

APPLYING PREVENTIVE AND PREDICTIVE BEST PRACTICE ON PLANT MAINTENANCE

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Abstract

Quite often in the industrial environment engineers are required to justify the addition or change of equipment when companies venture into investing in capital to increase production capacity or improve efficiency. Aged and outdated machinery and equipment are at times not economical to re-fabricate due to the improvement in manufacturing methods and obsolescence of old technology. Maintenance of machinery is often not done as it should be to achieve optimum availability where policies don't exist. Technological improvement has resulted in less robust, advanced and often more complex designs where modern technology replaces older designs making the old designs more expensive to produce in some cases. As a consequence the re-fabrication of old equipment becomes difficult to justify with the high cost. The maintenance cost of previous equipment also does not compare to modern equipment and negatively affects the competitiveness of organisations against their peers that utilize modern methods. The solution to staying competitive is to re-design, upgrade equipment, change maintenance policy or introduce technology. This research will highlight methods that can be utilized to ensure that the reliability of equipment remains at an acceptable level and also show evidence of improvement in reliability of equipment due to re-design and through continuous improvement initiatives. A case study for design and continuous improvement efforts with primary and secondary data sourced from Everite Building Products a manufacturer of fibre cement products is used and presented. The results confirm that the sustained reliability of equipment depends on the efforts by the user to keep equipment reliable through methods supporting predictive and preventive maintenance.

Keywords: Predictive, Preventive, Maintenance, Reliability and availability

1. Introduction

Maintenance is the function of retaining an item in or, restoring it to its original or, acceptable standard for use or "to meet its functional standard" (Gustavsson, 2014). Maintenance is generally accepted as a time consuming and costly activity (Narayan, 2012) that may render equipment unavailable if not effectively practiced.

Maintenance consists of corrective maintenance, preventive maintenance and continuous improvement. The broad definition of maintenance includes but is not limited to aspects shown in the diagram in figure 1 that shows an extension of this definition.

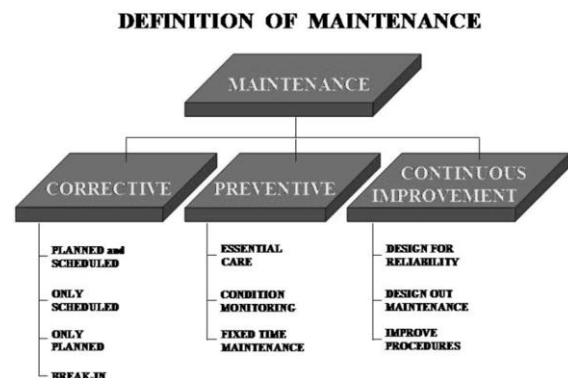


Figure 1: Definition of maintenance (<http://www.idcon.com>, 2013).

Predictive maintenance (PdM) is a program that considers the condition of the maintained

item and applies preventive measures to schedule maintenance activities to avoid failure (Mobley, 2012 ; Gustavsson, 2014). Figure 1 therefore correctly has the conditional monitoring under the field of preventive maintenance as it is a predictive measure that is used to prevent failure. PdM relies on the ability to recognize a significant change out of the normal or requisite operating conditions to signal a characteristic that needs to be corrected (Kodali, 2001).

Preventive maintenance (PM) is the periodic result of planned interventions or actions that aims to reduce the probability of breakdown that is a cause of loss of production (Loftsen, 2000). In order for preventive maintenance to apply, knowledge of the operation, process, equipment or machinery needs to be in place (Kodali, 2001). PM is time based and can be a legal requirement governed by regulations and standards for equipment and machinery that if not maintained, can have adverse health effects or injure individuals at work (OHSA, 85 of 1993). The result of this intervention can increase machine availability which is the measure of time an item is ready for use to execute the work for which it is intended and is expressed in percentage whether that item is in use or not. The goal of maintenance management is to maximize machine availability while minimizing operating cost (Loftsen, 2000; Colledani, 2014) thereby increasing business performance (Mateko, 2010). Business (Loftsen, 2000) and production (Colledani, 2014) sustainability in the manufacturing industry require the maintenance of resources.

Various maintenance methods can be utilized, each bringing about varying results. The selection and management of maintenance methods thus becomes an important function that influences machine efficiencies, availability and production output respectively. This maintenance method decision-making relies on supervisor's or management's experience and knowledge in maintenance, risk appetite, production targets, maintenance budgets, maintenance management plans, available reliability engineering theory and procedures, and various aspects relating to activities occurring at that time.

