ANALYSIS OF A TIME BASED AND CORRECTIVE MAINTENANCE SYSTEM FOR A SUGAR PRODUCING COMPANY

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ABSTRACT

The Southern Africa sugar producers' market is under threat from Brazilian sugar, with the latter's sugar landing in Southern African countries - Zimbabwe in particular – at 75% of the selling price of local producers. This paper outlines an investigation of the current maintenance systems of a Zimbabwean sugar producer and its shortcomings, with a view of optimization. Research has shown that maintenance can contribute between 15 to 75% of production costs, thus playing a critical role in product pricing and consequently competition. Maintenance records and interviews to maintenance personnel from the company were used to extract data relevant to the study. A bottleneck asset in the production line was chosen as a subject to measure the impact of the current maintenance system in cost terms. The study shows that the company is using a hybrid of time based and corrective maintenance. The paper also shows that the current maintenance philosophy resulted in downtime of eighty (80) hours on the subject asset over a four (4) year period, that translated to an equivalent of USD1.9 million in potential revenue lost; which downtime could have been avoided with better maintenance methods. The paper concludes by recommending the introduction of Condition Based Maintenance on the subject asset as an alternative to optimize the maintenance function of the company.

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1 INTRODUCTION

Globalisation has brought competition to the door step of local industry and therefore an increase in pressure to optimise the industry's operations. The Zimbabwean sugar industry is the second largest employer in Zimbabwe after Government [1] making it a major contributor to the national economy. The local industry - like other regional (SADC) sugar industries - has faced stiff competition over the past year from Brazilian sugar that is landing in the region at almost 75% of the local selling price (Brazil's US1.55/unit compared to Zimbabwe's USD2.00/ unit). The direct impact has been a sharp increase in sugar inventory levels due to consumer shift to Brazilian sugar. The purpose of this paper is to investigate the current maintenance systems of a Zimbabwean sugar producer and its shortcomings with a view of optimizing them.

The paper gives a brief description of maintenance types and an outline of the importance of maintenance in any business. It then focuses on a target asset for a local sugar manufacturer to determine the maintenance philosophy being employed and its shortcomings in cost terms.

2 TYPES OF MAINTENANCE

Komonen [2], Mahmood et al [3] and European Standards [4] define maintenance as a combination of all technical, administrative, and managerial actions during the life cycle of an item intended to keep it in or restore it to a state in which it can perform the required function. Dhillon [5] defines it as all actions appropriate for retaining an item, part, equipment in, or restoring it to, a given condition. Maintenance operations can be classified into two large groups namely Corrective Maintenance (CM) and Preventive Maintenance (PM) [6, 7, 8, 9, 10, 11]. Corrective maintenance involves replacement of failed units while in PM the system which is highly likely to exhibit a demobilising fault is replaced before that failure is allowed to occur. The two common forms of PM are scheduled or time based PM and condition-based maintenance (CBM) [7, 8, 9, 10].

2.1 Corrective maintenance

Corrective maintenance is performed to restore a system to a state of functioning after the system has entered a state of failure [8]. No maintenance action is carried out until the component or structure breaks down [9]. It is has no special maintenance plan in place. The machine is assumed to be fit unless proven otherwise. Corrective maintenance should be utilized only in non-critical areas where capital costs are small, consequences of failure are slight, no safety risks are immediate, and quick failure identification and rapid failure repair are possible [10]. The major disadvantage is that of high production downtime and high risk of equipment damage and secondary failure. It has an advantage of not having condition monitoring or maintenance planning costs [9].

