IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 6 (June. 2018), ||V (I) || PP 41-54

Development Of Risk Based Approach To Spare Part Inventory Management For Sugar Factories: A Case Study Of Chemelil Sugar Company.

Lagat Kiprotich Micah [1] Peter N Muchiri [2] James Nyambega Keraita [3]

[1]*Dedan Kimathi University of Technology micskiprotich*
[2]*Dedan Kimathi University of Technology , peter.muchiri*
[3]*Dedan Kimathi University of Technology james.keraita*
Corresponding Author: Lagat Kiprotich Micah

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. In order to achieve the objective the study employed a convergent parallel mixed method 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 as the main tools for collecting secondary data was used. Data was analyzed by use of descriptive statistics using Excel. From the Pareto analysis of boiler, pre mills, mills and juice treatment it was established that they 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.

Key Words: Risk, Spare part, Inventory

Date of Submission: 28-05-2018 Date of acceptance: 10-06-2018

I. INTRODUCTION

Equipment breakdown due to unavailability of spare parts has incurred challenges for the manufacturing industry in managing the inventory globally (Kamal, Jafni, & Zulkifli, 2015). Consequently spare parts unavailability has led to poor plant performance which eventually affects financial performance. This is underpinned by Scott & Consultant, (2004) who stated argued that, inventory management has the largest impact towards maintenance and plant performance. In fine 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, Jafni, & Zulkifli, 2015).

Risk-based approach in spare part inventory management and plant maintenance is essential for ensuring asset integrity in a process facility (Khan & Haddara, 2004). Risk is the 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, Silberschmidt, & Wintle, 2011). Such a stock out may result in production loss, having to procure spares at an additional cost ('distress cost'), knock on failures requiring more parts and/or resulting in more production loss, accidents, prolonged downtime, regulatory penalty and other consequences such as loss of goodwill (Bharadwaj, Silberschmidt, & Wintle, 2011). A risk-based approach to spare parts inventory management helps in effective allocation of limited resources (Jakiul, Faisal, & Mainul, 2012). However this calls for strategic procurement policy to ensure spare parts availability. In consequence the risk level can be minimized and plant availability can be maximized within the financial constraint. In risk based approach of inventory management resources are allocated to the most critical components and thereby increased availability and reduce risk (Marshal, Hamond, Obermeyer, & 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 basic functions to manage risk - risk identification, risk quantification, risk probability, and risk response where the first three, identification, quantification and probability, are sometimes grouped together under Risk Analysis or Risk Assessment (Bharadwaj, Silberschmidt, & Wintle, 2011). Some of the techniques used are Failure Modes, Effects, Criticality Analysis (FMECA) and Hazard and Operability Studies (HAZOPs) (Kamal, Jafni, & Zulkifli, 2015). These techniques become quantitative when consequences and failure probability values are estimated in numerical terms. In this situation, a risk profile of the spares is obtained by considering the likelihood of a failure to meet the demand for a spare in conjunction with the consequences of the failure to meet that demand (Kamal, Jafni, & Zulkifli, 2015). This risk profile is then used to find the optimal level of inventory such that financial benefit is maximized given an identified acceptable risk level. Therefore, the goal is to maintain the level of spare parts which provides minimum warehousing and delay costs on one side, while guaranteeing a high level of availability of spare parts on the other hand (Bharadwaj, Silberschmidt, & Wintle, 2011). The intermittent or uncertain demand the large numbers of spare parts and the risk of spare parts obsolescence 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 , Jafni, Zulkifli, & Abdul, 2016) who argues 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 used for the purpose of spare part inventory, plant maintenance and operation (Dhillion, 2002). Malaysia industry also is no exception to this issue where in construction industry alone, the management spent average RM40 million or 12% of the annual budget for the cost of maintenance (Heng, Zhang, Tan, & Mathew, 2009). In addition, (Krishnasamy, Khan, & Haddara, 2005) has discovered that manufacturing company spent about 80% from its operation cost to address issue on equipment failures and injury to people. These issues actually have drawn response among various parties of business and industries to look into 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 attributed to unscheduled factory stoppages, factory breakdowns besides lack of cane for grinding by the sugar factories (KSB., 2006). 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 dropped from 79.58% in 2006 to 74.91% in 2008 in comparison to the international set standard of 92% (Mwanaongoro & 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, Awiti, & Some, 1991; Otieno, Kegode, & Ochola, 2003). This has motivated 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.