Capital equipment needs to be kept at optimum operating levels and this can be done through periodic maintenance to sustain productive capacity of machinery and equipment and to extend periods of degradation (Camci, 2015). Machine availability can be directly affected by maintenance activities but so too can the safe working condition of equipment. Maintenance should prioritize on ensuring that equipment is safe to use where there are safety hazards with the use of equipment (Narayan, 2013; Chinniah, 2015) as legislated, regulated or prescribed by manufacturers, importers or sellers (OHSA,1993). A goal of maintenance is to increase or maintain machine availability with use which in-turn affects "profitability" (Narayan, 2013).

Failure prevention through Root Cause Failure Analysis (RCFA) of failures as well as the use of world class strategies of Reliability Centred Maintenance (RCM) and Total Productive Maintenance (TPM) (Mateko, 2010) can aid in the prediction, prevention and also prompt maintenance activities.

Preventive and predictive maintenance (PPM) best practice techniques use modern methods, tools and models to achieve effective and efficient maintenance. The focus of best practice techniques centres around undertaking the right maintenance at the right time through analysis (Camci, 2015) and understanding past and possible failures and the manner in which they are managed. The use of PPM has the aim of reducing equipment and system failure (Tang, 2015) thereby reducing operating and maintenance costs (Aghezaff, 2015).

PPM techniques require the understanding of the following key subject areas

- Failure Modes , Effects and critical Analysis (FMECA)
- Root Cause Failure Analysis (RCFA)
- The development of equipment maintenance plans
- Breakdown maintenance (BM)
- Preventive maintenance (PM)
- Predictive maintenance analysis
- Reliability Centred Maintenance (RCM)
- Equipment design modification

- System performance monitoring

The introduction of a maintenance plan through findings from analysis of the abovementioned areas needs to be practiced and reviewed so as not to lose its effectiveness over time.

1.1 Rationale of Study

Everite Building Products (EBP), manufacturer of fibre cement building products aims to minimize the rising cost of products it sells to the market. An increase in the cost of raw materials, labour and electricity and water all of which are significant contributors to the unit production cost of goods EBP produces lead to an increased sales price to the consumer. The rate at which this selling price increases annually should be relatively equivalent to competitors' price increases of equivalent or similar alternative products for the business to remain competitive. It is becoming increasingly difficult for modern day industries to survive (Kodali, 2001).

Unlike the increase of costs such as that of raw materials, there is the controllable cost of maintenance that can be reduced, maintained a level or controlled to increase at a rate less than that of an inefficiently managed maintenance system. Maintenance, service and support are necessary for aging and productive assets (Mgobhozi, 2012; Kodali, 2001). This research will measure maintenance activities and relate them to best practice methods and procedures.

1.2 Aim or objective

The aim of this study is to highlight the importance of doing the right maintenance at the right time through analysis of failures and potential failures and devising appropriate action (Camci, 2015).

Maintenance plans currently in use at EBP are evaluated and compared to research developed maintenance plans using studied literature, articles, case studies and consultations with management personnel responsible for maintenance as well as preventive maintenance best practice methods.

With the view that correctly maintained equipment results in higher production rates of quality products, this study seeks to identify, introduce and improve predictive and preventive maintenance specific to manufacturing at EBP with the aim of realizing potential profitable benefits and "maximize its maintenance productivity in economic terms" (Lofsten, 2000).

Innovative and improving technology and the introduction of new more efficient equipment and machinery as well as continuous improvement initiatives that can improve reliability, availability and maintainability (RAM) in the maintenance environment will be identified in a case study focused on a section of the EBP production process.

1.3 Research approach

Two approaches were used in the research namely, theoretical and practical research.

1.3.1 Theoretical research

Information from literature and seminars will be used to get a greater understanding and general industry perception in the field of preventive maintenance and will be supplemented by documentary evidence in the form of data used in the maintenance environment. Verbal evidence from a "knowledgeable informant" (Remenyi, 2011) will be included in the research giving insight into the production factory being studied.

1.3.2 Practical Research

The practical approach focused on EBP's factory maintenance and the effects to productivity. The case study for the re-design and continuous improvement was conducted on a multi-component QC packing station (figure 1) that needed to be simplified in order to further enhance justification of its investment. Before any work had started areas of concern were known and are identified in figure 1 of the packing stations.



