-Shaking rotating systems	-Unstable moving system - Leakages - Vibrating machines	-Worn-out -Improper fitting/tightening -Ageing	-Frequent inspection of nuts and bolts and replacing the loose/broken	2	5	10	1	10