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Effective Maintenance Strategy of Cane Crushing Mills for Improvement of Sugar Production in Kenya

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Abstract: *This paper proposes an effective maintenance strategy of Cane Crushing Mills for improvement of sugar production in Kenya. This study was conducted at Nzoia Sugar Company Limited where cane crushing mills have been operating at sub optimal performance due to frequent stoppages and numerous unplanned breakdowns. The existing maintenance system being used at the company cannot minimize these unplanned failures resulting into low productivity of the cane crushing mill. The aim of this study was to come up with an effective maintenance strategy which should improve the performance of the cane crushing mills as well as sugar production in Kenya. In this research the impact of maintenance practices was investigated to evaluate the maintenance practices of the cane crushing mills. Root Cause Analysis (RCA) was used to assess the impact of maintenance practices on mill performance and questionnaires were analyzed to evaluate the maintenance practices. An improved maintenance strategy was recommended using an evaluation matrix which compared strengths and weaknesses of various best practice maintenance strategies. It was recommended that the cane crushing mill required a tailor-made Total Productive Maintenance (TPM) framework since the failure rate of the equipment was affected by the maintenance strategy. The study contributed to theory and practice through development of a methodology to prioritize critical failures which is a basis of formulating performance metrics in maintenance decision making.*

Keywords- *Maintenance, Cane mill, Total Productive Maintenance, Overall Equipment Effectiveness*

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I Introduction

The sugar industry is a major contributor to the agricultural sector which is the mainstay of the economy and supports livelihoods of at least 25% of the Kenyan population. The sector accounts for about 15% of the agricultural Gross Domestic Product (GDP) and is the dominant employer as well as the source of livelihoods for most households in Kenya comprising Nyanza, Rift valley, Coast and Western provinces. However, Kenya has the highest production cost of sugar within the Common Market in Eastern and Southern Africa (COMESA) region as presented in Table 1 [1].

Table 1: Production Costs of Sugar in COMESA States (Kenya Sugar Board, 2015)

Country	Cost (USD per tonne)
Kenya	415-500
Sudan	250-340
Egypt	250-300
Swaziland	250-300
Zambia	230-260
Malawi	200-230

Sugar industries in Kenya have never attained the industry recommended standard of 89% in terms of capacity utilization. The annual production of brown sugar is consistently below the targeted value. Figure 1 shows the trend of brown sugar production and consumption in Kenya for a 4-year period. The low annual production of sugar is attributed to several factors such as frequent and unplanned mill stoppages, production losses and logistical challenges [2].

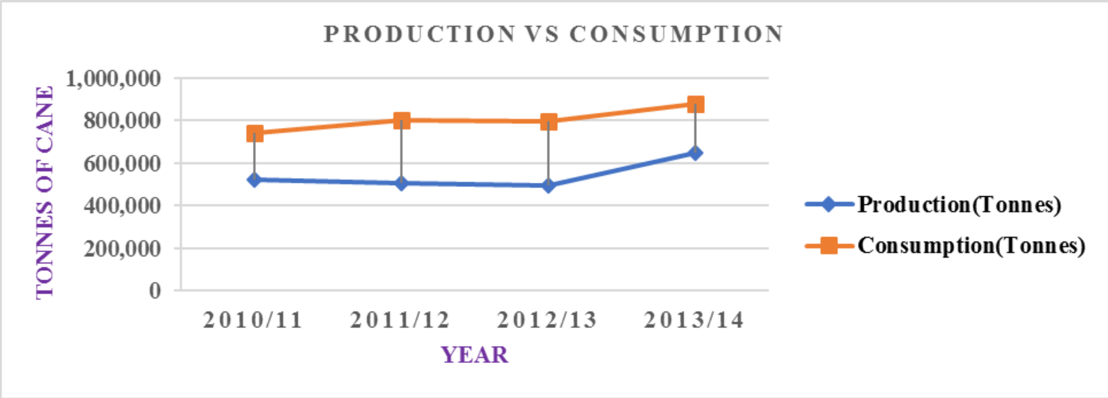

Figure 1: Production vs Consumption of Sugar in Kenya (Kenya Strategic Sugar Plan, 2014).

Over the years the sugar industry stakeholders have paid great emphasis to this emerging challenges in order to enhance sugar production. Concerted efforts have been made by the engineering experts to rehabilitate the sugar mills in order to improve on their availability and restore the sugar mills to as good as new condition [3].

Maintenance considerations play a key role during the life cycle of sugar equipment. The performance of sugar processing systems largely depends on the optimal utilization and management of available resources [4]. Availability, production cost and quality of sugar products is influenced by the condition of the equipment which are prone to stoppages due to unplanned failures if they are not well maintained. This affects production targets and costs in terms of downtime and inventory before the equipment is restored to operable state [5]. Therefore sugar industries should have effective maintenance programs which are anchored on proper maintenance planning, scheduling, maintenance execution and sustainable improvement activities.

A sugar equipment failure or breakdown is a condition in which an equipment or part no longer performs its function [6]. Equipment failures in sugar industries are categorized into four main classes: Mechanical failures, electrical failures, instrument failures and other failures [7]. Mechanical failures are associated with malfunction of mechanical systems such as bearings, shafts, welded joints, pumps, couplings, belts, gears etc. Electrical failures result from malfunction in electrical systems like motors, switchboards, electrical circuits, generators, lighting systems etc. Instrument related failures include malfunction in automatic control valves, actuators and programmable logic controllers. Probability theory and distribution of sugar equipment failures as a function of time can be used to model failure behavior in order to perform maintenance optimization for different equipment [8].