- Notable areas of concern
- Vertical lift assembly
- Cross travel
- Liftbox
- Rack & pinion driven t
- High pressure low volu centrifugal fan

Figure 2: Quality Control Packing Station for fibreglass flat sheets.

Historical records of corrective and preventive maintenance were analysed to determine maintenance needs based on records. To determine a basis for the reliability of components the original design needed to be studied and each original component identified. Table 1 shows the identification of parts and materials as designed initially.

Table 1: QC Station- original design drawing analysis

-A-	MECHANICAL SPARES / MATERIAL LIST:
1	X-Travel Support Member: 300 x 160 x 40.3 mm I-beam
2	X-Travel Support Member: 300 x 160 x 40.3 mm I-beam
3	X-Travel Gearbox base plate: 500 x 500 x 5 mm plate
4	X-Travel Vertical Support Member (incl. bracing similar to existing): 300 x 160 x 40.3 mm I-beam
5	Allow for Cable: Break & Escalator existing floor, cast new base, and allow for mounting plates to support existing Vertical Members.
6	X-Travel Rail: Diameter 60 mm Precision shaft screwed onto rail
7	X-Travel Drive Bearing Mounting Plate: 500 x 500 x 5 mm plate
8	Timing Pulley: A1 20 - 90 Timing Pulley
9	0.5 KW Panasonic Servo Motor
10	X-Travel Drive Bearings: SKF, UCF-208-40mm
11	X-Travel Drive Gearbox: 30:00 Ratio
12	Joint (Coupling Type: 2 Flanges, 4 TILUAK); PFK 90 Partner Type 4
13	Drive Shaft: Diam 60 mm
14	Timing Belt: A1 20 - 75 Timing belt
15	Vacuum Gripper Support: 60 x 60 x 5 mm Rectangular Tubing
16	Timing Belt Clamp: A1 20-75 Clamp
17	Timing Belt: A1 20 - 75 Timing belt
18	Idle Roller: Diam 40 x 60 mm
19	Timing Pulley: A1 20 - 90 Timing Pulley
20	Bearings: SKF, UCF - 208 - 40 mm
21	Drive Shaft:
22	Support Plates:
23	Bogey Gearbox: 25:02 Ratio: 40 rpm
24	0.5 KW Panasonic Servo Motor
25	Gearbox Mounting Plates:

Component description and material list of parts

Labelled Identification of parts from original design drawings

This formed the basis for the practical research. The collating of data for corrective action which is a closed loop process should give an indication of the frequent failures that need attention as well as highlight the need for problem solving through engineering, reliability practices or failure analysis techniques to identify and resolve problems through “radical” or “incremental” improvements (Choo, 2015). The data from EBP’s maintenance resource management system will be presented. While it is beneficial to have such a system, the effective management of resources by individuals is necessary for maintenance

activity to be efficiently conducted. Resources in the form of manpower, equipment, spares and the maintenance budget need to be measured and managed and compared to what they should be according to statistical plant maintenance needs (Bhadury, 2013). Time and performance based preventive maintenance will be examined as well as the introduction of inspection rounds and how this can be monitored (Liebstuckel, 2012).

2. Results and Interpretation

2.1.1 Theoretical Results and Interpretation

Where technology can be used to assess the condition of equipment or machinery (PdM), periodic preventive checks (PM) can be eradicated or reduced. The cost of replacing equipment or machinery due to breakdown, catastrophic failures and overall cost of maintenance makes condition monitoring tools imperative (Tang, 2015) as they can detect imminent failure or change in operating conditions of critical parts.

A cost-benefit analysis for PM needs to be conducted to prove the worthiness of interruption to revenue generating production. Successful PM programs generate measureable benefits (Mobley, 2000). Therefore if PM is not utilized PdM will need to be used to ensure that maintenance is performed before failure. If PdM is also not used CM will be needed after failure has occurred.

Using PPM can be very effective as it has the potential to reduce maintenance work and costs, product quality, equipment availability and productivity (Carlos, 2011;Carnero, 2005).

The selection of maintenance strategy is a reflection of the companies’ corporate vision that aims to place them at an advantage over competitors (Mgobhozi, 2012). Availability is the common goal of all operations that differ in policies. RCM can be used in selecting a suitable maintenance policy for an organization (Carnero, 2015). Performing Root Cause Failure Analysis (RCFA) can identify, justifiable opportunities for improvement by Return On Investment ROI (Mobley, 2002) proving that change in equipment can be of financial and production benefit and also prolong the life of equipment

as long as the recovery or payback period is in line with the organizations investment capabilities and protocols. Improvement increases the Overall Equipment Effectiveness of operations (OEE).