2.2 Time based maintenance

Time based or scheduled maintenance is performed at predefined ages of the system in order to reduce the probability of failure of the system [8]. An optimal breakdown window is pre-calculated by the original equipment manufacturer at the time of component design or installation and a preventive maintenance schedule is laid out. Maintenance is carried-out on periodic intervals, assuming that the machine is going to break otherwise [11]. The scheduling can be based on the number of hours in use, the number of times an item has been used, the number of kilometres the items has been used, according to prescribed dates, etc. [10]. The objective of time based maintenance is to prevent failures before they happen and therefore to minimize the probability of failure. It also increases the availability of the production facility [6]. The major advantages of time based maintenance is that it results in fewer catastrophic failures and there is greater control over spare parts and inventory. Maintenance is also performed in a controlled manner with a rough estimate costs well known ahead of time. Its greatest disadvantage is that since it is time based, machines are repaired when there is no fault and there still will be unscheduled breakdowns [11]. Another disadvantage is that the schedule is often not optimal because it is often drawn up on the supplier's recommendation, but made with either only limited local knowledge of the actual use conditions or from past experience [7].

2.3 Condition Based maintenance

Condition based maintenance is a type of maintenance policy that considers the current real state of system degradation [12, 13, 14, 15, 16]. It is based on the principle of using real-time data to prioritize and optimize maintenance resources. Such a system will determine the equipment's health, and act only when maintenance is actually necessary [11]. It is an emerging alternative to time based and corrective that employs predictive analytics over real-time data collected (streamed) from parts of the machine to a centralized processor that detects variations in the functional parameters and detects anomalies that can potentially lead to breakdowns [11]. The major highlight of CBM is that unexpected breakdown is reduced or even completely eliminated. Parts are ordered when needed and maintenance performed when convenient therefore maximising equipment life. Its drawbacks are of the high investment costs and additional skills that might be required.

2.4 Current trends in Maintenance

Eti et al [7] and Marcelo et al [17] highlighted the growth of new maintenance concepts and techniques that include Failure mode and effect analysis (FMEA) and condition monitoring in optimising maintenance operations. Goriwondo et al [18] used FMEA and ABC analysis to analyse and improve the production systems of a pharmaceutical company. In a study of telematics companies, Palem [11] showed that companies saved between 8 and 12 % by changing from traditional maintenance schemes to CBM. Neural networks were recently used successfully as a technique for the system prediction part of condition based maintenance systems [19]. Nguyen [20] used a Montecarlo simulation to evaluate the expected cost of preventive maintenance and a genetic algorithm for optimisation. DeCarlo and Arleo [12] coined formulae that can be used to assess the cost of any maintenance plan.

2.5 The link between maintenance and business

De Carlo and Arleo [12] mentioned planning of maintenance activities as one of the core elements in the design of a production system and that the production process flows regularly if the different systems are available when required by the production plan. Bengtsson [21] and Cortzee [22], agree that the maintenance costs range from 15-70% of the total production cost and that about 5% or more of the total production costs is spent unnecessarily due to bad maintenance. Dhillon [5] gives the cost of maintaining equipment as varying between 2 to 20 times the equipment acquisition costs over its lifecycle. These high figures of maintenance costs signify the importance of the maintenance function in any business. An optimised maintenance system will ultimately allow an organisation to compete effectively in the market. Ramachandra et al [23] notes that systematic maintenance procedures offer tremendous possibilities for saving money and materials. Maintenance activities are a major cost factor in most industries, affecting both return on capital and production throughput [23]. Ramachandra et al [23] and Acherman [24] further compare the benefits of maintenance and effects of poor maintenance to any organisation. Table 1 shows the comparison with factors which directly or indirectly contribute to the company's profit.

Table 1: Effects of poor maintenance vs. benefits of sound maintenance [23,24]

Effects of poor maintenance	Benefits of a sound maintenance system
Increased down time	Reduction in downtime to achieve production targets
Poor efficiency	Reduction in loss of materials in process, thus minimising resource usage
Deterioration of Equipment	Increased equipment life
Poor quality of product	Consistent product quality thus achieving quality objectives
High labour cost	Reduction in overtime
Loss of material in process	Optimum spares inventory
High production cost	Optimum operational cost of the machines
Non compliance with legislation	Compliance to legislation
Increased hazards	Timely replacement of spares and machines
High chances of job and plant accidents	Increased job and plant safety

3 COST OF MAINTENANCE

The cost of maintenance is defined as costs that include lost opportunities in uptime, rate, yield, and quality due to non-operating or unsatisfactorily operating equipment in addition to costs involved with equipment-related degradation of the safety of people, property, and the environment [5, 25].