There are several maintenance policies which are used in sugar industries to describe the triggering mechanism (s) for maintenance actions. Failure Based Maintenance (FBM) is done only after a breakdown has occurred. It is therefore a reactive policy in which unforeseen breakdowns disrupt production and its use depends on critical analysis of the costs of Corrective Maintenance (CM) against Preventive Maintenance (PM) costs [9]. Condition based maintenance (CBM) is where maintenance action (PM) is made whenever a specific system parameter reaches a predetermined value, condition or situation. It is a predictive policy which is achieved through techniques such as: vibration analysis, tribology, thermography, ultrasonic testing, electrical testing and other techniques. Use or time based maintenance is a preventive policy in which maintenance actions are carried out at pre-determined time intervals which depends on equipment use. However, precautionary and corrective activities are carried out whenever needed [10]. Design-out Maintenance (DOM) is a proactive policy which aims at improving the design of a system in order to lower its Mean Time To Repair (MTTR) or increase its Mean Time Between Failure (MTBF). Opportunity based maintenance (OBM) is a passive policy in which maintenance actions (PM) are done only when an opportunity arises [11]. However, CM is done whenever necessary.

In addition there are several maintenance concepts which refer to the maintenance policies and actions in which maintenance is planned and supported. Quick & Dirty decision chart (Q & D) is a concept where decision tree diagrams with failure and repair behavior questions are answered through the branches in the tree diagram until an appropriate policy is found. Life Cycle Costing (LCC) is a concept in which the Total Cost of Ownership (TCO) is calculated from the design phase to disposal phase of equipment since a cheap machine is not necessarily cheap in terms of operation and maintenance [12].Total Productive Maintenance (TPM) concept requires total participation of all levels in an organization whose objective is to enable efficient and effective use of equipment and also establishing a thorough preventive maintenance system [13]. There are various tools used to achieve TPM such as; Overall Equipment Effectiveness (OEE), 5S, 6 sigma, Pareto (ABC) analysis, Ishikawa or Fishbone diagrams etc [11]. Reliability Centered Maintenance (RCM) is a concept which employs the Failure Mode Effect Analysis (FMEA) approach in its implementation [14]. Decision charts are used to address different equipment failures with a strong focus on reliability, safety and environmental integrity of the equipment.

II Methodology

2.1 Maintenance Strategy Modelling and Evolution

The maintenance strategy was modelled in a four stage framework in the evolution towards world class asset management. This was achieved by taking into account interrelating factors within asset management and suggested the direction to progress in terms of sustainable long-term maintenance effectiveness. Figure 2 shows the stages towards world-class maintenance based on how maintenance actions are carried out and supported. The first stage is when maintenance is considered reactive whereby corrective actions are conducted only after a breakdown has occurred. Stage II is when maintenance management is seen as being defensive or preventive. Reactive maintenance is still important at this stage though a reasonable amount of preventive maintenance is carried out. At stage III maintenance is viewed as offensive with maintenance being considered as a critical support for manufacturing and business strategy. Though it is not fully exploited, reactive maintenance is replaced by preventive and predictive methods. Finally, stage IV is when maintenance is considered as a strategic matter, fully exploited and externally supportive. Greater attention is paid to more advanced techniques, tools and concepts. At these stage world class maintenance standards are fully in place.

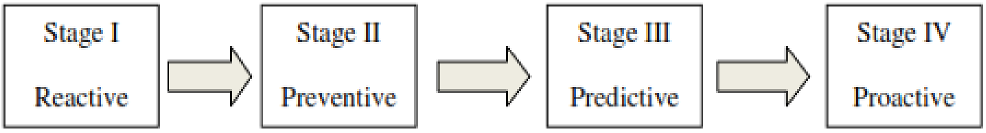

Figure 2: Stages of Maintenance Evolution

The stages of maintenance were also associated with life cycle cost of the equipment since it was observed that life cycle cost decreases as asset management evolves towards world class standard. At stage I, maintenance is reactive with high life cycle costs since maintenance budgets are high as presented in Figure 3. Across the stages of maintenance evolution life cycle costs of the equipment reduce significantly.

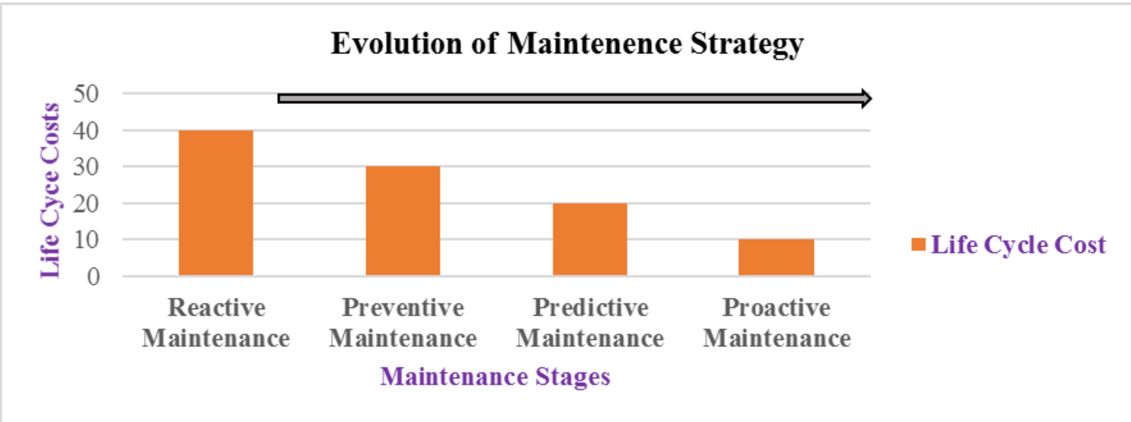

Figure 3: Life cycle Cost of Equipment during Stages of Maintenance Evolution

Therefore in selecting an effective maintenance strategy for implementation required care and a very clear understanding of the organization’s goals, its capabilities, the organizational culture and the effort required for implementing the strategy. The selection was done with extreme caution since the results become apparent after a few years by which time the organization would have put in considerable effort and resources into the implementation. It was observed that one maintenance strategy was better than the other by the extent the strategy relates with other business functions and by the degree to which it enhances competitive advantage. The process of selecting an effective maintenance strategy began by evaluating the effectiveness of the current strategy and determining the direction to progress in the four stage framework. This helped to identify the gaps in maintenance actions and areas of improvement before deciding on the next steps towards maintenance effectiveness.