Higher OEE can cause organisations to be more competitiveness as it translates to reduced maintenance costs and machine downtime with an increase in production or quality over a studied time period.

Industries that reveal production figures can help other organisations benchmark against competitors. The figures, although they may differ in how they are achieved in terms of processes, can serve as industry performance indicators and measures of OEE (Mobley, 2002). OEE is not a valid corporate measure against competitors as it should measure the assets performance against itself and argues that it should compare like equipment and the resulting production output.

TPM is closely related to OEE in that it aims to increase the overall effectiveness of equipment and machinery as was originally intended when it was introduced (Kodali, 2001)

TPM aims to have the following in production environments

- No breakdowns
- No accidents
- No defects
- No waste

These drive an increase in quality and production at reduced cost and improved productivity. This in turn increases equipment availability thus increasing OEE.

A predictive and preventive maintenance system in the form of an ERP (Enterprise Resource Planning) system can be utilized to better plan maintenance, the resources required, manage stock holding and measure the effectiveness or benchmark maintenance activities. This automated system should be able to increase the effectiveness of maintenance planning by:

- notify what maintenance action should take place if maintenance action is required
- give the optimum completion time of the maintenance event
- allocate appropriate skills

- list the spares required
- measure how long it takes to complete the task and rate the duration against historical information

All this can be done with the aim of optimizing the maintenance function and managing the resources which in turn can reduce waste (Okogbaa, 1992).

Machine component capability in terms of functionality needs to be well-known so as not be over-maintained and result in disturbance of manufacturing operations and compromised performance. OEM's conduct various tests on their manufactured components and conduct quality assessments on parts that certify their functionality. This information as well as data on equipment specification, performance capabilities, operational thresholds and recommended maintenance intervals needs to be an integral part of maintenance plans.

A possible solution to this non-productive personnel behaviour is creating production and maintenance teams that are multi-disciplinary or have a high level of skills to perform maintenance functions on frequently occurring failures and who can diagnose the problem within the team there-by calling upon the correct support to get machines and equipment to normal operating conditions. This can be done by analysis of frequently occurring breakdowns to justify the change and by training and up-skilling staff to be capable of handling a wide range of disruptions and who can contribute to the improvement of operations through the increased knowledge and experience. This greater awareness can increase safety, improve employee interest in work and give rise to improved availability which in turn promotes TPM (Kodali, 2001). This results in an organisations Internal Knowledge Stock (IKS) increasing its problem solving ability by means of Generative Problem Solving (GPS) at various employee levels (Choo, 2015).

Maintenance planning should come from analysis of data and studied events from operation. This should be reviewed and assessed for change after the introduction of every continuous improvement initiative so as to re-allocate maintenance resources such as labour and re-align budgets and inventory after the change (Choo, 2015). Technology

has the advantage of reducing labour intensive effort and if this is not realized, maintenance will likely have under-utilized personnel. Data of time spent doing maintenance work before and after changes to operations and equipment or even maintenance strategies is a good measure of personnel requirements in maintenance and the effectiveness or failure continuous improvement initiatives.

The effect of design and modifications can affect most individuals in the operations. Machine operators need to be trained on using equipment, maintenance needs to have a plan for maintenance, the stores needs to have adequate spares, the new assets will be registered as depreciating assets and the support of the machines from EKS's will need to be utilized. All these influences need to be carefully considered when continuous improvement initiatives are proposed.

When attempting to introduce change, consideration is needed where

- 1) the organizations maturity on adopting the technology has to be considered
- 2) operations and culture of the organization need to be considered
- 3) management of information from the technologies needs to be done by individuals qualified, capable, trained or experienced to manage it

An organizations "internal human capital" can positively affect continuous improvement through innovation stemming from incremental or major improvement initiatives that can come about from knowledge of operations (Choo, 2015).

Successful introduction of new technology can be measured by the resulting availability and reliability as will be displayed in the case study conducted at EBP. Use of predictive techniques can maximize value of equipment and prolong the by predicting imminent failure allowing earlier intervention.

