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Incorporation Of A Reliability Centred Maintenance Strategy Into An Existing Fixed Time Maintenance Strategy With The View To Improve Availability Performance

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ABSTRACT
This research study investigates implementable reliability improvement opportunities available in a sugar manufacturing plant that can produce an increase in availability performance. It recommends different maintenance policies for different equipment based on the operating context of the equipment. The Reliability Centred Maintenance (RCM) methodology is followed and results are compared to world class sugar manufacturing industry benchmarks. The study can be a useful resource to plant managers seeking to heighten plant availability.

Keywords: - *maintenance, reliability, availability-performance, maintainability, plant*

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I. INTRODUCTION

A significant amount of operating costs in industry is attributed to maintenance costs. Maintenance can be defined as the way in which organisations try to avoid failure by taking care of their physical facilities [7]. Instead of perceiving it as a necessary evil, maintenance can be viewed as a tool to improve Availability Performance and extend life of equipment. Machine failure can have major detrimental effects on a company's operations, reputation and profitability.An effective and efficient maintenance policy would ensure quality products at optimum production levels while lengthening the life span of plant and equipment. Even when the equipment is ultimately replaced, well maintained equipment will have a higher disposal value than poorly maintained equipment. In view of this, most companies are rethinking their maintenance policies. No policy can be singled out as the best for all factories, thus different management adopt different policies with the aim of minimising maintenance costs and maximising Availability Performance (AP).

II. JUSTIFICATION

Triangle limited, an operations division of Tongaat Huletts of South Africa, is an agro-processing company in the southern Lowveld of Zimbabwe. Their main operation is the crushing of sugarcane and processing the juice to produce sugar. They also produce ethanol and gel fuel as by products.The company uses a **fixed time maintenance** policy. This is a type of Preventive Maintenance strategy in which equipment is maintained (adjusted, repaired, restored, replaced, etc.) on the basis of either clock time or machine-run time. It is time driven, that is maintenance activities are performed because it is time to.Under the Fixed Time Maintenance policy, the company has a planned total shutdown on Monday fortnightly. During this shutdown, a lot of time driven maintenance tasks are executed, the bulk of which may be unnecessary. During start up, self-inflicted wounds cause delays, compounding to the loss of production time [5].Also, even after this shutdown during which a number of overhauls are done, the company still experiences catastrophic failures during the production run. In view of this, it is necessary to implement a better maintenance policy and this project evaluates RCM as a candidate for a policy. This project seeks to incorporate RCM into the fixed time maintenance strategy in order to improve Availability Performance [3].

III. RELIABILITY CENTRED MAINTENANCE CONCEPT

This is a process used to determine the maintenance requirements of any physical asset in its operating context [8]. It integrates fixed time maintenance, predictive techniques, proactive maintenance and reactive maintenance, using the most suitable policy for each asset. These principal maintenance strategies, rather than being applied independently are optimally integrated to take advantage of their respective strengths, and ensure that equipment will continue to function in the required manner over its design life-cycle with a minimum amount of maintenance and downtime. The goal of this approach is to reduce the life cycle costs while achieving the required reliability and availability. The diagram below shows the components of an RCM program [9].