2.2 Assesment of Mill Failures and Root Cause Analysis

In the assessment of mill failures, secondary data on frequency of mill failures and downtime was collected for a period of 14 weeks at the factory mill. This data helped to identify the most critical failures affecting the mill performance by selecting failures with the highest frequency of occurrence. The data also helped to determine whether the failures were within statistical control by plotting the failures on a statistical control chart. This assessment of mill failures was done to establish whether the failures resulted into an acute or chronic problem which would provide a basis for remedial actions to be taken. Identification of critical failures helped to separate the vital few causes from the trivial many causes of mill failures.

A root cause analysis was then conducted based on the most critical failures determined through pareto analysis. The factors affecting mill service performance and causes of service failures were investigated. The most critical components to be studied were also identified and the causal factors leading to each failure were evaluated. These causes were then classified into categories either as either maintenance-related, design-related or operation-related. These categories were compared to obtain specific causes with the greatest impact on mill performance. The category with the greatest impact on the mills were taken as the root cause of low mill performance.

2.3 Maintenance Strategy Evaluation

In the evaluation of maintenance strategy, questionnaires were prepared and sent to a sample of mill experts at the factory. The questionnaire was developed based on employee, technical and managerial aspects of maintenance. Its evaluation was based on a four point Likert scale where 1 meant stage I, 2 meant stage II, 3 meant stage III and 4 meant stage IV in line with the four stage maintenance framework. Respondents rated the degree or extent of practice of each element in the questionnaire based on the four point response scale. The questionnaire was designed using 26 items divided into 3 sections in order to provide deeper insights in maintenance interventions at the mills. A numerical score (N) was calculated using the relation given by:

$$N = \frac{1}{n} \sum_{i}^{n} x_i$$

Where

xi **-** is the rating score for each test item and n- is the number of respondents

The numerical score provided an opinion of the relative importance of the factors in the maintenance strategy and corresponded to the stage of maintenance discussed in 2.1. The validity and reliability of the score was subjected to the appropriate sample and response rate.

2.4 Maintenance Strategy Validation

The maintenance strategy was subjected to validation test to check the accuracy of the four stage framework of maintenance. The Overall Equipment Effectiveness (OEE) for the mills was calculated based on three metrics: performance rate, availability rate and quality rate. This value was computed from secondary data collected from the production process at the factory for a 14-week period. The data on daily cane crushing volumes helped to determine the performance rate of the mills while data on downtime due to mill failures was used to compute the availability rate. Then data on rejected products and products subjected to rework from mills was used to calculate the quality rate. The value of OEE was found by multiplying the three metrics. The calculated value of OEE was compared with the value obtained from questionnaires and determine any deviation.

2.5 Maintenance Strategy Design and Selection

In the selection of an effective maintenance strategy, the study used a qualitative approach to collect data through direct observation and interview method with engineering experts at the factory. The interviews were based on focus groups and individual depth interviews for in-depth clarity and understanding of the situations and underlying issues at the mills. Quantitative techniques were also used at the strategy selection stage in which salient features of best practice maintenance systems which are applicable in manufacturing industries were identified. Parameters such as nature of maintenance activity, core intention, implementation focus, process changes and measures of effectiveness were investigated to identify superior maintenance practices for selection. Based on the parameters listed several maintenance strategies were identified and selected.

A comparison was made for the maintenance strategies identified in relation with their consistency with the methods employed, company goals, advantages, shortcomings and approach to employees. This was achieved through expert advice and discussions with engineers from the sugar company. The feedback from the engineering team was presented on a 5-point importance rating scale in terms of factors influencing methods, goals and employee involvement in the maintenance strategies. An evaluation matrix was prepared, and an overall comparison was done after finding the aggregate score and the maintenance strategy with the highest rating was selected.

III Results And Discussion

3.1 Assessment of Mill Failures

Data on frequency of failures and downtime was collected for a period of 14 weeks. The most critical failures affecting the mill performance were identified and were then subjected to statistical process control. The results showed that mill failures were a chronic problem at the mills as they were within statistical control and were presented as shown in Figure 4.

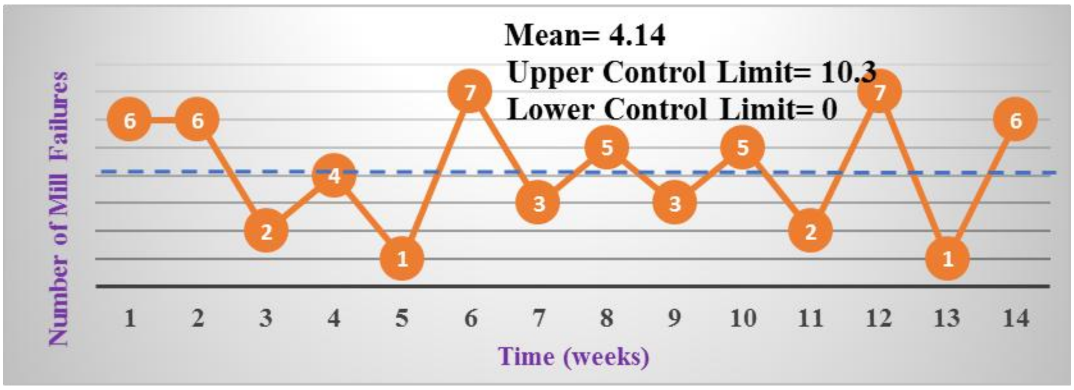

Figure 4: Statistical Process Analysis of Mill Failures

A further analysis of mill failures revealed that mechanical failures were the vital few failures accounting for 79% of the total failures as presented in Figure 5.