2.1.2 Practical Results and Interpretation

RCFA could be performed from the existing old machine where the wear rate, failures and frequently failing parts were identified. The analysis of maintenance data for the old QC station collected from the EBP's ERP system is shown in table 2 which is an extract of all

the maintenance action on the machine. It details the failure type, action performed, duration and personnel involved.

Table 2: Component and parts failure analysis

Work order / Job card number	Description of maintenance action required	Description of machine/area to be worked	Foreman requested to respond to maintenance action	Responsible person assigned to respond to maintenance request	Manually calculated hours from job card issued back after completion of work
4585292	Roller bed chain broken	QC04	Casper Erasmus	JW Moorcraft	1
4586159	Roller bed chain broken	QC04	Casper Erasmus	Danie Claassen	1
4586942	Production change	QC04	Casper Erasmus	Obert Maschane	1
4587013	Alignment problem on rollerbed	QC04	Casper Erasmus	Danie Claassen	1a
4587620	Mean on new safety handrail	QC04	Mark de Beer	Piet Sibiya	1
4590394	Change dust hose at QC4	QC04	Casper Erasmus	Laet Sebuse	1
4590992	Check north side cross travel	QC04	Desmond Njere	Edwin Smei	1
4592004	Trolley gearbox issue	QC04	Casper Erasmus	Danie Claassen	1
4593012	Repair lights	QC04	Desmond Njere		1
4593135	Repair & align roller bed	QC04	Desmond Njere	Pontsho Mmakola	2
4593143	Change dust hose	QC04	Casper Erasmus	Obert Maschane	1
4593151	Weld bracket on linear shifter	QC04	Mark de Beer	Jaco Basson	1
4593402	Attend to rail at QC area	QC04	Mark de Beer	Obert Maschane	1
4593561	Fix mis-alignment	QC04	Casper Erasmus	Danie Claassen	1
4594416	Monthly trip on QC offloader - E	QC04	Carel Horn	Obert Maschane	2
4594424	Monthly trip on QC offloader - M	QC04	William Steven Moriarty		1
4594460	U/Check on QC offloader - M	QC04	William Steven Moriarty		1
4594580	U/Check on QC offloader - E	QC04	Carel Horn	Obert Maschane	2
4595489	Attend to roller bed chain	QC04	Casper Erasmus	Obert Maschane	1
4595669	Assist with production change	QC04	Casper Erasmus	Danie Claassen	1
4595939	Size change	QC04	Casper Erasmus	Obert Maschane	1
4597609	Change dust hose	QC04	Casper Erasmus	Jan Eilers	1
4597908	Repair chain on rollerbed	QC04	Casper Erasmus	Obert Maschane	1
4598986	Repair chain & sprocket on cfb	QC04	Casper Erasmus	Obert Maschane	1
4599276	Attend to flex pipes by head 2	QC04	Casper Erasmus	Laet Sebuse	1
4600141	Check trolley out of rail	QC04	Casper Erasmus	Danie Claassen	1
4600510	Call out to adjust 4 QC speed	QC04	Desmond Njere	De Power Clastering (Atride)	1
4601815	Change dust hose	QC04	Casper Erasmus	Sinky Malagapa	1
4602017	Attend to vacuum fan	QC04	Casper Erasmus	Obert Maschane	1
4602525	Attend to chain	QC04	Casper Erasmus	Obert Maschane	1
4605728	Chain on roller bed broken	QC04	Casper Erasmus	Danie Claassen	1
4607786	U/Check on QC offloader - M	QC04	Casper Erasmus		1
4607871	U/Check on QC offloader - E	QC04	Desmond Njere		1
4608771	Check reject roller drive	QC04	Desmond Njere	Gudani Duhagidaha	1
4609697	QC 4 machine is freezing	QC04	Desmond Njere	Philip Dreyer	1
4609727	Check van charge at north side	QC04	Desmond Njere	Gideon Strydom	1
4609843	Revert reject roller drive into	QC04	Desmond Njere	Thabani Maseko	1

The data collected over 8 months is categorized into 29 failed components, failure types or machine areas in Table 3. This data which shows the frequently failed parts prior to performing RCFA was discussed with experienced personnel who know the nature of failures as they have worked with the machines on a daily basis and are credible sources. The data can also be quantified in terms of labour cost of maintenance as this is how much time was spent resolving the problem.

