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 Aged and outdated machinery and equipment are at times not economical to re-fabricate due to the improvement in manufacturing methods and obsolescence of old technology.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.

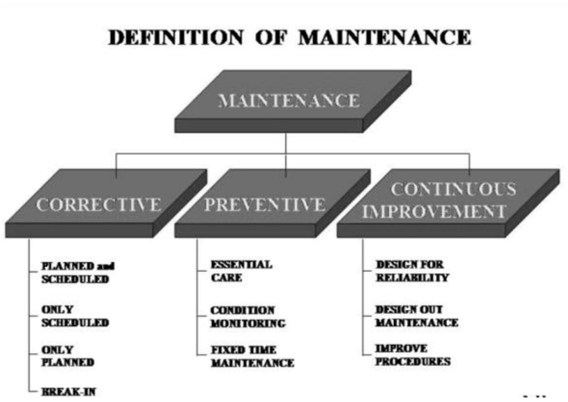


Figure 1: Definition of maintenance (http://www.idcon.com, 2013).

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 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.

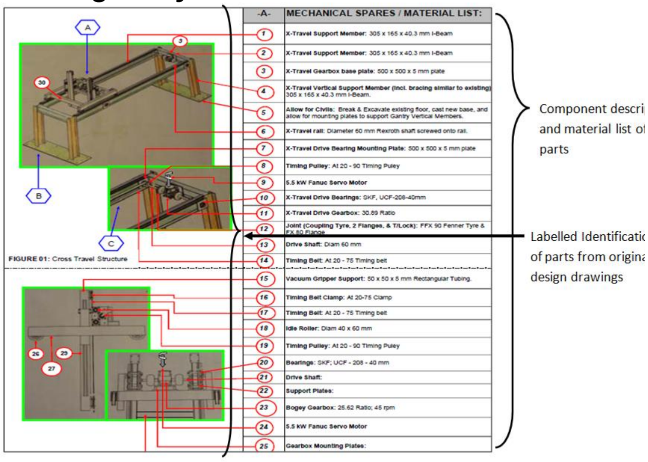
1.3.2 Practical Research

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.

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:** 305 x 165 x 40.3 mm I-Beam
2	**X-Travel Support Member:** 305 x 165 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)** 305 x 165 x 40.3 mm I-Beam.
5	**Allow for Civils:** Break & Excavate existing floor, cast new base, and allow for mounting plates to support Gantry Vertical Members.
6	**X-Travel rail:** Diameter 60 mm Rexroth shaft screwed onto rail.
7	**X-Travel Drive Bearing Mounting Plate:** 500 x 500 x 5 mm plate
8	**Timing Pulley:** At 20 - 90 Timing Puley
9	**5.5 kW Fanuc Servo Motor**
10	**X-Travel Drive Bearings:** SKF, UCF-208-40mm
11	**X-Travel Drive Gearbox:** 30.89 Ratio
12	**Joint (Coupling Tyre, 2 Flanges, & T/Lock):** FFX 90 Fenner Tyre & FX 80 Flange
13	**Drive Shaft:** Diam 60 mm
14	**Timing Belt:** At 20 - 75 Timing belt
15	**Vacuum Gripper Support:** 50 x 50 x 5 mm Rectangular Tubing.
16	**Timing Belt Clamp:** At 20-75 Clamp
17	**Timing Belt:** At 20 - 75 Timing belt
18	**Idle Roller:** Diam 40 x 60 mm
19	**Timing Pulley:** At 20 - 90 Timing Puley
20	**Bearings:** SKF; UCF - 208 - 40 mm
21	**Drive Shaft:**
22	**Support Plates:**
23	**Bogey Gearbox:** 25.62 Ratio; 45 rpm
24	**5.5 kW Fanuc Servo Motor**
25	**Gearbox Mounting Plates:**