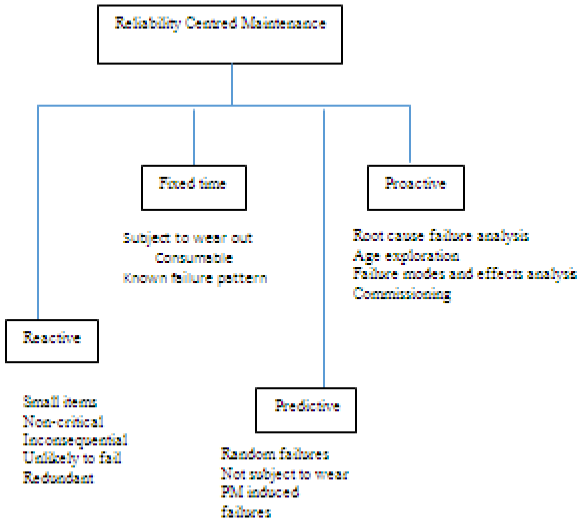

Figure 1 : Components of an RCM program

A.A BRIEF HISTORY OF RCM

Reliability Centred Maintenance originated in the Airline industry in the 1960's. By the late 1950's, the cost of maintenance activities in this industry had become high enough to warrant special investigation into the effectiveness of those activities. Accordingly, in 1960, a taskforce was formed consisting of representatives of both the airlines and the **FAA** to investigate the capabilities of preventive maintenance [2].
This led to the 747 maintenance steering group document (MSG1). This document was used to develop the maintenance program for Boeing 747 aircraft, the first maintenance program to apply RCM concepts. This program was a success as it significantly reduced the number of items that had to be overhauled. It also reduced the number of labour hours required for a given number of hours of operation[5].

B.TYPES OF RCM

There are many paths and processes in coming up with an RCM program.

Rigorous RCM

Rigorous RCM analysis has been extensively used by the aircraft, space, defence and nuclear industries where functional failures have the potential to result in large losses of life, national security implications, and/or extreme environmental impact. A rigorous analysis is based on a detailed Failure Modes, Effects and Criticality Analyses (FMECA) and includes probability of failure and system reliability calculations.While this process is appropriate for these industries, it is not necessarily the most practical or best approach to use for facilities and utilities systems maintenance. For these systems, a more intuitive RCM analysis process may be more appropriate.This is due to the high cost of the rigorous approach, the relative low impact of failure of most facilities systems, type of systems and components to be maintained and the amount of redundant systems in place. Failure modes that result in high costs or personnel injury can still be analysed using the rigorous way while other failure modes are treated the intuitive way.

Streamlined RCM

This is an intuitive approach which identifies and implements the obvious, usually condition based, tasks with minimal analysis. It eliminates the low value maintenance tasks based on historical data and Maintenance and Operations personnel input. The intent is to minimize the initial time in order to realize early benefits that help offset the cost of FMECA and condition monitoring capabilities development.However its reliance on historical records and personnel knowledge can introduce errors into the process that may lead to missing hidden failures where a low probability of occurrence exists. Also, this method requires that at least one individual has a thorough understanding of the various condition monitoring technologies.
This approach should be used when:

- The function of the system or equipment is well understood.
- Functional failure of the system or equipment will not result in loss of life or catastrophic impact on the environment or business unit.

C.RELIABILITY IMPORVEMENT TECHNIQUES

There are three major ways of improving availability performance, which are;

[1] To improve reliability at constant maintainability
[2] To improve maintainability at constant reliability
[3] To improve both reliability and maintainability
[4] Efforts to increase availability should therefore be focused on areas of low reliability or areas of low maintainability.

C.EQUIPMENT PARTITIONING AND SELECTION OF TARGET

In introducing an RCM framework at the company, it is in line with best practise to identify an area where benefits from the program can be realised quickly, without prior major capital investments in order to gain support from management for a full scale implementation of RCM. In order to identify the best section for implementation of a pilot project, failure records from previous years were analysed. This enabled the identification of low reliability and low maintainability areas. A study of production records also revealed bottleneck equipment, whose failure can bring the plant down and whose reduction in capacity results in major profit losses.

Project findings

[1] Wrong maintenance practices
[2] One of the major drawbacks of FTM is "self-inflicted wounds." Self-inflicted wounds are breaks downs that occur as a result of incorrect maintenance practices. The company has two major pieces of equipment along the cane preparation line, which are the shredder and cane knives. The current maintenance practice for these two machines has been introducing an imbalance into the system, which would result in amplified vibrations.
[3] Clustering of tasks and maintenance labour utilisation
[4] Certain maintenance tasks require stopping the plant since some equipment cannot be bypassed. In many cases however, stopping the plant is a process. By clustering maintenance tasks and doing as many tasks as possible during a stoppage, the time lost during stopping and starting equipment is distributed over many tasks and ultimately reduced.
[5] Equipment due for replacement
[6] Analysis of the failure trends of some equipment revealed that the equipment is in the wear-out stage of its life. Its failure rate is increasing and its maintainability is decreasing. The cost of unreliability for this equipment was found to be higher than the cost of replacing the equipment.
[7] Equipment in need of redesign
[8] Proactive tasks are a very powerful tool in RCM. From the analysis of failure records, certain items were identified where condition monitoring was not feasible, and the failure rate was too high for fixed time tasks or reactive tasks. In such cases, redesign was the most effective and efficient route.