Table 3: Failure data of old QC

	MONTHS								TOTAL HRS	COUNT	%
	1	2	3	4	5	6	7	8			
1 Misalignment	0	0	0	1	0	0	0	0	1	2	0.340611
2 Trolley gearbox	1.5	1.5	2.25	0	0	0	0	0	5.25	8	0.894034
3 Rollerbed	20.18	10.5	47.5	8	11.75	5.75	7.5	4	119.78	81	20.394028
4 Electrical trip	2.5	0	0	0	0	0	0	0	2.5	4	0.425664
5 Vertical lift	1	7	32	7	8	0	0.5	5	60.5	46	10.30348
6 Lost Sequence	0	0	0	0	0	0	0	0	0	0	0
7 Liftbox	17.4	19.25	39.25	15.25	6.75	3.5	5	13.25	119.75	94	20.394028
8 Mechanical repairs	0.75	0	3.5	0	0	0	0	0	4.25	8	0.723788
9 Production change	0	0	0	1	0	0	0	2	3	4	0.520171
10 Air pipe	4	9.5	27.25	0	0.5	1.5	1	1	45.25	36	7.766235
11 Trolley / gearbox	1	1.5	4.25	1.25	3.5	1.75	0	0	13.25	18	2.255248
12 Conveyor	0	1	6	0	0	1	0.75	1	9.75	6	1.666479
13 Limit mechanical	-2	0.5	4	1	7	0	2.5	1	18	17	3.0655
14 Offloader Cross travel	5.25	3	6.5	1	2	1	1	1	20.75	14	2.92684
15 Lights	0	0	0	0	0	0	0	0	0	0	0
16 Trolley rails/trolley off rail	1	0	0	0	0	0	0	0.5	1.5	2	0.255438
17 Size change	0	0	0.5	0	0	0	0.5	1	2	4	0.520171
18 Electrical programming	12	0	5.25	0	1.5	0	0	0	19	8	1.295894
19 Vacuum fan	26.5	1.5	6	0	13.5	0	2.5	4	59	24	10.04683
20 Roller drive	1.5	0	0	0	0	0	0	0	1.5	4	0.255438
21 Squaring table	2.3	0.5	12	11	0.5	3.75	3	3	37.55	38	6.946775
22 Offtake-taperlock	0	0	0	0	0	0	0	0	0	0	0
23 ??	0.5	3	4	0	1.5	0	0	0	9	4	1.53275
24 Compressed air line	0	1	5	7	1.19	0	1.5	1.5	17.19	28	2.917334
25 Trapped	2.5	0	1	0.5	0.5	0	0.5	0	5	4	0.652328
26 Cross travel	0	0	0	0	0	0	0	0	0	0	0
27 No. 2 pulley gearbox	0	0	0	0	0	0	0	0	0	0	0
28 Electrical parts	7.5	1	2	0	1	0	0	0	11.5	4	1.98314
29 REPAIR OFFLOADER	110.01	60.75	208	55.3	60.13	17.25	26.25	48.25	587.18	423	100

Using GPS, new ideas to improve on old designs were utilized through working with knowledgeable individuals internally (IKS) and externally (EKS) (Choo, 2015). Introduction of technology also increased the skills level of employees that would maintain and utilize the technology.

The results of the new QC machine are shown in table 4 after modification. The data used to compile the table was taken over a period of 11 months.