There are fundamental costs associated with maintenance and are classified into four areas [5]:

- **direct costs** – these costs are related with keeping the equipment in good operating condition and include costs of periodic inspection and preventive maintenance, repair cost, overhaul cost, and servicing cost
- **lost production costs** – these costs relate to the loss of production due to primary equipment breakdown and unavailability of standby equipment
- **degradation costs** – these costs are associated with deterioration in the equipment life due to unsatisfactory / inferior maintenance
- **standby costs -** these costs are relate to costs incurred in operating and maintaining standby equipment. Standby equipment is used when primary facilities are either under maintenance or inoperable [5]

3.1 Factors Influencing Maintenance Costs

De Carlo and Arleo [12] and Dhillon [5] give the following reasons for maintenance costing:

- Compare competing approaches to maintenance
- Determine maintenance cost drivers
- Compare maintenance cost effectiveness to industry averages
- Prepare budget and costs control
- Provide input in the design of new equipment/item/system
- Provide input in equipment life cycle cost studies
- Make decisions concerning equipment replacement
- Improve productivity

3.2 Cost of Maintenance Formulae for Corrective and Planned Maintenance

De Carlo and Arleo [12] evaluated the total cost related to each maintenance type using the main cost and time parameters related to maintenance. Each maintenance type has cost and time items that mainly affect on its average unit cost. Time to retrain system after its unscheduled stop is the critical parameter in corrective maintenance whilst material or spares costs are the major cost drivers for planned maintenance [12]. The following are the costs models as evaluated by De Carlo and Arleo [12]:

i. **Corrective maintenance total cost, C_c**

$$C_c = C_{LP} \times (t_d + t_a + t_r + t_{rs} + t_q) + (C_L \times t_r) + C_M \quad (1)$$

ii. **Planned Maintenance total cost, C_p**

$$C_p = C_{LP} \times (t_r + t_{rs}) + (C_L \times t_r) + C_M \quad (2)$$

Where;

C_{LP} = Lost productivity hourly cost,
C_L = Hourly labour cost
C_M = Material cost
t_d = Time of diagnosis
t_a = Time required for maintenance service activation
t_r = Repair time
t_{rs} = Time for reactivation of production
t_q = Time for system retrain after the unplanned shutdown

4 CASE STUDY

The cost of maintenance models were applied to a particular case study, a sugar factory of one of Zimbabwe's sugar producers. A cane shredding unit, which is an asset within the sugar production line of the company, was used in order to simplify the study.

4.1 Objectives of the study

Traditionally the company has been disregarding lost productivity in their maintenance costing models. The objectives of this study are therefore to;

- Analyse the existing maintenance plan on the shredding unit using the cost models in section 3.2 and compare the costs with those calculated by the company
- Introduce Condition based maintenance (CBM) concepts and assess the likely benefits should it be adopted on the shredding unit

4.2 Methodology

The study was limited to the shredding unit only and a 38 week production / crushing season. Interviews were conducted on eighteen (18) milling section maintenance team. The shredding unit falls under the milling section of the sugar mill. The interviews aimed at extracting information on employment designation of the interviewees, the years experience in the milling section and the maintenance philosophy being applied on the shredding unit. All the personnel in the section were selected since they are responsible for all maintenance actions on the unit. The planning office maintenance records of the company were used to ascertain total downtime hours due to breakdown. Cost of maintenance calculations were done for a period of 4 years (2010 to 2013 inclusive) using the formulae by De Carlo and Arleo [12].

4.3 Cane shredding unit

The purpose of the shredding unit is to complete the preparation and disintegration of the cane, so as to facilitate the extraction of juice by the mills [26]. The disintegration opens the cane cells and liberates the juice, making it more accessible and easily extracted. The schematic below shows the general setup of the shredder, its capacity and the capacities of other equipment along the milling production line. The capacities of the juice extraction unit and the can knives are higher than that of the shredding unit making the latter a bottleneck unit in the production line i.e. 320tonnes cane per hour (TPH) against 290TPH respectively. Figure 1 shows the arrangement of units in the milling production line.