1.1 Problem Statement

The spare part inventory management has been a preserve of the procurement department whose stocking policy is based on the order quantity and associated costs (cost of spare part, holding cost and ordering cost). The maintenance team utilizes the spare parts to ensure maximized machine availability for production. The two teams (Procurement and maintenance) are very crucial in plant performance though there is a risk on the type and amount of spare parts in the inventory for effective maintenance. Therefore, there is a need to develop a risk based approach to spare part inventory management in the sugar industry.

1.2 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.

II. RESEARCH METHODOLOGY

2.1 Research Design

In this research the case study research design was adopted. This design entails in-depth study of a particular research problem rather than a sweeping statistical survey. It entailed an 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

2.2 Data collection

Secondary data was used which was collected using document analysis of the factory maintenance and spare part inventory (spare part store) records. Records on frequencies of failure, down time, lead time (time to delivery of spare part) and availability in the market from the spare parts inventory records and plant maintenance records were used.

2.3 Data analysis and presentation

2.3.1 To identify the risk due to unavailability of spare part

This entailed identification of down time in the factory 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. The histogram was drawn to aid in risk identification in the factory.

2.3.2 To asses 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:

Risk based on the lead time

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

Risk based on the availability

Risk (Criticality index) = Availability (Severity) X Frequency of failure (Occurrence)
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)
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 drawn to compare the criticality index and the risk priority number of the spare parts considered in the study.

Risk based on the down time

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

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 (i), (ii) and (iii).

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

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

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

III. RESULTS AND DISCUSSION

3.2 Risk 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 the figure 3.1 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 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.

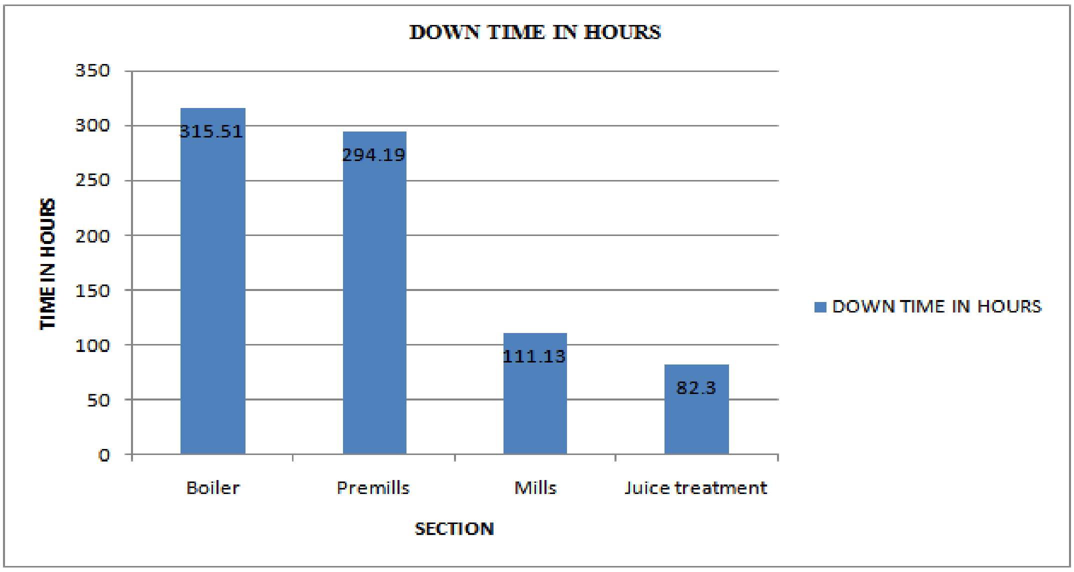

Figure 3. 1 Downtime in the four sections (Pre mills, Mills, Boiler and Juice treatment)

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 3.2. The researcher analyzed 20 spare parts that caused the failure in the factory four sections as shown in figure 3.2 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 figure3.1 and figure3.2 the study realized that the extended down time in the four sections could be probably adduced to spare part frequency of failure.