Table 4: Failure data of new QC

	MONTHS											TOTAL HRS	COUNT	%	
	1	2	3	4	5	6	7	8	9	10	11				
1 Misalignment	7.95	0.1	3.81	2.5	0.5	1.5	0	0	0	0	0	22.08	20	5.17	
2 Trolley gearbox	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	0.25	
3 Rollerbed	10.25	9.34	4.1	2	8.5	11.5	1.5	11.25	0	1	2.3	64.17	50	15.61	
4 Electrical trip	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5	1.25	
5 Vertical lift	1.5	1.5	7.83	1.5	4.25	0	0	0	0	0	0.5	25.58	14	3.72	
6 Lost Sequence	1.58	0	0	0	0	0	0	0	0	0	0	0	1	0.25	
7 Liftbox	18	0.5	4.84	18	7.75	1	1	0	0	1	4.5	58.98	50	14.52	
8 Mechanical repairs	1.5	0	0.5	0.5	2	0	0	0	0	0	0	0.25	16.75	4.08	
9 Production change	1	0.75	0.75	0.75	0.5	0.5	0	2.25	0	0.5	0	5.33	9	2.33	
10 Air pipe	5.1	5.81	3.81	5.25	8.5	8.5	0	6.25	0	2.5	6.25	49.92	40	11.98	
11 Trolley / gearbox	0.75	1	5.25	5.25	1	3	3.75	11.75	0	3	1.5	36.25	26	8.82	
12 Conveyor	1	1	1	1	0	0	0	0	0	0	0	0	1	0.25	
13 Limit mechanical	1	1	1	1	0	0	0	0	0	0	0	0	1	0.25	
14 Offloader Cross travel	1.5	0	0	0	1	1	0	0	0	0	0	0	3	0.75	
15 Lights	1	1	1	0.5	0	0	0	0	0	0	0	0	1	0.25	
16 Trolley rails/trolley off	4	0	0.52	0	1.25	0	0	0	0	0	0	6.17	5	1.29	
17 Size change	0	1.5	1.5	0.5	1.5	1	1	3.75	1	0	0	12.25	10	2.88	
18 Electrical programming	0	1.5	1.5	1.5	0	0	0	0	0	0	0	0	0	0	
19 Vacuum fan	0	0.5	2	0	1.5	0	2	0	0	2.5	0	15.5	15	3.77	
20 Roller drive	0	0	0	0	0	0	0	0	0	0	0.5	3.5	4	1.02	
21 Squaring table	0	1	0	3.34	2.5	1.5	0.75	8.08	3	0.5	2.5	23.17	26	6.94	
22 Offtake-taperlock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23 ??	0	0	4.75	0.5	0	0	0	0	0	0	0	0	0	0	
24 Compressed air line	0	1	1	0	0	0	0	0	0	0	0	0	0	0	
25 Tripped	0	0	0	0	1	0.68	0	1	0	0	0	4.38	4	1.07	
26 Cross travel	0	0	2.25	0	0	0	0	0	0	0	0	12.25	9	2.38	
27 No. 2 pulley gearbox	0	0	0.5	0	0	0	0	0	0	0	0	0.5	1	0.25	
28 Electrical parts	0	0	0	0	5.08	0.75	12	13.25	0	0	0	0	20.25	18	4.52
29 Repair offloader	0	0	0	0	0	0	12	12	0	0	0	0	12	3.0	
	55.54	35.09	47.24	39.59	16.81	22.74	25.1	88.08	11	11	30.13	410.98	378	100.00	

The effects of the improvements are shown in table 5 that shows the improvements by comparing the monthly average of failures before (Table 3) and after (Table 4) the upgrades.

Table 5: Monthly average comparison of breakdown data.

BREAKDOWN	OLD QC			NEW QC			% CHANGE
	8 MONTHS			11 MONTHS			
	TOTAL HRS	COUNT	AVER HRS/MONTH	TOTAL HRS	COUNT	AVER HRS/MONTH	
1 Misalignment	7.95	2	0.3	22.08	20	2.0	83%
2 Trolley gearbox	5.25	3	0.2	6.25	6	0.6	30%
3 Rollerbed	110.75	85	15.0	64.17	50	5.8	39%
4 Electrical trip	2.5	2	0.3	2.25	3	0.2	65%
5 Vertical lift	60.5	40	7.6	25.58	14	2.3	31%
6 Lost Sequence	1.58	0	0.0	1.58	1	0.1	NEW
7 Liftbox	119.28	99	15.0	59.98	52	5.4	36%
8 Mechanical repairs	4.25	3	0.5	16.75	9	1.5	287%
9 Production change	3	2	0.4	5.33	9	0.5	125%
10 Air pipe	45.25	30	5.7	49.25	60	4.5	79%
11 Trolley / gearbox	13.25	13	1.7	36.25	26	3.3	192%
12 Conveyor	9.75	9	1.1	0	0	0.0	NEW
13 Limit mechanical	3.8	17	2.3	1	1	0.1	-4%
14 Offloader Cross travel - electrical	20.75	14	2.6	3.5	3	0.3	12%
15 Lights	0	0	0.0	1.75	2	0.2	NEW
16 Trolley rails/trolley off rails	15	2	0.2	6.17	5	0.6	29%
17 Size change	3	4	0.3	12.25	10	1.3	48%
18 Electrical programming	19	7	2.4	3.33	4	0.3	13%
19 Vacuum fan	59	22	7.4	15.5	15	1.4	19%
20 Roller drive	15	2	0.2	2.5	4	0.2	11%
21 Squaring table	37.85	33	4.7	23.17	26	2.1	45%
22 Offtake-taperlock	0	0	0.0	0	0	0.0	NEW
23 ??	9	6	1.1	6.33	6	0.6	51%
24 Compressed air line	17.33	29	2.1	4	4	0.4	17%
25 Tripped	5	6	0.6	4.16	6	0.4	61%
26 Cross travel	0	0	0.0	12.25	9	1.1	NEW
27 No. 2 pulley gearbox	0	0	0.0	0.8	1	0.0	NEW
28 Electrical parts	11.5	5	1.4	20.25	18	1.8	125%
29 REPAIR OFFLOADER	0	0	0.0	12	1	1.1	NEW
	587.39	423	73.4	410.98	378	37.4	51%