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

4585392	Roller bed chain broken	QC04	Casper Erasmus	JW Moorcroft	1
4586299	Limit bracket broken off	QC04	Casper Erasmus	Danie Claasen	1
4586942	Production change	QC04	Casper Erasmus	Obert Maschame	.50
4587013	Aligment problem on rollerbed	QC04	Casper Erasmus	Danie Claasen	4
4587620	Make up new safety handrails	QC04	Mark de Beer	Piet Sebiloane	–
4590394	Change dust hose at QC4	QC04	Casper Erasmus	Lasi Sebuse	.50
4590992	Check north side cross travel	QC04	Desmond Njerere	Edwin Smal	1.50
4591004	Trolley gearbox loose	QC04	Casper Erasmus	Danie Claasen	1
4591012	Repair lights	QC04	Desmond Njerere		1
4591135	Repair & align roller bed	QC04	Desmond Njerere	Pontsho Mmakola	.25
4591143	Change dust hose	QC04	Casper Erasmus	Obert Maschame	.50
4591151	Weld bracket on linear shifter	QC04	Mark de Beer	Jaco Basson	1
4591400	Attend to rails at QC area	QC04	Mark de Beer	Piet Sebiloane	4
4593561	Fix mis-alignment	QC04	Casper Erasmus	Obert Maschame	.75
4594416	Monthly Insp on QC offloader E	QC04	Carel Homan		2
4594424	Monthly insp QC offloader - M	QC04	William Steven Moriarty		4
4595460	S/Check on QC offloader - M	QC04	William Steven Moriarty		.50
4595574	S/Check on QC offloader - E	QC04	Carel Homan		2
4596489	Attend to roller bed chain	QC04	Casper Erasmus	Obert Maschame	.75
4596569	Assist with production change	QC04	Casper Erasmus	Obert Maschame	.75
4597529	Size change	QC04	Casper Erasmus	Danie Claasen	.50
4597609	Change dust hose	QC04	Casper Erasmus	Danie Claasen	.50
4597908	Repair chain on rollerbed	QC04	Casper Erasmus	Jan Ehlers	1
4598986	Repair chain & sprocket on r/b	QC04	Casper Erasmus	Obert Maschame	1
4599276	Atend to flexi pipes by head 2	QC04	Casper Erasmus	Lasi Sebuse	.75
4600417	Check trolley out of rail	QC04	Casper Erasmus	Danie Claasen	.50
4600610	Call out to adjust 54 QC speed	QC04	Desmond Njerere	Sa Power Gauteng (Alrode)	–
4601815	Change dust hose	QC04	Casper Erasmus	Sinky Makgopa	.75
4605517	Attend to vacuum fan	QC04	Casper Erasmus	Obert Maschame	.50
4605525	Attend to chain	QC04	Casper Erasmus	Obert Maschame	.50
4605728	Chain on roller bed broken	QC04	Casper Erasmus	Danie Claasen	1
4607766	S/Check on QC offloader - M	QC04	Casper Erasmus		4
4607871	S/Check on QC offloader - E	QC04	Desmond Njerere		–
4609041	Check reject roller drive	QC04	Desmond Njerere	Gudani Dzhugudzha	.50
4609067	QC 4 machine is tripping	QC04	Desmond Njerere	Philip Dyantyi	.50
4609227	Check vac change at north side	QC04	Desmond Njerere	Gideon Strydom	1
4609243	Reset reject roller drive trip	QC04	Desmond Njerere	Thulani Mneuni	.50