IV. RECOMMENDATION

The sub-sections below describe the various recommendations from identified opportunities for implementing RCM. Most of the opportunities identified can be implemented easily without major capital investments, and the benefits can be realised within a single season.

A.RECOMMENDATION FOR SHREDDER SYSTEM

The major recommendations for the shredder system are to replace two rows after 2 weeks, and to implement tribology for the bearing and electric motor. The costs for the proposed and current policy are shown below.

Table 1 : *Cost analysis for shredder*

PARAMETER	CURRENT	PROPOSED
Reliability	25.6	74.8
Average failure rate	0.006118	0.0008655
Expected failures in one week (**f**)	1.03	0.15

<table>
<tr><td colspan="2">Average downtime (D; Hrs.)</td><td>1.091</td><td>0.164</td></tr>
<tr><td colspan="2">Crushing rate of line (R; TCH)</td><td>300</td><td>300</td></tr>
<tr><td colspan="2">Loss of production (L; Tonnes of sugar)</td><td>42.14</td><td>6.14</td></tr>
<tr><td colspan="2">Cost of unreliability</td><td>$16 856</td><td>$2 456</td></tr>
<tr><td rowspan="2">Maintenance cost</td><td>Cost of spares</td><td>$5000</td><td>$5000</td></tr>
<tr><td>Loss of production due to planned downtime</td><td>$2*\frac{300}{8}*p = \$30\ 000$</td><td>$1.5*\frac{300}{8}*p = \$22\ 500$</td></tr>
<tr><td colspan="2">Total cost for policy</td><td>$51 856</td><td>$29 956</td></tr>
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The cost of unreliability and cost of maintenance are compared in the bar graph below.

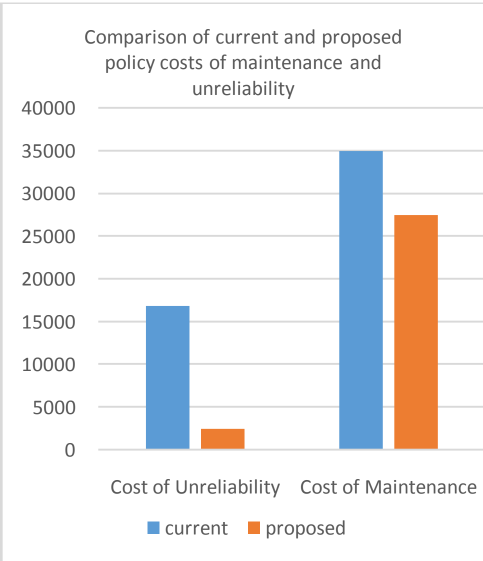

Figure 2: Cost of unreliability and cost of maintenance for shredder

This recommendation is an example of clustering of tasks. It does not change the cost of spares but it improves reliability and distributes the starting and stopping times. A reduction in maintenance cost by $21 900 can be expected if the recommendation is implemented.

B.RECOMMENDATION FOR CANE KNIVES

The first recommendation for the cane knives system is clustering of tasks. By changing two rows every two weeks, instead of one row a week, the starting and stopping time is reduced and also the balancing of the knives rotor is improved. The second recommendation is to automate the feed mechanism so as to avoid overloading and to smoothen the feed process. The costs for the current and proposed programs are shown below.