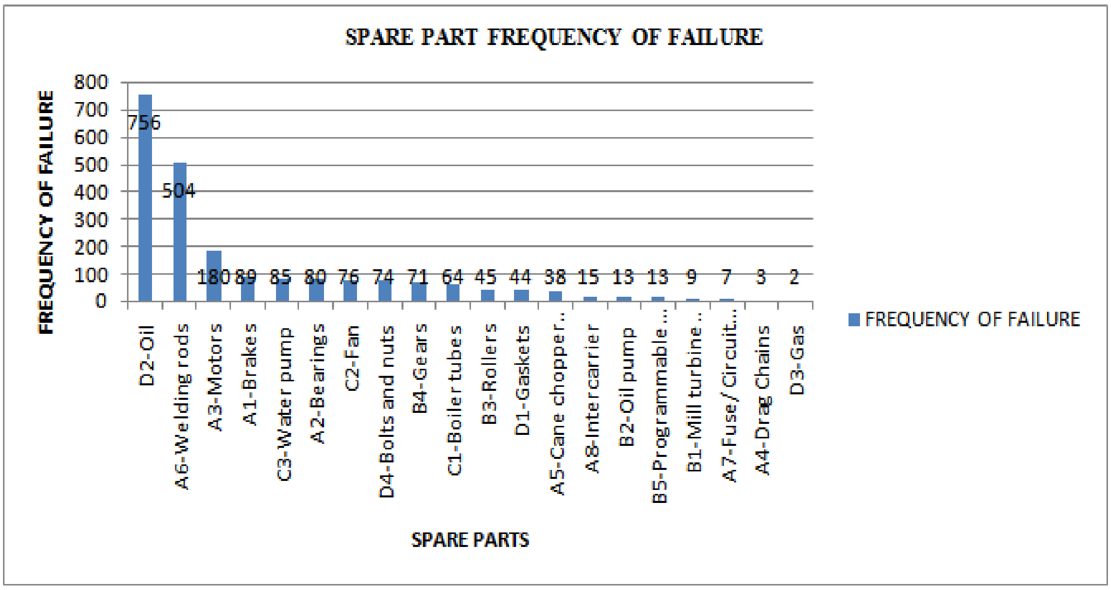

Figure 3. 2 Spare parts against risk occurrence in one year

3.2 To asses 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.

3.2.1 Risk analysis based on lead time

For the four sections whose down time was analyzed in figure 3.1, the extended down time was due to unavailability of the spare part due to extended lead time as shown in figure 3.3. From table 3.1 and the risk matrix shown in table 3.2, 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 3.1 had a rating of 3-6 according to the risk matrix indicated in table 3.2. The semi critical spare parts were: Welding rods, Mill turbine governor, Oil pump, Bearings, Rollers, Programmable Logic Controllers (PLC), Oil, Brakes, Inter carrier, Boiler tubes and Fan.The non critical spare part indicated in table 3.1 and table 3.2 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 3.3.

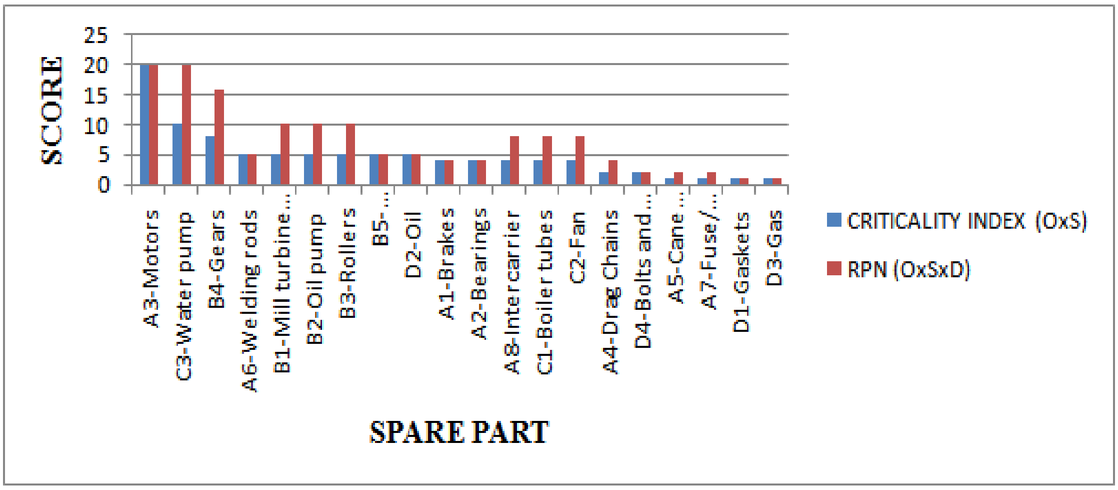

Figure 3. 1 Risk Priority Number compared with the criticality index of the spare parts based on the lead time

Table 3. 2 Risk based on lead time

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 3. 3 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

High Risk(Critical)
Medium Risk(Semi critical)
Low Risk(Non critical)

From the graph in figure 3.3, 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 3.1 and figure 3.3, 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).