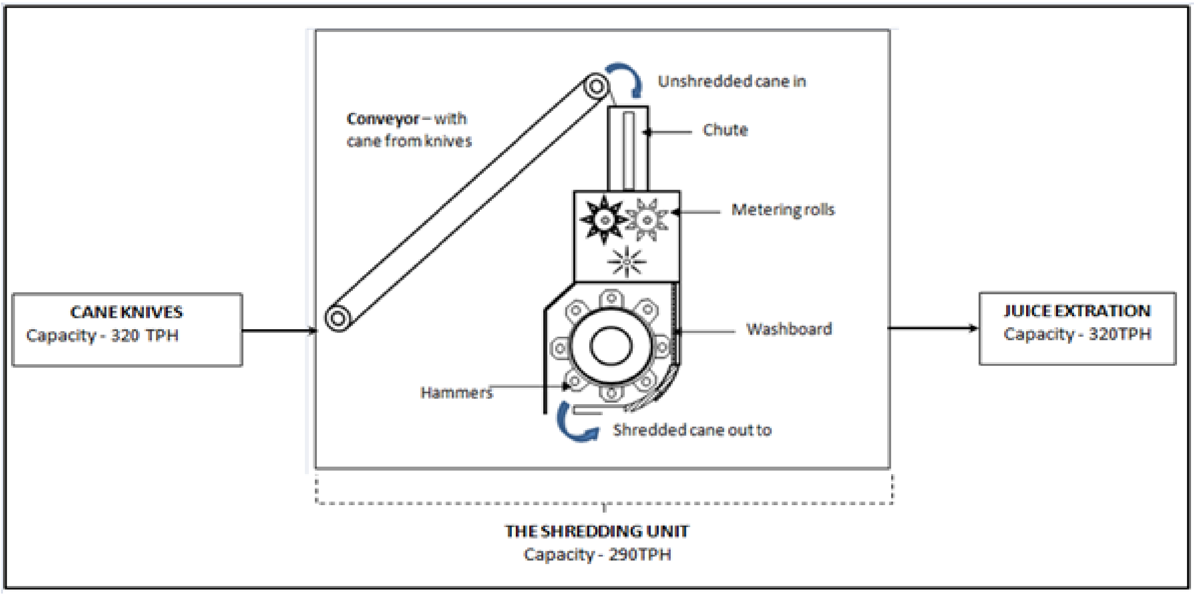

Figure 1: Arrangement of equipment in the milling production line

4.4 Findings from interviews and maintenance records

Based on the responses from the eighteen (18) maintenance personnel through the interviews, and records from the maintenance planning office, the company was found to be employing a hybrid of planned maintenance and corrective maintenance on the shredding unit. Planned maintenance work orders are printed the beginning of every week. Scheduled restoration tasks are carried out 8hrs every fortnight for a *38* week production season and a major scheduled restoration maintenance work is carried at the end of every milling season. This is done on a yearly basis for 14 weeks. Corrective maintenance is done each time a break down occurs. 80.75 hours of downtime due to breakdowns were recorded in the past four years and a corrective maintenance approach was used to attend to the breakdowns. Figures 2 and 3 show the causes of the breakdowns and the repair time in the duration 2010 to 2013.