Table 2 : Cost analysis for knives

PARAMETER	**CURRENT**	**PROPOSED**
Reliability	65.93	74.8
Average failure rate	0.00248	0.0007134
Expected failures in one year (**f**)	15.12	4.32
MTTR	1.393	1.393
Average downtime (**D**; Hrs.)	21.06	6.02
Crushing rate of line (**R**;	300	300

TCH)				
Loss of production (**L**; Tonnes of sugar)			6 320	1 806
Cost of unreliability			$316 000	$90 300
Cost of improving reliability	Cost of new Equipment	Feed mechanism purchase and installation	0	$6 800
		Vibration monitoring purchase and installation and training.	0	$13 000
	Annual cost of spares		$28 880	$28 880
	Annual loss of production due to planned downtime		$9 720 000	$4 860 000
Total cost			$10 064 880	$4 998 980

The Implementation of the recommendation will improve productivity by reducing downtime. The estimated increase in productivity is $4 860 000 in one season. The payback period for the capital investment is therefore 0.004 years.

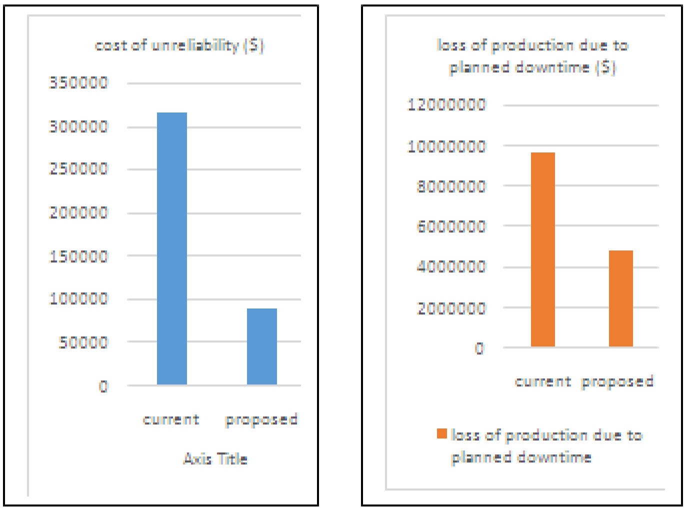

Figure 3 : Cost of unreliability and loss of production for knives

1.1 Recommendations for syrup transfer pumps

The major recommendation for syrup transfer pumps is to replace both pumps. This is justified by the cost of unreliability and loss of production due to reduced capacity. The following table shows the cost under the current and under two proposed programs.

Table 3 :*Cost analysis for pumps*

PARAMETER		CURRENT	PROPOSED	
			Replace one pump	**Replace both pumps**
Reliability (% per year)		62.84	95.7	95.7
Average failure rate		0.00007682	0.000007267	0.000007267
Expected failures in one year (**f**)		0.465	0.044	0.044
Average downtime (**D**; Hrs.)		10	10	10
Required flow rate (m^3/Hr)		90	90	90
Actual flow rate (m^3/Hr)		67.5	90	90
Loss of production (**L**; Tonnes of sugar per year)	Loss due to stoppages	251	23.76	23.76
	Loss due to reduced capacity	81 648	151	0
Cost of unreliability		$32 759 600	$69 904	$9 504
Cost of improving reliability Cost of spares ($)		$56 (annual cost of gland packing)	22000+56= $22 056	(22000+56)*2 = $44 102
Total cost		$32 759 656	$91 960	$53 616

The recommendation with the lowest total cost is the third option which is to replace both pumps. An increase in productivity by $32 706 040 can be realised.

1.2 Recommendations for the bagasse conveyor system

The faults being experienced reflect the incapability of the system to handle the material being conveyed which is bagasse. Two recommendations were made, and compared on the basis of cost. The first one (**A)** is to monitor the condition of the chute using sonic predictive technology, and the second (**B)** is to redesign the system and install a chute that can handle the material at the design conveying rate without choking. These recommendations, together with the current system (**C)** are compared on the basis of cost in the following table.