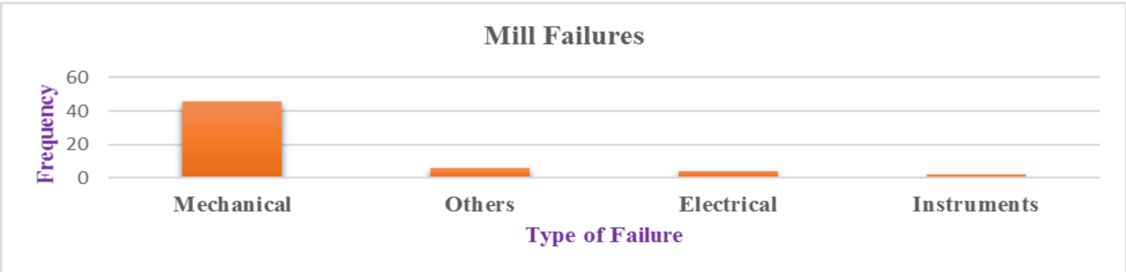

Figure 5: Assessment of Mill Failures

The mechanical failures were then investigated further to determine the most critical failures or components affecting mill performance. The results were presented in Figure 6. It was found that mill chokes accounted for 27% of the total failures, bearing failure 14%, inter-carrier failure 12%, pump failures 12% and were considered as the most critical failure types whose root cause(s) were to be investigated.

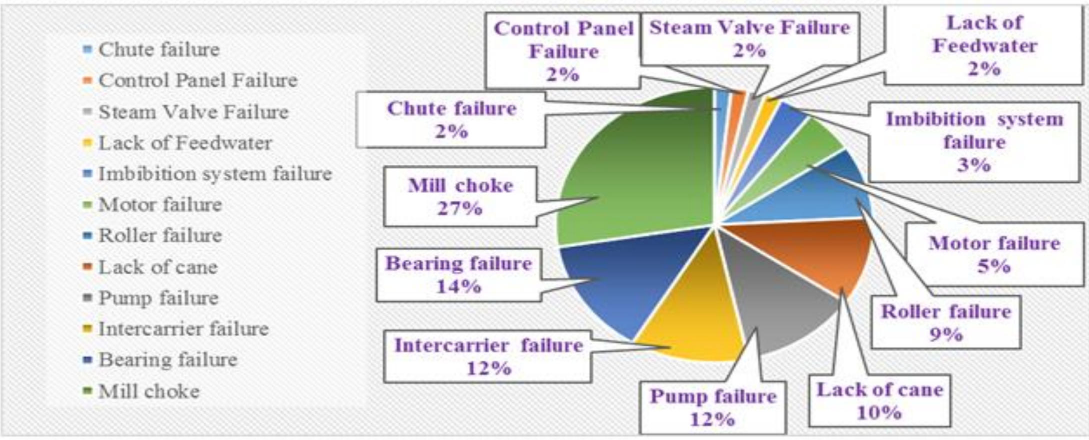

Figure 6: Assessment of Mechanical Failures

3.2 Root Cause Analysis of Mechanical Failures

A root cause analysis for mechanical failures was conducted. The causes of mechanical failures were grouped into three categories as maintenance-related factors, design-related factors and employee-related factors. Each mechanical failure was analyzed based on the three broad groups. Analysis of mill chokes showed that maintenance-related factors accounted for 60% of the total failures with design-related causes accounting for 13% of the total failures. The causal factors leading to mill chokes included: poorly shredded cane, mill contamination, unsteady mill roller tension, poor mill lubrication and mill overloading. Assessment of bearing failures revealed that maintenance-related factors accounted for 42% of the total failures with employee-related causes accounting for 33% of the total failures. The causal factors leading to bearing failures included: poor bearing alignment, bearing seal failure, bearing overloading, mechanical vibrations and corrosion. The results were presented in Figure 7. It was observed that the maintenance practices in place at the milling section were inadequate to reduce mill chokes and bearing failures.

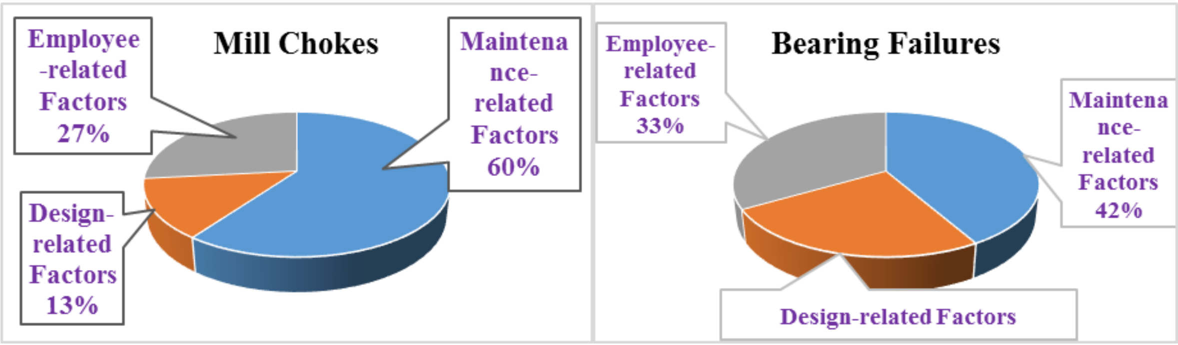

Figure 7: Assessment of Mill Chokes and Bearing Failures

Analysis of Inter-carrier and pump failures showed that maintenance-related factors accounted for 50% of the total failures with employee-related causes accounting for 33% and 30% of the total failures respectively. The causal factors leading to inter-carrier failures included: overloading and broken conveyor while the causal factors leading to pump failures included: broken axles, broken impellers and broken seals. The results of inter-carrier and pump failures were presented in Figure 8 below. It was observed that the maintenance practices in place at the milling section were inadequate to reduce inter-carrier and pump failures.