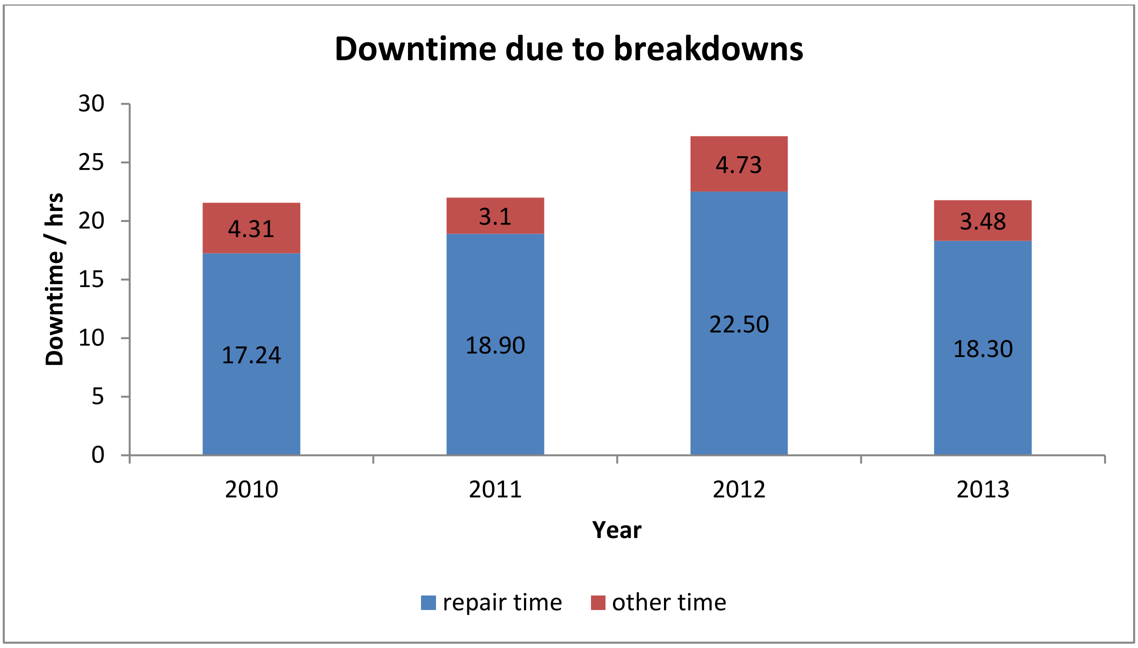

Figure 2: Downtime due to breakdowns

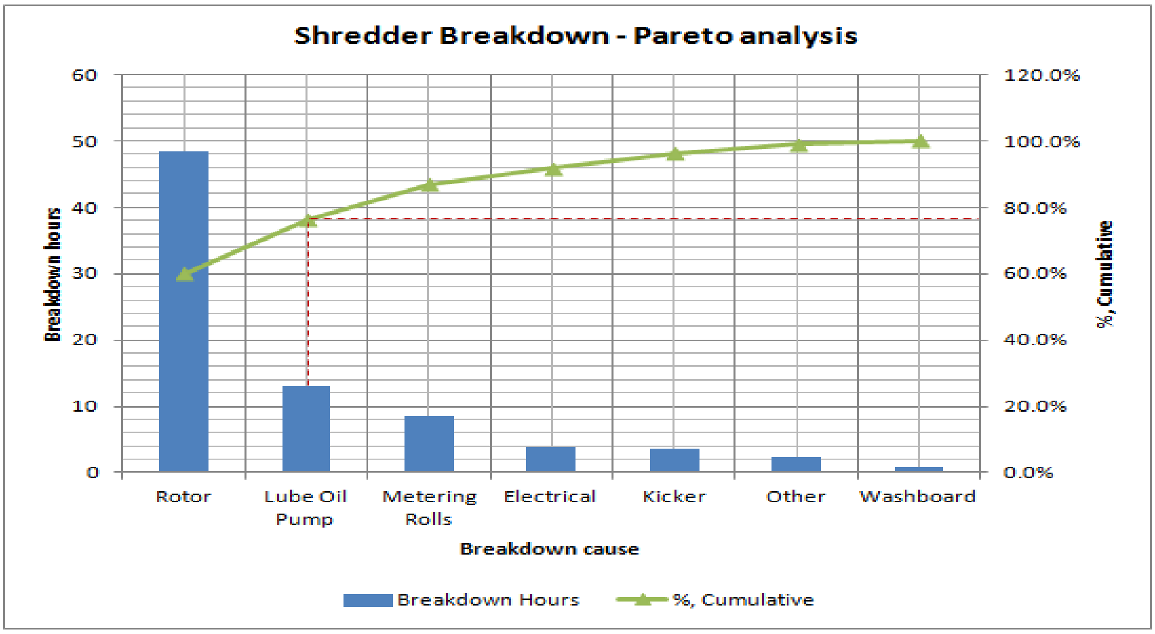

Figure 3: Causes of breakdowns on the shredding unit

4.5 Analysis of breakdowns

Repair time was 80% of the total downtime due to shredder breakdowns. The predominant equipment failures in the period under review were the rotor and lubrication oil pump. The two equipment failed a combined twenty one (21) times to account for 76% of the total breakdown hours.