3.2.2 Risk based on availability

From table 3.3, 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 3.4, reveals 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 Inter carrier as shown in table 3.3. 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 3.3. 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 Inter carrier had a low failure frequency (Occurrence) and available hence medium risk of 3 and 6.

The semi critical spare parts from figure 3.4, the Boiler tubes, Mill turbine governor, Rollers, Oil pump, Gears, Fan and the Inter carrier 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 3.4. The spare part failure has no impact on production and locally available which explains its non criticality (Catarina & Isabel, 2017). Figure 3.4 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.

Table3. 4 Risk based on the availability

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

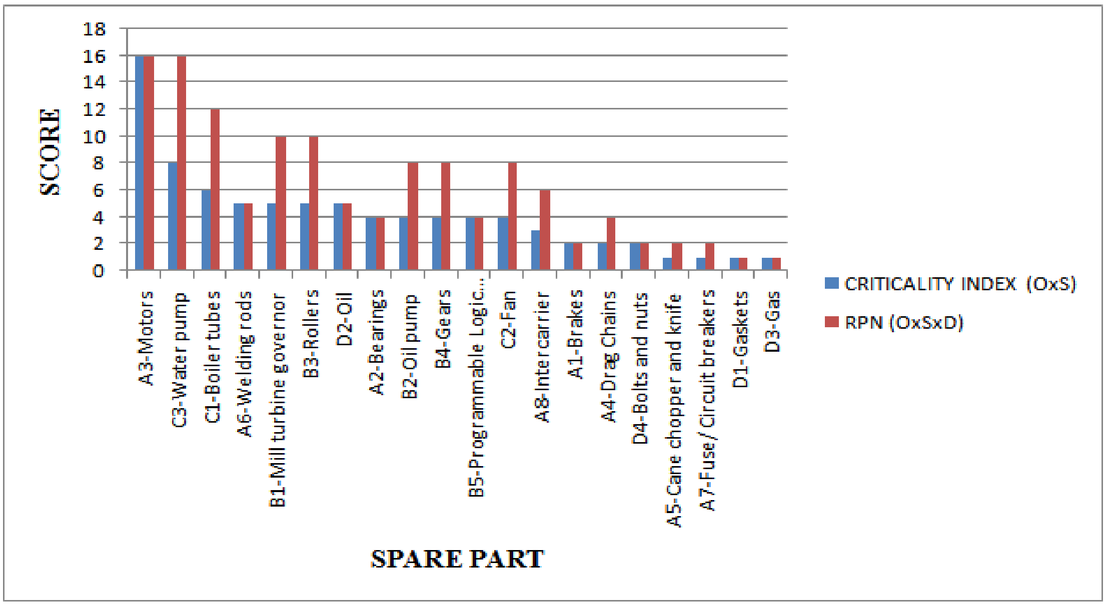

Figure 3. 3 Risk Priority Number compared with the criticality index of the spare parts based on Compatible spare parts and availability

3.2.3 Risk based on the down time

From table 3.5 and table 3.6 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 3.5 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, Khan, & Hasan, 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 3.6. 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 R. , 2017).

After the analysis shown in table 3.4, the semi critical spare parts were; Cane chopper and knife, Fuse/Circuit breakers, Inter carrier, 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 3.5, the semi critical spare part who's RPN doubles the criticality index were Cane chopper and knife, Fuse/ Circuit breakers, Inter carrier, 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 makes use of sensors to establish baselines and detect subtle changes in factors like vibration, which can be used to predict impending breakdowns and failures, often allowing more time for contingency planning and scheduling downtime for equipment to minimize production 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 3.5. From figure 3.6 the drag chain had a doubled RPN as compared to the criticality index due to its un detect ability of its failure.