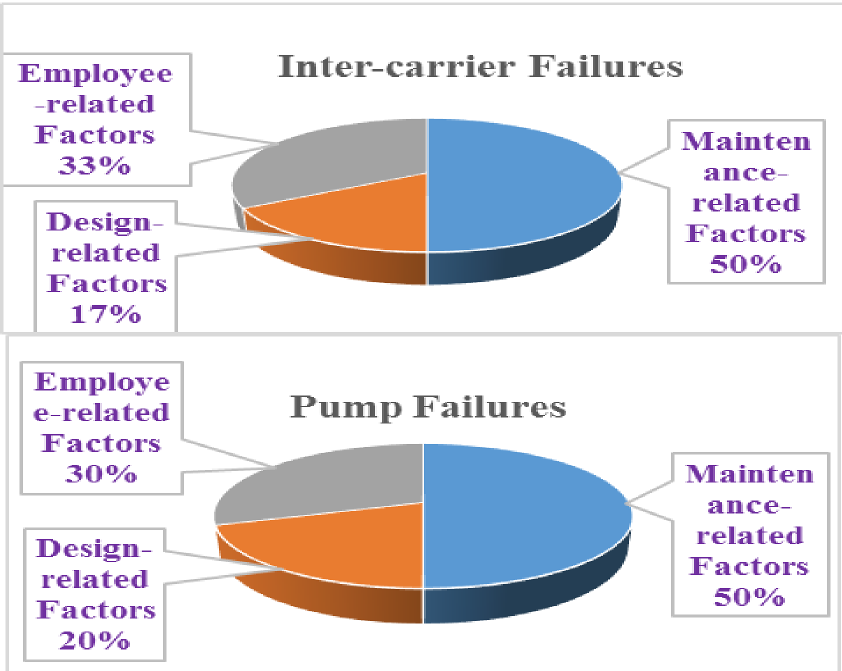

Figure 8: Assessment of Inter-carrier and Pump Failures

The overall assessment was done by summing up all the failures based on individual categories, a comparison was made, and results presented in Figure 9. Maintenance-related causes were the main causes of mill failures accounting for 51% of the total causes, while employee- related causes and design-related causes accounted for 30% and 19% of the total causes respectively.

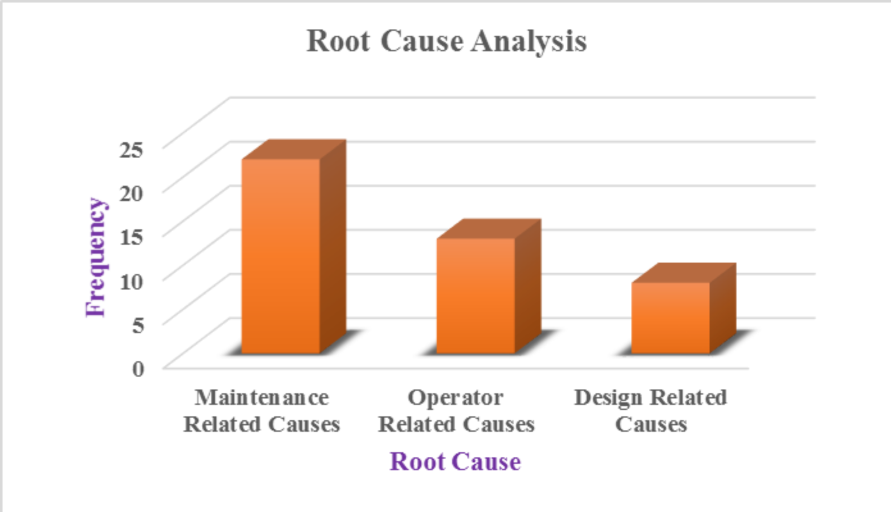

Figure 9: Root Cause Analysis of Mechanical Failures

It was concluded that maintenance practices had the greatest impact on the cane mill performance and were the root causes of low mill performance.

3.3 Maintenance Strategy Evaluation

The maintenance strategy was evaluated to establish its effectiveness at the sugar company by sending questionnaires to 32 factory staff and 17 valid responses received for evaluation with a 53% response rate which was noted as satisfactory. The responses were quantified in each category based on the likert scale. The categories under investigation were human factors, managerial factors and technical factors.

Figure 10 shows the results for human evaluation of maintenance strategy.The average score of human evaluation gave a score of 2.39 with personnel recruitment giving the least average score of 1.67.This showed that human resource recruitment procedures were not focused on hands-on or practical skills and competencies of employees but instead relied heavily on theoretical abilities or skills during personnel recruitment.

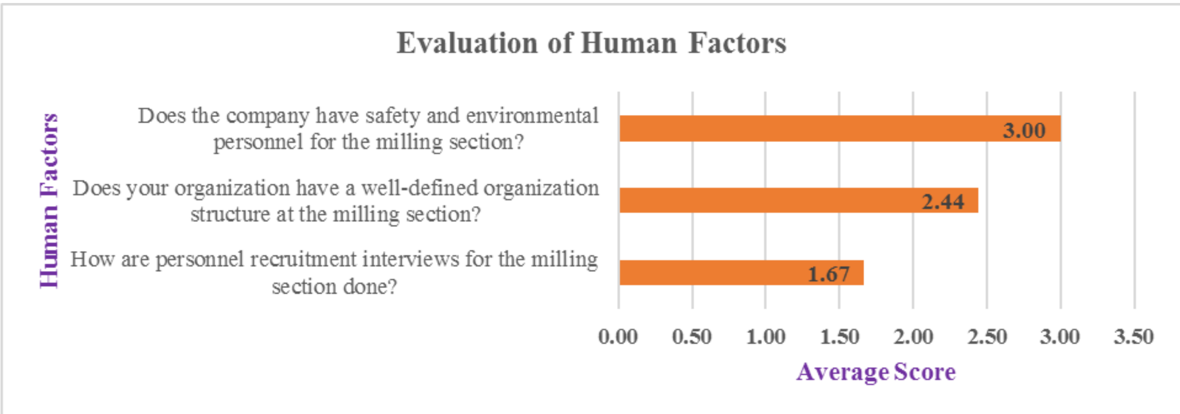

Figure 10: Human Evaluation of Maintenance Strategy

Analysis of managerial aspects of maintenance was also conducted. This evaluation gave a score of 2.08 with use of maintenance manuals giving the least importance score of 1.33. However, the company certification for standards gave the best importance score of 3.89 as shown in Figure 11. This showed that despite the organization being certified, some quality management procedures such as use of maintenance manuals were not adequately followed.