5 COST OF MAINTENANCE ANALYSIS

The cost of maintenance analysis was done to compare the current understanding of maintenance cost by the company to the maintenance costing model as coined by De Carlo and Arleo [12].

5.1 Cost of maintenance calculation with model by De Carlo and Arleo [12]

Using the equations (1) and (2), the costs of the current maintenance plan on the shredding unit over a four year period was calculated.

5.1.1 Lost productivity hourly cost, C_{LP}

The hourly cost of lost productivity was calculated using an average sugar price per tonne, ***p***, and the output of the production line per hour, *m*. Average price was derived from the prevailing local and world market sugar prices of USD 800.00 and USD 480.00 respectively [14]. The output sugar using a cane to sugar ratio of 8 for a 290 tonnes of cane per hour production line is 36.25 tonnes of sugar per hour (*tsph*). Lost productivity hourly cost becomes:

$$C_{LP} = m \times p \qquad \textbf{(3)}$$

$$C_{LP} = 36.25tsph \times US\$640.00$$

$$\boldsymbol{C_{LP} = US\$\ 23{,}200.00\ per\ hour}$$

- **Assumption**: Since the company does not have a definite sales policy, it was assumed that half of lost production were to be sold in Zimbabwe at the current rate of US*$800.00 per tonne* and half in a European market at the prevailing rate of *$480.00 per tonne*. This gives an average selling price of *$640.00 per tonne*

5.1.2 Hourly labour cost, C_L

The hourly labour cost was calculated using the hourly rate of an artisan and two aides. The rates are ***US$8.52/hr*** and ***US$4.93/hr*** for artisan and aide respectively. For work requiring an artisan and two aides the total cost becomes:

$$C_L = \$8.52 + (2 \times \$4.93)$$

$$\boldsymbol{C_L = \$18.38\ per\ hour}$$

5.1.3 Material cost, C_M

Material cost is the sum of the cost of all spares used in the period under review. Table 2 lists the most significant material used and the associated costs during the period:

Table 2: Material costs

Material	**Annual usage in US$**	**Four year costs**
50mm High carbon steel Plate, *EN8*	*$100,183.00*	*$400,732.00*
Welding rods	*$25,375.00*	*$101,500.00*
Bearings	*$29,100.00*	*$116,400.00*
Total	*$154,658.00*	***$618,632.00***

- **Note:** Six (6) bearings were replaced during breakdown or corrective maintenance to imply \$58,200 as C_M for corrective maintenance and the difference from total being C_M for planned maintenance.

5.1.4 Time parameters for Corrective maintenance, $(t_d + t_a + t_r + t_{rs} + t_q)$

The ***80.75*** breakdown hours for the period of four years equal the sum of the time parameters used in equation (1). Thus for corrective maintenance;

$$80.75hrs = t_d + t_a + t_r + t_{rs} + t_q \qquad (4)$$

- **Note**: From section 4.2, 80% of the downtime is spent as repair time, t_r; thus;

$$t_r = 0.8 \times 80.75$$

$$\boldsymbol{t_r = 64.6hrs}$$

5.1.5 Time parameters for planned maintenance, $(t_r + t_{rs})$

Time parameters of planned maintenance equal the product of the number of planned stoppages in a year, *S*, and stoppage hours per planned stop, *N*. Thus;

$$t_r + t_{rs} = S \times N \qquad (5)$$

$$t_r + t_{rs} = 19 \times 8$$

$$t_r + t_{rs} = 152\ hrs\ per\ year$$

$$\boldsymbol{t_r + t_{rs} = 608\ hrs\ over\ a\ four\ year\ period}$$

- **Note:** Since most adinimistartive work is down prior to stoppage, 90% of the downtime is spent as repair time, t_r; thus;