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

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										
		1	2	3	4	5	6	7	8	TOTAL HRS	COUNT	%
1	Misalignment	0	0	0	1	0	0	0	1	2	2	0.340611
2	Trolley gearbox	1.5	1.5	2.25	0	0	0	0	0	5.25	3	0.894104
3	Rollerbed	20.25	10.5	47.5	8.5	11.75	5.75	7.5	8	119.75	85	20.39409
4	Electrical trip	2.5	0	0	0	0	0	0	0	2.5	2	0.425764
5	Vertical lift	1	7	32	7	8	0	0.5	5	60.5	40	10.30348
6	Lost Sequence	0	0	0	0	0	0	0	0	0	0	0
7	Liftbox	17.5	19.25	39.25	15.25	6.75	3.5	5	13.25	119.75	90	20.39409
8	Mechanical repairs	0.75	0	3.5	0	0	0	0	0	4.25	3	0.723798
9	Production change	0	0	0	1	0	0	0	2	3	2	0.510917
10	Air pipe	4.5	9.5	27.25	0	0.5	1.5	1	1	45.25	30	7.706325
11	Trolley / gearbox	1	1.5	4.25	1.25	3.5	1.75	0	0	13.25	13	2.256548
12	Conveyor	0	1	6	0	0	1	0.75	1	9.75	6	1.660479
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	3	0	1	1	20.75	14	3.53384
15	Lights	0	0	0	0	0	0	0	0	0	0	0
16	Trolley rails/trolley off rai	1	0	0	0	0	0	0	0.5	1.5	2	0.255458
17	Size change	0	0	0.5	0	0	0	0.5	1	2	4	0.340611
18	Electrical programming	12	0	5.5	0	1.5	0	0	0	19	7	3.235805
19	Vacuum fan	26.5	1.5	6	0	13.5	0	2.5	9	59	22	10.04803
20	Roller drive	1.5	0	0	0	0	0	0	0	1.5	2	0.255458
21	Squaring table	2.3	0.5	12.5	12	0.5	3.75	3	3	37.55	33	6.394973
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	6	1.53275
24	Compressed air line	0	1	5	7	1.13	0	1.5	1.5	17.13	29	2.917334
25	Tripped	2.5	0	1	0.5	0.5	0	0.5	0	5	6	0.851528
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	5	1.958514
29	REPAIR OFFLOADER	0	0	0	0	0	0	0	0	0	0	0
		110.05	60.75	209	55.5	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 1	2	3	4	5	6	7	8	9	10	11	TOTAL HRS	COUNT	%
1	Misalignment	7.75	0	3.83	2.5	0.5	1.5	0	3	0	0	3	22.08	20	5.37
2	Trolley gearbox	3	0.5	0	0	3	0	0	0	0	0	0	6.5	6	1.58
3	Rollerbed	10.25	9.34	4.5	2	8.5	11.5	3.5	11.25	0	1	2.33	64.17	50	15.61
4	Electrical trip	1.25	0.5	0	0.5	0	0	0	0	0	0	0	2.25	3	0.55
5	Vertical lift	1.5	1.5	7.83	5	4.25	1	0	4	0	0	0.5	25.58	14	6.22
6	Lost Sequence	1.58	0	0	0	0	0	0	0	0	0	0	1.58	1	0.38
7	Liftbox	12	6.5	4.83	13	7.75	1	2	6	1	1	4.5	59.58	52	14.50
8	Mechanical repairs	1.5	0	0.5	0.5	2	0	0	12	0	0	0.25	16.75	9	4.08
9	Production change	1	0.75	0	0	0.5	0.33	0	2.25	0	0.5	0	5.33	9	1.30
10	Air pipe	5.5	5.25	3.25	5.25	15	0	0	6.25	0	2.5	6.25	49.25	60	11.98
11	Trolley / gearbox	0.75	1	5.25	5.25	1	3	3.75	11.75	0	3	1.5	36.25	29	8.82
12	Conveyor	2	0	0	0	0	0	0	0	0	0	0	2	1	0.49
13	Limit mechanical	1	0	0	0	0	0	0	0	0	0	0	1	1	0.24
14	Offloader Cross travel -	1.5	0	0	0	1	1	0	0	0	0	0	3.5	3	0.85
15	Lights	1	0	0	0.75	0	0	0	0	0	0	0	1.75	2	0.43
16	Trolley rails/trolley off	4	0	0.92	0	1.25	0	0	0	0	0	0	6.17	5	1.50
17	Size change	0	1.5	0	0.5	1.5	1	1	3.75	1	0	2	12.25	19	2.98
18	Electrical programming	0	0	1.83	0	0	0	0	1.5	0	0	0	3.33	4	0.81
19	Vacuum fan	0	0.5	2	0	1.5	0	2	0	0	2.5	7	15.5	15	3.77
20	Roller drive	0	2	0	0	0	0	0	0	0	0	0.5	2.5	4	0.61
21	Squaring table	0	1	0	3.34	2.5	1.5	0.75	8.08	3	0.5	2.5	23.17	26	5.64
22	Offtake-taperlock	0	3	0	0	0	0	0	0	0	0	0	3	1	0.73
23	??	0	0.75	4.75	0.33	0.5	0	0	0	0	0	0	6.33	6	1.54
24	Compressed air line	0	1	3	0	0	0	0	0	0	0	0	4	4	0.97
25	Tripped	0	0	2	0	1	0.16	0	1	0	0	0	4.16	6	1.01
26	Cross travel	0	0	2.25	0	0	0	0	4	6	0	0	12.25	9	2.98
27	No. 2 pulley gearbox	0	0	0.5	0	0	0	0	0	0	0	0	0.5	1	0.12
28	Electrical parts	0	0	0	0.67	5.08	0.75	0.5	13.25	0	0	0	20.25	18	4.93
29	Repair offloader	0	0	0	0	0	0	12	0	0	0	0	12	1	2.92
		55.58	35.09	47.24	39.59	56.83	22.74	25.5	88.08	11	11	30.33	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.

		OLD QC 8 MONTHS			NEW QC 11 MONTHS			% CHANGE
	BREAKDOWN	TOTAL HRS	COUNT	AVE HRS/ MONTH	TOTAL HRS	COUNT	AVE HRS/MONTH	
1	Misalignment	2	2	0.3	22.08	20	2.0	803%
2	Trolley gearbox	5.25	3	0.7	6.5	6	0.6	90%
3	Rollerbed	119.75	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	0	0	0.0	1.58	1	0.1	NEW
7	Liftbox	119.75	90	15.0	59.58	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	129%
10	Air pipe	45.25	30	5.7	49.25	60	4.5	79%
11	Trolley / gearbox	13.25	13	1.7	36.25	29	3.3	199%
12	Conveyor	9.75	6	1.2	2	1	0.2	15%
13	Limit mechanical	18	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	1.5	2	0.2	6.17	5	0.6	299%
17	Size change	2	4	0.3	12.25	19	1.1	445%
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	1.5	2	0.2	2.5	4	0.2	121%
21	Squaring table	37.55	33	4.7	23.17	26	2.1	45%
22	Offtake-taperlock	0	0	0.0	3	1	0.3	NEW
23	??	9	6	1.1	6.33	6	0.6	51%
24	Compressed air line	17.13	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	0.5	1	0.0	NEW
28	Electrical parts	11.5	5	1.4	20.25	18	1.8	128%
29	REPAIR OFFLOADER	0	0	0.0	12	1	1.1	NEW
		587.18	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.

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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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