Table 3. 6 Risk based on the down time

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-Programmable Logic Controllers(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

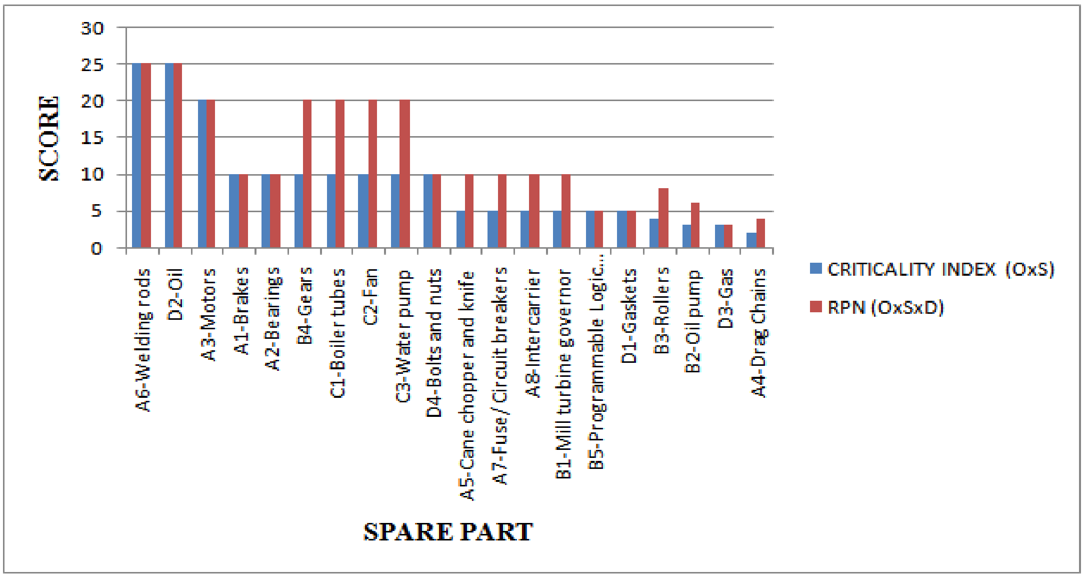

Figure 3. 4 Risk Priority Number compared with the criticality index of the spare parts based on down time

3.2.4 Summary for the risk analysis and evaluation

Criticality analysis is the tool to use if you want to improve reliability and manage plant assets based on risk instead of perception (LCE, 2016). From table 3.5 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 of between 8 to 25 three factors considered. Suppliers providing critical spare parts should go through a certification process and be under contract to mitigate unexpected lost production time and delayed deliveries (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 3.5 and table 3.2. 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 3.7.

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. Maintaining high-value assets and reducing downtime are just two aspects of spare parts planning and management (Schroeder, 2018).

Table 3. 7 Table on the criticality index based on the lead time, availability and down time

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 semi critical spare parts are 3 spare parts as shown in table 3.7. From figure 3.6 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 3.7 which contributed a failure frequency of 51.9%, 47.5% down time and 51.9% number of spare parts consumed as shown in figure 3.6.These parts were locally available hence a percentage lead time of 35.3% as shown in figure 3.6.

The non critical spare parts were 6 in number as shown in table 3.7. The lead time was very low at a percentage of 3.8% as shown in figure 3.6. 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 3.6.