Table 4 : Cost analysis for bagasse conveyor candidate policies

PARAMETER			**A**	**B**	**C**
Cost of implementation	Purchase price		$4 000	$3 000	0
	Cost of	Installation	$2 000	0	0
		Training	0	$1 000	0
	Rebuilding cost		0	$500	0
Cost of unreliability	Hourly failure rate		0.0002	0.00101	0.0267
	MTTR (Hrs.)		1.03	1.03	1.03
	Downtime per Hr (Hrs.)		0.000206	0.00104	0.0275
	Loss of production ($/Hr.)		5.15	26.00	687.50
	Seasonal loss of profit (1 season is 6048 Hrs.)		$12 459	$62 899	$1 663 200
Annual cost of operation			$22 000	$22 500	$22 000
Annual cost of maintenance			$1 814	$9 163	$242 220
TOTAL COST			$20 273	$99 062	$1 927 420

1.3 Improve record keeping and maintenance cost tracking

RCM seeks to identify and implement the best maintenance strategy for each unit, within its context of operation. In order to achieve this, there is a need for information on the history of the item within that context. This information might be the MTBF, which will be used to optimise the maintenance interval, or the mean life of the equipment within that context, which will be used to schedule replacement.In any case RCM is highly reliant on the availability and accuracy of the history of operation of equipment within a given context. Therefore it is highly recommended that the company improves its database and record keeping practices. Also care must be taken to ensure that every failure is recorded and that the time to repair and spares used are also documented.This will tremendously increase the paperwork, but the benefits are immense in terms of AP and ultimately profit.

1.4 Produce separate schedules for similar equipment in different operating contexts

Currently a single schedule is produced for all similar equipment, irrespective of the equipment's operating context. Electric motors have a single similar schedule, centrifugal pumps share the same schedule [M 3], and gearboxes share the same schedule [Schedule M1], and so on. Using this approach ignores the fact that some failure modes are more likely in certain operating environments than others.Producing separate schedules depending on operating environments enables optimisation of equipment life and reduction of catastrophic failures.The major drawback is the increase in paperwork, but this is a small price to pay for the gains to be realised.

V.OVERALL IMPACT OF RECOMMENDATIONS ON SYSTEM AVAILABILTY AND RELAIBILITY

The impact of recommendations on the plant is best described in terms of the change in KPIs. The table below shows the availability difference between the current and proposed system.

Table 5: Overall Availability Performance

Equipment	AP (Current)	AP (Proposed)
Cane knives	0.944	0.963
Shredder	0.944	0.961
Bagasse conveyor	0.935	0.964
Syrup pumps	0.930	0.976
Rest of the system	0.974	0.974
Resultant Plant AP	0.755	0.848

The following graph is a plot of the information in the above table. It shows that availabilities for each of the equipment analysis can improve, and the ultimately the AP for the whole plant can be raised.

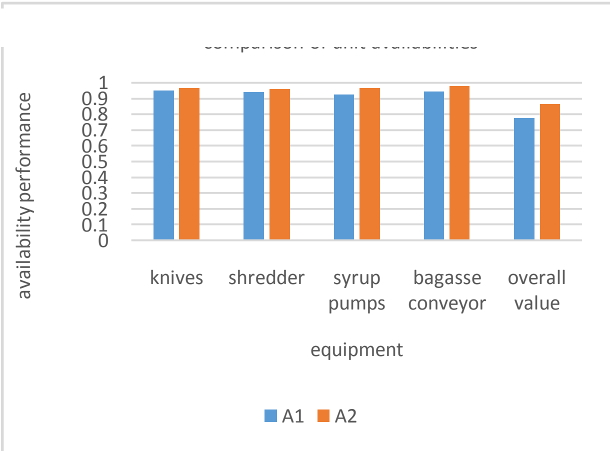

Figure 3 :Comparison of unit Availabilities

The following graph shows the impact of the proposed framework on the reliability of equipment.