$$t_r = 0.9 \times 608hrs$$

$$\boldsymbol{t_r = 547.2\ hrs\ over\ a\ four\ year\ period}$$

5.1.6 Corrective maintenance cost calculation, C_c

Using equation (1) and the actual times calculated for the shredder, the cost of corrective maintenance over a four (4) year period are;

$$C_c = C_{LP} \times (t_d + t_a + t_r + t_{rs} + t_q) + (C_L \times t_r) + C_M \qquad (6)$$

$$C_c = (\$23{,}200.00 \times 80.75) + (\$18.38 \times 64.6) + \$58{,}200.00$$

$$\boldsymbol{C_c = \$1{,}932{,}787.35}$$

5.1.7 Planned maintenance cost calculation, C_p

Using equation (2) and the actual times calculated for the shredder, the cost of planned maintenance over a four (4) year period are;

$$C\square_p = C_{LP} \times (t_r + t_{rs}) + (C_L \times t_r) + C_M \qquad (7)$$

$$C_p = (\$23{,}200.00 \times 608) + (\$18.38 \times 547.2) + \$560{,}432.00$$

$$\boldsymbol{C_p = \$14{,}676{,}089.54}$$

5.2 Maintenance cost calculation by the company

The company has been considering direct maintenance costs only in its maintenance costs model such that the total cost of maintenance was given as a summation of the material costs in table 2 of section 5.1.3 and labour costs for both planned maintenance and corrective maintenance as given in section 5.12. The total maintenance cost from the company's perspective was given by:

$$Total\ maintenance\ cost = Total\ material\ cost + total\ labour\ cost \quad \textbf{(8)}$$

$$Total\ maintenance\ cost = \$\mathbf{618,632.00} + (\$18.38 \times 612.1\square\square\square\square\square\square)$$

$$Total\ maintenance\ cost = \$\mathbf{629,882.40}$$

5.3 Cost of maintenance summary

The total cost of maintenance on the shredding unit totalled $16,608,876.89 in the four years under review against the company's view of a cost of $629,882.40. $1,932,787.35 which represents almost 13% of the total costs of maintenance was as a result of corrective maintenance.

6 CONDITION BASED MAINTENANCE (CBM) CONCEPTS

Condition based maintenance is a type of maintenance policy that considers the current real state of system degradation [12], [13]. CBM attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviours of a physical asset [15],[27]. CBM recommends maintenance actions based on the information collected through condition monitoring and attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviours of a physical asset [27].

6.1 CBM underlying principle

CBM predicts failure in equipment and optimizes its policy by monitoring the equipment's age and health condition [28]. De Carlo and Arleo [12] indicated that there are many measurable health degradation parameters that can be properly monitored and that different monitoring techniques allow keeping under control the operating parameters that are the most significant for the system degradation, in order to identify the most appropriate time for the execution of maintenance activities dynamically. According to Bengtsson [21] and Mobley [29], condition based maintenance serves the following two functions:

- to determine if a problem exists in the monitored item, how serious it is, and how long the item can be run before failure, and
- to detect and identify specific components in the items that are degrading and diagnose the problem.

Inspection can involve the use of human senses (noise, visual, e.t.c), monitoring techniques or function techniques [30]. The most common techniques are dynamic monitoring (vibration and sound), temperature monitoring, chemical monitoring, particle monitoring, physical monitoring, electrical monitoring and human inspection.

6.2 Condition monitoring for the shredding unit

The analysis in section 4.5 showed that the shredder rotor and lubrication oil pump accounted for 76% of shredding unit breakdowns. Monitoring of the bearing will most likely predict failure or stoppage linked to the rotor, while monitoring the lubrication oil circuit will also most likely predict failure linked to the lubrication oil pump.

6.2.1 Vibration and temperature monitoring for shredder rotor bearing

Vibration measures a rotating shaft's position relative to stationary components in order to guard against changes that would result in catastrophic contact [31]. Vibration is also considered by SKF [31] and Cibulka et al [32] as the best operating parameter to judge dynamic conditions such as balance, bearing stability, and stress applied to components since many machinery problems manifests as vibration. Vibration monitoring on shredder bearing can successfully monitor the behaviour of the rotor thus predicting failure and avoiding unplanned stoppages.