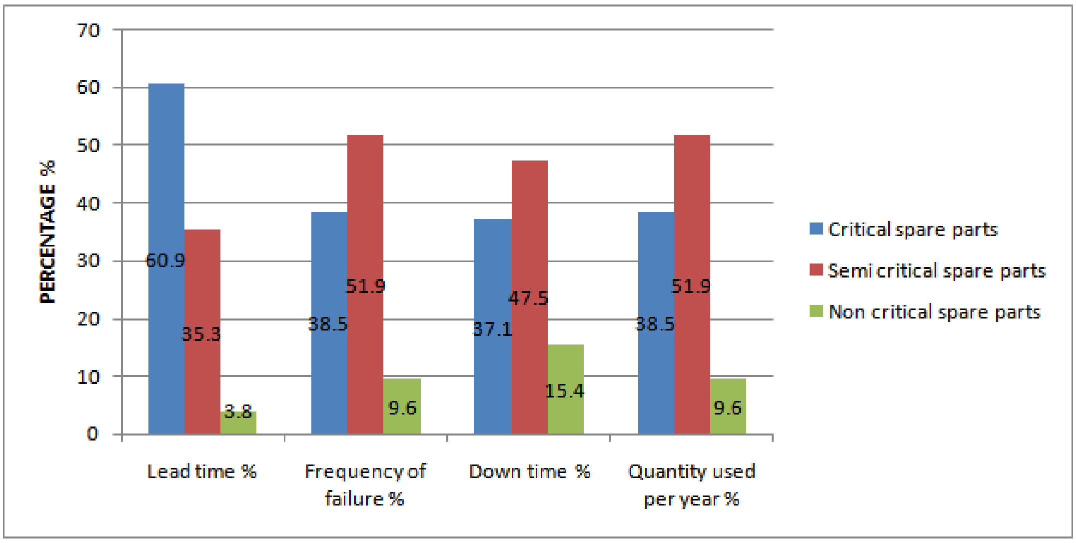

Figure 3. 5 Comparing the percentages of lead time, frequency of failure, down time and quantity of spare part consumed in one year

3.3 To determine inventory risk mitigation strategies

The researcher developed strategies of ordering spare parts based on their criticality.

3.3.1 Strategy of ordering critical spare parts

From table 3.7, 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 16 pumps, 75 Gears, and 24 motors. 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.

Table3. 7 Critical spare parts

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

Reorder points

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

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

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

Table 3. 8 Reorder points, Lead time demand and Safety stock for critical spare parts

SPARE PARTS	**Lead time demand**	**Safety stock**	**Reorder point**
Motors	13	12	24
Water pumps	4	13	16
Gears	30	45	75

3.3.2 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 3.9, it was observed that the lead times of the semi critical spare parts was an average of 1-96 days calling perpetual inventory control as a strategic approach of optimizing the stock levels. According to Hanson, Ackah, & Agboyi, (2015) a perpetual inventory control process reviews inventory status daily to determine inventory replenishment needs. To utilize perpetual review, accurate tracking of all Stock-Keeping Units is necessary. Perpetual review will be implemented through a re-order point and order quantity that will be done on a daily basis. Reorder points for Oil, Welding rods, Brakes, Bearings, Boiler tubes, Fan, Inter carrier, PLC, Oil pump, Rollers and Mill turbine governor were 122, 97, 11, 125, 4, 6, 7, 20, 10, 10 and 10 respectively as shown in table 3.10. This implies that inventory must be updated in real time to take care of high frequencies of failures associated with semi critical spares.

Table 3. 9 Semi critical spare parts

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 3. 10 Reorder points, Lead time demand and Safety stock for semi critical spare parts

SPARE PARTS	**Lead time demand**	**Safety stock**	**Reorder point**
Oil	11	112	122
Welding rods	3	95	97
Brakes	4	8	11
Bearings	42	83	125
Boiler tubes	1	4	4
Fan	2	5	6
Intercarrier	4	3	7
PLC	7	14	20
Oil pump	4	7	10
Rollers	4	7	10
Mill turbine governor	4	7	10

3.3.3 Strategy of ordering non critical spare parts

From table 3.11, 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 3.10 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 3.12 for Bolts and nuts, Cane chopper and knife, Drag Chains, Gaskets, Gas and Fuse/ Circuit breakers at 120, 6, 4, 20, 4 and 12 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 3. 11 Non critical spare parts

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 3.12 Reorder points, Lead time demand and Safety stock for non critical spare parts

SPARE PARTS	**Lead time demand**	**Safety stock**	**Reorder point**
Bolts and nuts	9	111	120
Cane chopper and knife	1	6	6
Drag Chains	1	4	4
Gaskets	2	19	20
Gas	1	4	4
Fuse/ Circuit breakers.	1	12	12

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

From the study finding s it remains necessary for the plant maintenance to balance the issue of risk associated with shortage of spare parts and of inventory. In view of this situation, the spare parts become a critical matters and it is good starting point to tackle the issues from looking at the perspective of risk based approach to spare parts inventory management . In this regard the paper proposes a risk based approach for based on criticality index in management of spare parts in the sugar industry.

Down time and spare part frequency of failure are the risk identification strategies used by the the sugar factories.This was justified by the length of time that the mills, premills, boilers and juice treatment remain unoperational due to spare part related issues.The study also submits that critically 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 during 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.

Spare part risk mitigation strategies remain the most effective means of guaranteeing reduced down time and spare part failure 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 in 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.

4.2 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;

There should be effective implementation risk based approach to spare part inventory management by the sugar industries for reduced failure frequencies, tone and time loss due to stoppages. Besides a comprehensive spare part inventory system data clean-up effort might be required to address issues of under stocking and overstocking of spare parts for effective spare part optimization.