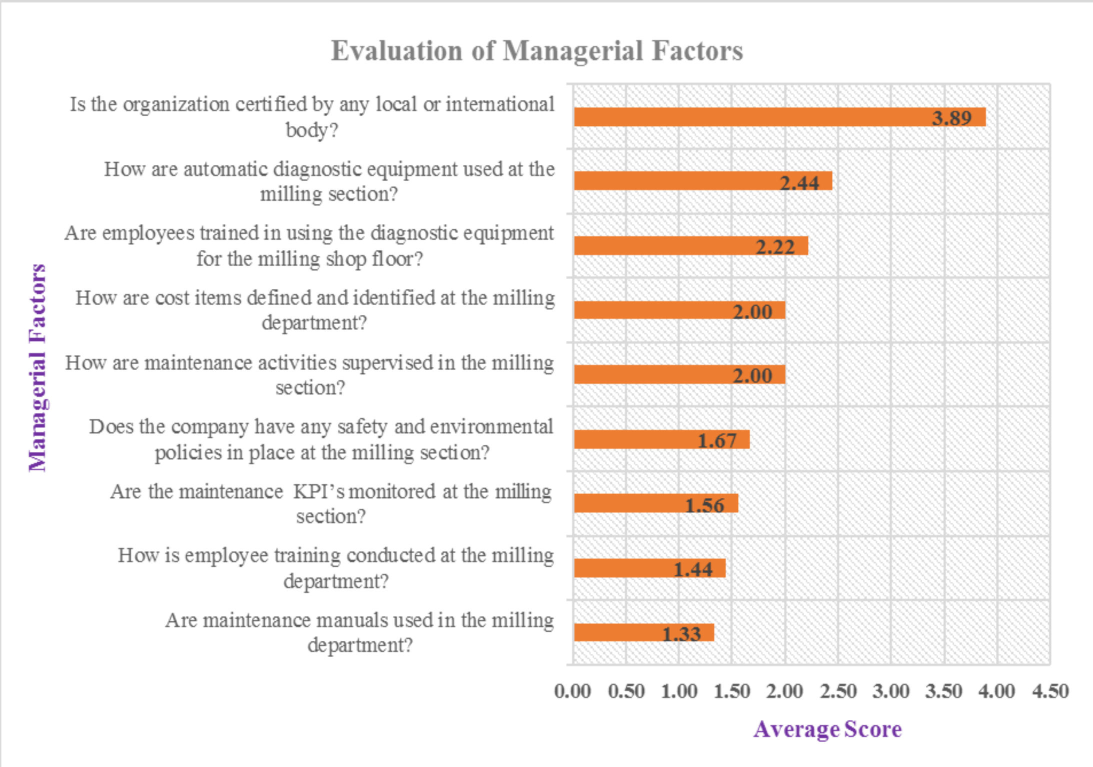

Figure 11: Managerial Evaluation of Maintenance Strategy

The technical evaluation had a score of 1.8 with the use of CMMS/ERP in performing tasks having the least score of 1.22 while maintenance of failure records gave the best importance rating of 2.67 as shown in Figure 12. This showed that the level of automation at the milling department was not adequate to support maintenance and operation of the mills.

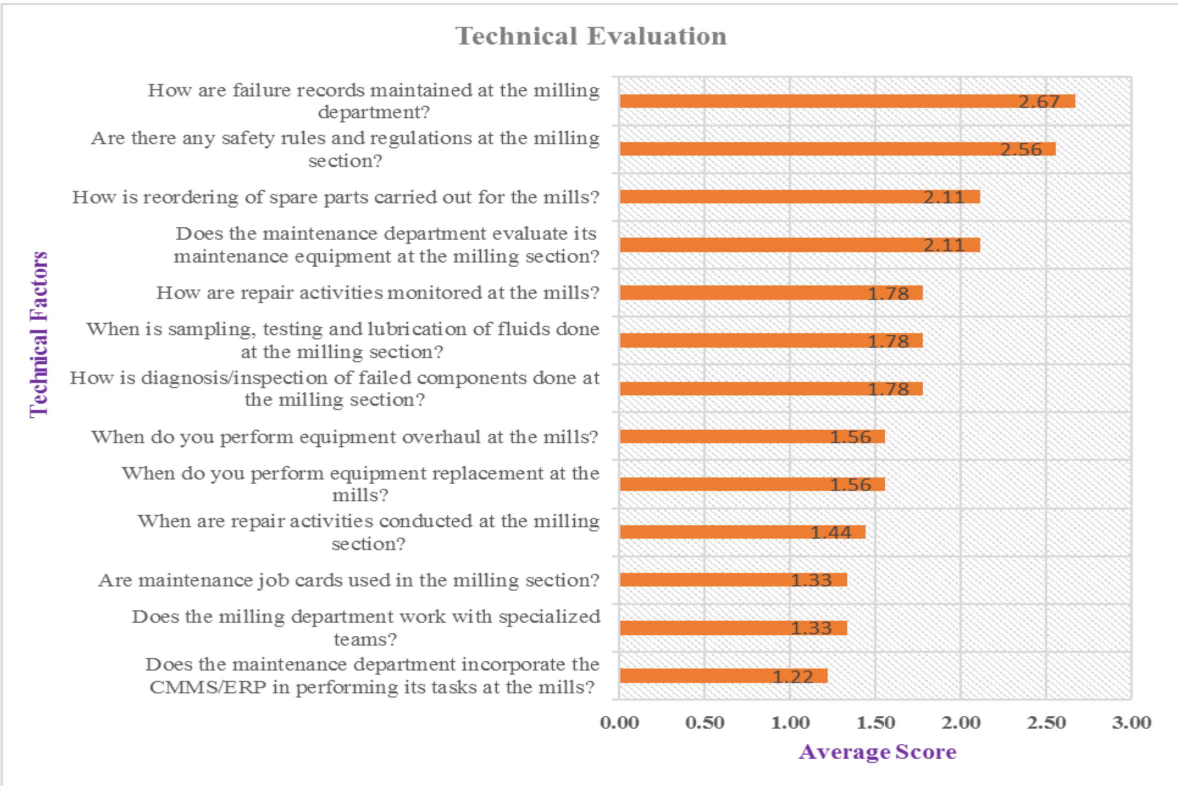

Figure 12: Technical Evaluation of Maintenance Strategy

3.4 Overall Maintenance Strategy

The three scores of evaluation in section 3.2 were aggregated to obtain the overall score and presented in Figure 13. Comparison of all the three aspects of maintenance was made with employee evaluation giving the highest importance rating score, followed by managerial aspects and then technical evaluation. This showed that the planning and execution of maintenance activities at the mills were not adequate to monitor the condition of the mills.