According to SKF [31], temperature measurement is a useful indicator of the mechanical condition of a specific component, such as a bearing. The temperature of a bearing will rise due to friction when it starts to fail. Temperature monitoring on shredder bearing can also successfully monitor the performance of the rotor.

6.2.2 Pressure monitoring for lubrication oil circuit

Pressure monitoring of the lubrication oil circuit by trending the differential pressure across the supply will successfully monitor the lubrication oil pump and oil circuit functionality. Pressure monitoring of the oil circuit should therefore be considered for monitoring performance of the lube oil pump.

6.3 Potential benefits of CBM on shredding unit

If CBM were to be applied on the shredding unit, one direct benefit would be a direct reduction of the corrective maintenance costs due to the failure prediction nature of CBM. Since the CBM system will focus on shredder rotor and the lubrication oil circuit, it can be assumed that the system will likely predict at most 76% of the shredder breakdowns. This will also lead to a corrective maintenance cost reduction of at most 76% of the current costs, translating to potential savings of $1,468,918.39 over a four year period

7 FINDINGS

The following findings were noted on the current maintenance plan:

1. **Planned maintenance -** All maintenance work carried out on the shredding unit is primarily planned maintenance work and cost $14,676,089.54 in the past four years against the company’s view of a total cost of maintenance of $629,882.40 . The planned maintenance work was carried out eight (8) hours every fortnight for a 38 week production season. A further 14 weeks was spent on major planned maintenance work every year.
2. **Corrective maintenance -** Corrective maintenance work that was done on the shredding unit cost $1,932,787.35 in same period. An analysis of the breakdowns that warranted corrective maintenance showed that two causes of breakdowns accounted for 76% of the total downtime due to breakdowns. The two were shredder rotor and lubrication oil pump.
3. **Shortcomings of current maintenance plan** – Despite having a comprehensive maintenance plan in time based (planned) maintenance, the sugar producing company was incurring a further 13% of its budgeted planned maintenance costs on the shredding unit due to corrective maintenance (i.e. $1,932,787.35). The added costs on corrective maintenance is an indication of a deficiency in the current maintenance plan

8 RECOMMENDATIONS

The following were recommended in order to improve the maintenance operations.

1. **Adoption of Condition Based maintenance -** Due to the high level of unexpected failure in cost terms on the shredding unit and the likely benefits of CBM, it is recommended that the Zimbabwean sugar producer adopts CBM as a maintenance strategy on the shredding unit. CBM recommends maintenance actions based on the

information collected through condition monitoring and attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviours of a physical asset [27]. The nature of CBM is such that it predicts a failure and thus avoiding unexpected failures and plant stoppages. This will likely reduce the cost of maintenance by at least 13 % through eliminating the current cost of corrective maintenance and also reducing the current cost of planned maintenance. However a feasibility study and cost befit analysis to consider the life cycle costs of implementing CBM against the costs of the existing maintenance plan should be done before changing to CBM. The cost benefit analysis should cover issues like setup costs of a CBM system, operational or running costs, training and support services among other things.

2. **Focus of the proposed CBM system** – the proposed CBM system should focus on the two major causes of breakdowns on the shredding unit i.e. rotor and lubrication oil problems. The CBM system should successfully monitor vibration and temperature of the rotor bearing and oil pressure in the lubrication oil circuit in order to eliminate at most 76% of the breakdown causes.

9 CONCLUSION

The paper has shown that the Zimbabwean sugar manufacturer is employing a hybrid of planned maintenance and corrective maintenance on the shredding unit. The corrective maintenance is resulting in an additional maintenance cost of 13% to the already huge planned maintenance bill. These maintenance cost figures are discouraging in a sugar market that is characterised by diminishing prices and stiff competition from South America. In order to optimize the maintenance operations of the sugar producer, the paper has recommended adoption of a condition based maintenance system on the subject asset.

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