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.

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

REFERENCES

[1]. Alexander, B., & Adam, S. (2011). Critical equipment classification and cost reduction within professional maintenance. Göteborg, Sweden: Chalmers University of Technology.
[2]. Bharadwaj, U. R., Silberschmidt, V. V., & Wintle, J. B. (2011). Risk based optimisation of spares inventory managemenT. Advances in Production Engineering & Management , 6 (3)173-184.
[3]. Catarina, T., & Isabel, L. (2017). Multi-criteria classification for spare parts management: a case . Procedia Manufacturing , 11 , 1560 – 1567.
[4]. Dhillion, B. (2002). Engineering maintenance, a modern approach. New York : CRC Press.
[5]. Ellacott, J. (2017, 4 4). 3 causes of equipment failure (and what you can do to prevent it). Retrieved 2 28, 2018, from https://www.fiixsoftware.com/blog/3-causes-of-equipment-failure-and-what-you-can-do-to-prevent-it/
[6]. Harris, F. W. (1990). How many parts to make at once. Factory: The Magazine of Management , 38 (6).
[7]. Hassan, J., K., F., & H., M. (2012). A risk-based approach to manage non-repairable spare parts inventory. Journal of quality in maintenance engineering , 18(3),344-362.
[8]. Kaumbutho, P., Awiti, L., & Some, D. (1991). Analysis of Sugarcane and Sugar Production Costs for the Kenyan Sugar Industry . Kenya Sugar Authority.
[9]. Kevin, R. (2017). Risk-Based Maintenance to Defeat Downtime. Retrieved February 26, 2018, from https://www.pharma-integrates.com/risk-based-maintenance-defeat-downtime/
[10]. Khan, F., & Haddara, I. (2004). Risk-based maintenance (RBM): a new approach for process plant inspection and maintenance Process Safety. 252-265;.
[11]. LCE. (2016). Life cycle engineering The Role of Critical Spares Analysis in Validating Spare Parts Recommendations. Retrieved 2 25, 2018, from https://www.lce.com/The-Role-of-Critical-Spares-Analysis-in-Validating-Spare-Parts-Recommendations-1364.html
[12]. Mwanaongoro, S., & Imbambi, R. (2014). Assessment of relationship between plant and equipment maintenance strategies and factory performance of the Kenya Sugar Firms. Asian Journal of Basic and Applied Sciences , 1(2) .
[13]. Roberts, P. (2007). Failure modes ,Effects and criticality analysis. UK: Warwick manufacturing group.
[14]. Rooij, R. (1998, 9 20). A spare parts stocking policy based on equipment criticality. Retrieved 2 28, 2018, from https://www.sciencedirect.com/science/article/pii/S0925527397000509#!
[15]. Schroeder, B. (2018). Effective spare parts management and services are crucial for optimization, success. Retrieved 2 28, 2018, from http://www.inspirage.com/2015/03/effective-spare-parts-management-and-services-is-crucial-for-optimization-success/
[16]. Sigma. (2017). 7 Things to Consider for Successful Spare Parts Management. Retrieved march 1, 2018, from https://www.sigmathermal.com/spare-parts-management/
[17]. Slater, P. (2018). Spare Parts Inventory: An Exercise in Risk Management. Retrieved feb 25, 2018, from https://reliabilityweb.com/articles/entry/spare_parts_inventory_an_exercise_in_risk_management
[18]. Valmet, R. (2018). Spare parts criticality analysis. Retrieved Feb. 25, 2018, from http://www.valmet.com/en-US/Medias/north-america-eNewsletters/paper-and-board-enews/the-importance-of-planning/spare-parts-criticality-analysis/
[19]. Wally, W. (2011). 2 steps to determine spare criticality. Retrieved 2 25, 2018, from https://www.plantservices.com/articles/2011/09-steps-to-determine-spare-criticality/
[20]. Wally, W. (2010). CMRP of Life Cycle Engineering; Keep your eye on the ball: Visualize goals to help your team attain them. Retrieved April 26, 2017, from https://www.lce.com/Spare-Parts-Can-Kill-Your-Plants-Efficiency-1231.html

Lagat Kiprotich Micah "Development Of Risk Based Approach To Spare Part Inventory Management For Sugar Factories: A Case Study Of Cheekily Sugar Company."IOSR Journal of Engineering (IOSRJEN), vol. 08, no. 6, 2018, pp. 41-54.