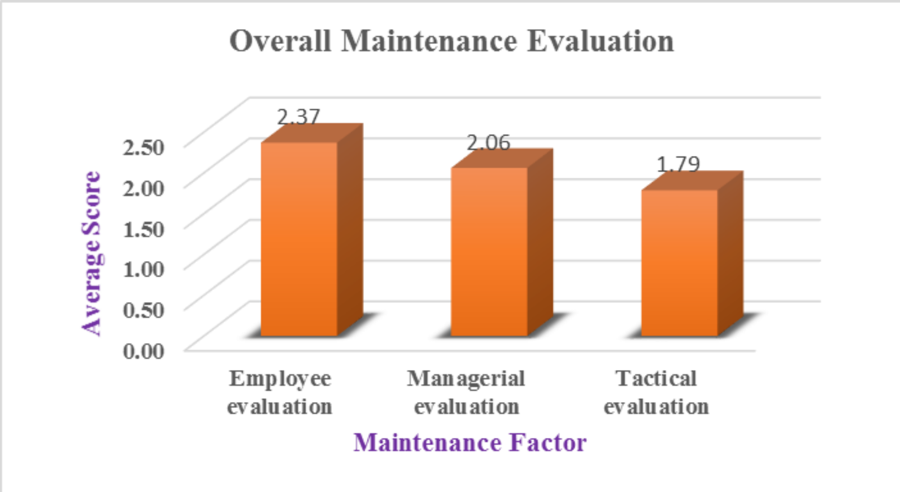

Figure 13: Overall Maintenance Strategy Evaluation

The overall score was found by averaging all the three aspects of maintenance and gave a score of 2.09 which also showed that maintenance practices were at stage II which was below the recommended world-class standard.

3.5 Validation of Maintenance System using OEE

The Overall Equipment Effectiveness (OEE) for the production process was computed to validate the maintenance strategy established from the questionnaire analysis in section 3.3. Mill data collected for a 14-week period was used and gave the following results.

Average sugar produced (Target value) = 3,125.439 TCD

Theoretical cycle time $= \frac{24}{3,125.439} = 0.0077$ ***hours/Tonne***

Average sugar produced (Actual value) = 2,224.84 TCD

Actual cycle time $= \frac{24}{2,224.84} = 0.0108$ ***hours/Tonne***

Total mill downtime = 248.79 hours

Production time= 2352 hours

Average sugar recovery ratio= 0.966

OEE= Availability rate (A) × Performance rate (S) × Quality rate (Q)

Where,

Availability (A) $= \frac{\textit{Operating time}}{\textit{Production time}}$

Operating time= Production time – Downtime

Performance rate (S) = Operating speed rate × Net operating rate

Operating speed rate $= \frac{Theoretical\ cycle\ time}{Actual\ cycle\ time}$

Actual processing time= Actual output × Actual cycle time

Net operating rate $= \frac{Actual\ processing\ time}{Operating\ time}$

Quality rate (K) = 1 – Quality loss

Based on the data OEE was computed as follows:

Availability (A) $= \frac{Operating\ time}{Production\ time} = \frac{2{,}352 - 248.792}{2{,}352}$ ***= 0.8942***

Performance rate (S) = Operating speed rate × Net operating rate $= \frac{0.0077}{0.0108} \times \frac{2{,}103.2}{2{,}352}$ ***= 0.6375***

Quality rate (K) = 1 – Quality loss= 0.966

OEE= Availability rate × Performance rate × Quality rate = 0.891 × 0.653 × 0.966= 0.552

OEE calculated value was compared with world class values and summarized in Table 2.

Table 2: Comparison of calculated OEE with recommended values

Metric	Calculated value	World class value
Availability rate	0.8942	0.9
Performance rate	0.6375	0.95
Quality rate	0.96765	0.99
OEE	**0.552**	**0.85**

OEE for the production process was found to be 0.552 compared to the world class value of 0.85. Since this value of OEE was far below world class value, it confirmed that maintenance strategy of the production process was at stage II. Hence the maintenance strategy evaluation was accurate in predicting the maintenance strategy of the milling process.

3.6 Selection of Improved Maintenance Strategy

In this study three maintenance strategies were identified, and an effort made to select one strategy to be proposed at the sugar company. These strategies were: Condition Based Maintenance (CBM), Total Productive Maintenance (TPM), and Reliability Centered Maintenance (RCM). The selection of an improved maintenance strategy was based of the 15-point criteria as described in section 2.5. This selection was conducted by a team of engineers in the maintenance department in which a 5-point importance rating was used to compare the selected factors in each maintenance strategy. A rating of 1 implied least desirable while 5 was most desirable factor. The cost of maintenance system implementation was not considered since maintenance costs were assumed to be highly dependent on the organization and the extent of maintenance practices.

The first evaluation of maintenance strategy selection focused on the methods used and was driven by several factors such as simplicity of the maintenance strategy, capability of standardization, effort needed for strategy implementation, built-in continual improvement, degree of change and scalability of the maintenance strategy. The evaluation was presented in Table 3.