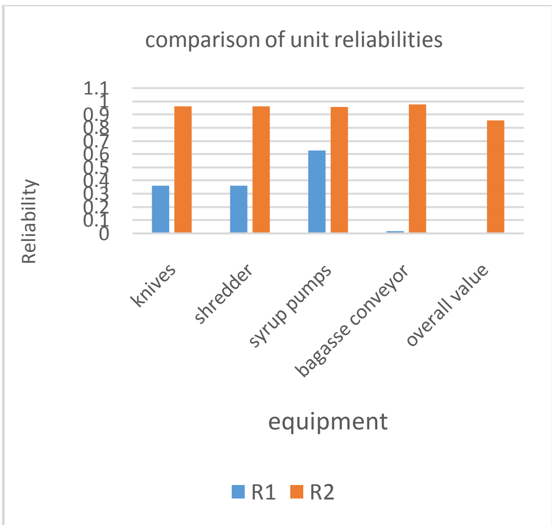

Figure 4: *Comparison of unit reliabilities*

The other KPIs used are Overall Equipment Effectiveness and Process Rate. The following table shows the variation of the KPIs with the implementation of the framework.

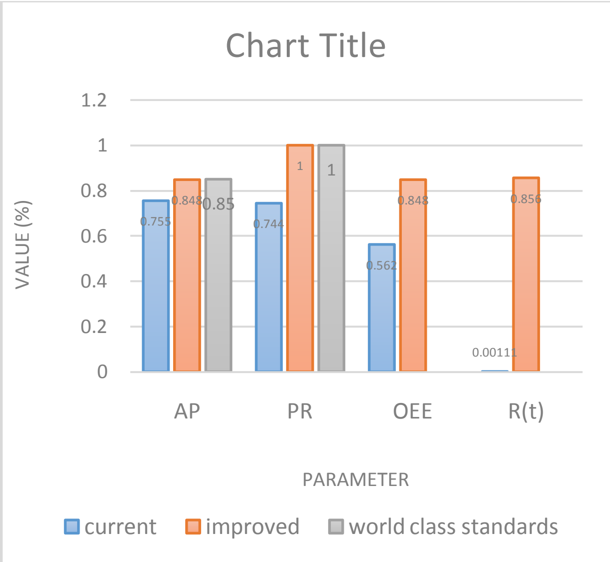

Figure 5: Variation of KPIs

V. VI.CONCLUSION

From the cited cases, it is evident that the plant stands to gain a lot from an RCM analysis. By implementing the program in just one section of one production line (extraction line), the reliability and availability can become comparable to world standards.

Reliability Centred Maintenance is the way to go. The benefits it poses are a great improvement on the existing Fixed Time Maintenance policy. From the analysis of critical equipment carried out, all KPIs are improved by the implementation of RCM. AP rises from 75.50 % to 84.80%. Reliability rises to 85.6%. Furthermore the benefits of implementation can be realised within one crushing season. As shown in the following graph, implementation of the framework would make the performance of the company comparable to world standards. This would make the company more competitive in the global market.

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ATHORS' PROFILES

Kumbi Mugwindiri, did Bsc Mechanical Engineering Honours at the University of Zimbabwe, and Masters in Manufacturing Systems at Cranfield University, England. Currently, lecturing Engineering Management at the University of Zimbabwe. Worked as Workshops Engineer for Zimbabwe Phosphates Industries responsible for heavy maintenance of process plant equipment . In 1993 carried out a project with the Ford Motor Company to determine ways of improving working patterns and practices, this was a European Union wide project. In 2000, he undertook collaborative research in Clean Technologies at Tulane University in New Orleans. Has worked with many organizations researching/and or consulting in Maintenance Engineering and Cleaner Production.

Ignatio Madanhire, graduated with a BSc Mechanical(Hon) Engineering and MSc in Manufacturing Systems and Operations Management in 1993 and 2010 respectively from the University of Zimbabwe. He has been a mechanical engineer with Department of Water – Large Dam Designs, and also worked as a Senior Lubrication Engineer with Mobil Oil Zimbabwe as well as Castrol International dealing with blending plants and lubricants end users. Currently, he is a lecturer with the University of Zimbabwe in the Mechanical Department lecturing in Engineering Drawing and Design. Has published a number of works on cleaner production in a number of journals.