Once compared, the data reflects a decrease of 51% of breakdown hours on a monthly basis as displayed in table 5.

With this significant impact the following can occur

- reductions in stock-holding of spares required
- modifications or retrofits of other old machinery
- re-assigning the maintenance personnel to other areas interest
- optimising of preventive maintenance to further reduce breakdowns
- restarting the RCFA process with data collected and repeating the exercise

The negative aspects of the results are the new 6 breakdown areas as well as the increase in breakdown hours in areas that are marked in red in the “% change” column.

3. Conclusion

3.1. Introduction

Best practice methods for preventive maintenance assist an organisation in optimising maintenance through reducing maintenance costs, improving the system availability, improving safety and the reliability of equipment (Chinniah, 2015). This in effect means the increase in OEE where operations are more efficient, the improvement in quality standard and increase in safety of all people working. The objective for the organisations maintenance is to shift from reactive and preventive maintenance to planned maintenance that is constantly monitored and the paper highlights methods and changes that need to be implemented to achieve this.

3.2. Research conclusions

Transfer of knowledge and skills as well as the up-skilling of individuals to enhance IKS as well as the use of TPM can sustain the organization through competitive times as the aims of these two areas are centred around people and their ability to work together toward a common goal while growing their skill and contributing to company growth. EBP can benefit from the introduction and implementation of policies and strategies highlighted in the research. The feedback from the organizations ERP system needs further manipulation to get valuable information and can be altered to suit systems researched and those available in the market to assist in the planning of maintenance activities. The impact and management of this change can be researched further as this will drive maintenance from the software but also needs to be managed by individuals who can advise contrary to the recommendations of software where necessary. Predictive and preventive actions and planning can only be implemented following maintenance action and the assessment of past events over a period of time. The maintenance data of past events needs to be credible, reliable and have details needed to make important decisions. Scheduling and planning is reliant on this data and the system to support this information is a key business tool that is needed.

3.3. Case study conclusions

Where reliability levels are not acceptable, an effort to reduce the breakdown maintenance effect of poorly maintained equipment is needed. This can be done by assessing the failed products or equipment, assessing the damage and finding ways to mitigate in the form of redesign or applying predictive and preventive maintenance.

Analysis of failures was conducted, the frequency of failures was considered and the origin of the equipment and machinery used was investigated to show what deviation from original designs was done over time. The findings after completion of improvements shows the impact to maintenance activities and resources which can be translated to financial terms allowing a sound measurement of the return on investment which as researched is not a common trait after introduction of assets that organization invest in.

Re-design has the potential of improving breakdown and failure rate frequency and thus contributing to greater availability and production time. Areas of further continuous improvement can always be found after the re-design process as noted on the results of the case study. The results and benefits of continuous improvement and re-design and the positive effect on the reliability of components validate the exercise and investment and should be a practice exercised in the maintenance environment. Of interest is that redesign can introduce new failure areas that were unforeseen at design stage and these need to be managed.

4. Recommendations

The use of tools and processes can be implemented into maintenance policy as key guidelines for managing maintenance. The design and of these tools can be researched further as it requires participation from different disciplines or departments in the organization for any benefit to be realised. A computerized program to support maintenance is needed that complies to an already established policy and assists in the execution of an already defined structure and maintenance plan.

The management of change and the impact on sustaining knowledge to advance organizations to becoming more competitive in a fast changing environment where the reliance of external service providers is an essential aspect that can be researched further.

Further work on MTBF and MTTR can further enhance the reliability of components and refine maintenance intervals. Further work for replace the right parts before imminent failure by utilizing predictive and preventive maintenance can justify predictive technology.

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