Table 3: Evaluation of Methods used during Implementation of Maintenance Strategy

Evaluation of Methods Used	TPM	CBM	RCM
Simplicity of method	5	4	1
Scalability of method	3	3	5
Effort prioritization	5	1	5
Capability of standardization	2	2	4
Degree of change	3	5	5
Effort required	1	5	1
Built-in continual improvement	5	1	3
TOTAL	**24**	**21**	**24**

Evaluation of methods used in maintenance strategy implementation showed that TPM and RCM were superior strategies compared to CBM since their implementation was simple and required less effort. CBM was least preferred due to its complexity during implementation.

The second evaluation of maintenance strategy selection focused on the goals of the maintenance strategy and was driven by several factors such as the complexity of the strategy to goals or whether goals could be measured for each strategy and the time needed during maintenance strategy implementation. The evaluation was summarized and presented in Table 4.

Table 4: Evaluation of Goals of Maintenance Strategies

Evaluation of Goals	**TPM**	**CBM**	**RCM**
Goal complexity	1	5	2
Measurable goals	1	4	4
Time frame	5	3	5
TOTAL	**7**	**12**	**11**

Evaluation of goals of maintenance strategies showed that CBM was a superior maintenance strategy compared to TPM and RCM. In CBM, the goals of maintenance strategy were observed to be simple and straightforward. It was also observed that RCM and TPM required a lot of time to attain full maintenance strategy implementation hence they were least preferred.

The third evaluation was employee contribution to the success of the maintenance strategies. In this evaluation several factors were selected for comparison such as employee skill demands, employee participation and focus, training requirements and how the strategy can be sustained. The evaluation was presented in Table 5.

Table 5: Evaluation of Employee Support in Maintenance Strategies

Evaluation of Employee Support	**TPM**	**CBM**	**RCM**
Skill required	5	1	2
Employee participation	5	2	2
Individual focus	5	2	2
Training requirement	3	4	4
Sustainability	2	4	4
TOTAL	**20**	**13**	**14**

Evaluation of employee support in maintenance strategies showed that TPM had superior focus on employees than CBM and RCM. This was supported by the fact that TPM philosophy involves total participation and training of all employees.

The overall maintenance strategy comparison was conducted, where all the three aspects of maintenance strategies namely methods used, goals and employee support were combined and a total score calculated. The overall analysis was presented in Table 6.

Table 6: Overall Maintenance Strategy Evaluation

Evaluation Criteria	**TPM**	**RCM**	**CBM**
Methods Used	24	24	21
Goals	7	11	12
Employee Support	20	14	13
TOTAL	**51**	**49**	**46**

TPM gave the highest score of 51, followed by RCM with 49 and CBM with a score of 46. This showed that TPM was a better maintenance strategy for improvement cane mill performance than RCM and CBM.

IV Conclusion

This study investigated the impact of maintenance practices on the cane crushing mills. Root Cause Analysis (RCA) was used to assess the impact of the existing maintenance strategy on mill performance while responses from questionnaires were analyzed to evaluate its effectiveness. The results obtained after conducting RCA on the existing maintenance strategy were validated using OEE. An evaluation matrix was used to select an effective maintenance strategy by comparing strengths and weaknesses of various best practice maintenance strategies on the cane mills. Finally, an effective maintenance strategy was recommended for the cane crushing mill. The study contributed to theory and practice through development of a methodology to prioritize critical failures which is a basis of formulating performance metrics in maintenance decision making. The study also provided valuable insights for sugar industries to consider in order to meet the country's increasing sugar demand and also provide a sustainable surplus for export.

Acknowledgements

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Conflict of Interest Declaration

This research was undertaken as a requirement for the award of Master of Science degree in Industrial Engineering and Management at Dedan Kimathi University of Technology. The study was conducted at Nzoia Sugar Company Ltd which provided all the relevant equipment and materials for data collection.

References

[1]. Deepak P.P, Jagathy Raj V.P. "CBM, TPM, RCM and A-RCM." *A Qualitative Comparison of Maintenance Strategies*, Vol. 4, IJMBS Issue 3, India (2014).

[2]. Fore S, Zuze L. "Improvement of Overall Equipment Effectiveness through Total Productive Maintenance." *World Academy of Science, Engineering and Technology* (2010).

[3]. Frost, Sullivan. *Improving Plant Performance: Overall Equipment Effectiveness (OEE).* (2005).

[4]. Irungu P.M. "Maintenance Evaluation of Manufacturing Industries in Kenya." *Msc. Thesis, School of Engineering, Dedan Kimathi University of Technology*, Kenya (2015).

[5]. Jonathan W. "Measurement: Reliability and Validity Measures." *John Hopkins University School of Public Health* (2007).

[6]. Kegode, Odek, Ochola. "*The Challenges and Way Forward for the Sugar Sub-sector in Kenya.*" (2003).

[7]. Liliane P., Frank V.P. "Maintenance Decision Making." *1st ed., Leuven, Belgium* (2006).

[8]. Liliane P., Srinivas K.P. "Evaluating the Effectiveness of Maintenance Strategies." *Leuven, Belgium* (2006).

[9]. Mel B. "Using Overall Equipment Effectiveness for Packaging Line Improvement." (2011).

[10]. *Nzoia Sugar Company: Factory Monthly Production File* (DOC. No. NSC/FACT/LAB/FMPF-01).

[11]. Pekka K. "Applying Total Productive Maintenance." *TPM Principles in the Flexible Manufacturing Systems*. ISSN: 1402-1536, ISRN: LTU- 00/23-SE (2000).

[12]. Peter M, Liliane P. "Performance Measurement Using Overall Equipment Effectiveness (OEE)." *Literature Review & Practical Application, International Journal of Production Research Centre for Industrial Management (CIB)*, Leuven Belgium (2006).

[13]. Raffaele L, Maria E.N. "Managing Overall Equipment Effectiveness to improve Factory Performance."(2013).

[14]. Vassiliadis C.G, Pistikopoulos E.N. "Maintenance Scheduling and Process Optimization under Uncertainty." *Department of Chemical Engineering, Imperial College, London, UK* (2000).

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