Evaluating Maintenance Strategies Effectiveness on Overall Equipment Utilization

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Abstract

The performance and competitiveness of manufacturing companies is dependent on the reliability, availability and productivity of their facilities. To ensure the plant achieves the desired performance, maintenance managers need a good understanding of the effectiveness of different maintenance systems. The company understudy had been experiencing frequent breakdowns of critical machines and this, negatively affected productivity. The researchers set objectives to establish the causes of machine breakdown, determine the level of plant utilization and availability, evaluate the percentage of sales lost due to downtime and determine the level of mean time to repair (MTTR). The hypothesis tests developed were based on the mentioned objectives as the major indicators of maintenance effectiveness. Direct observations, structured interviews and company records were used to collect data. Microsoft excel, and megaStat were used for data analysis. The results came double folded indicating breakdown maintenance not effective as it under-utilized the plant's equipment, lowered plant availability, decreased the sales and increased the level of mean-time to repair (MTTR). The researchers developed and recommended an effective reliability centred maintenance (RCM) decision diagram as a major contributor to equipment availability and reliability and productivity improvement for the company.

Keywords: Maintenance, Equipment Utilization, Effectiveness, Maintenance Strategies

1. Introduction

An evaluation of the effectiveness of maintenance strategies on overall equipment utilization has been a challenge due to factors such as size, cost, complexity, and competition. Needless to say, today's maintenance practices are market driven especially in the manufacturing and process industries were competition continues to be the driving force. The performance and competitiveness of manufacturing companies is dependent on the reliability and productivity of their production facilities (Coetzee, 1997; Madu, 2000, Fleischer et al .., 2006). This need to improve the production system's performance has bought the maintenance function in the limelight.

Many companies are seeking to gain competitive advantage with respect to cost, quality services and on-time deliveries and indeed there is a consensus among authors (Madu, 1999; Cooke, 2000; Madu, 2000) that equipment maintenance and system reliability are important factors that affect the organization's ability to provide quality and timely services to customers and to be ahead in competition. The effect of maintenance on these variables (Dunn, 2002) has prompted increased attention to the maintenance area as an integral part of productivity improvement. Maintenance is rapidly evolving into a major contributor to the performance and profitability of manufacturing systems.

Maintenance is defined as a combination of all technical and associated administrative activities required to keep equipments, installations and other physical assets in the desired operating condition or restore them to this condition (BSI, 1984; Pintelon et al., 1997; Pintelon and VanPuyvelde, 2006). Charged with this responsibility of ensuring that the plant achieves the desired performance, maintenance managers need a good understanding of the effectiveness of maintenance systems on overall equipment utilization.

The company under study is a manufacturing company specialized in the manufacturing of polypropylene (PP) woven sacks, and laminated block bottom bags as cement and lime packaging materials. The company produces both industrial and domestic PP woven sacks for the local companies as well as for exporting. The maintenance strategies used in the maintenance of the various equipments have had a negative and positive impact on the productivity of the company. The increase in the demand for the products has also affected equipment maintenance therefore, the company had been experiencing frequent machine breakdowns that often disrupted production operations and ultimately affected customer needs in terms of delivery. According to (Fore. S and Zuze L; 2010) the presence of an effective maintenance system helps an organisation to increase machine availability, reduce production downtime, production losses and overtime costs therefore it was important for this research to be carried out as it would result in the above mentioned benefits. It has also been noted by (Muchiri and Pintelon; 2008) that the competitiveness of manufacturing companies depends on the availability and productivity of their production facilities and this can only be possible if the production losses are identified and eliminated so that the manufacturers could bring their products to the market at a minimum cost and on time. Thus it was imperative that an evaluation of the effectiveness of maintenance systems be conducted on the different important elements of performance indicators for maintenance processes.

2. Theoretical and Conceptual Frame-Work

According to (Wardhaugh and Jim 2004)) the importance of selecting a range of maintenance key performance indicators (KPI) lies on picking the ones that will improve both equipment reliability and maintenance performance and not simply indicate problems in your business. The researchers therefore developed a conceptual framework to study the KPIs (see figure 1) on the effectiveness of maintenance systems. The hypotheses were then formed on these KPIs in order to achieve the research objectives.

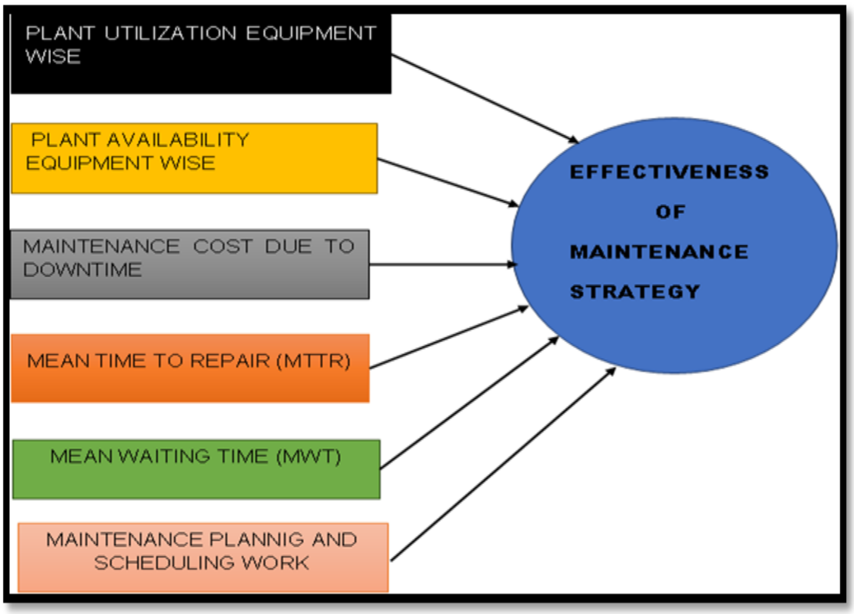

Figure 1: Conceptual frame-work

By applying the scientific maintenance method to prove if a maintenance action will produce a desired reliability outcome, useful KPIs are created to drive proactive maintenance performance that will permanently fuse into a business to increase the effectiveness of the maintenance systems (Priel, 1974). Therefore, in this research, the theories on the KPIs were based on the research on maintenance effectiveness KPIs measuring scale developed and analysed by (Wardhaugh & Jim, 2004; Priel, 1974).

2.1 Plant Utilization Equipment Wise

Plant utilization equipment wise is a key performance indicator (KPIs) in evaluating the effectiveness of maintenance strategy in that, the higher the percentage of plant utilization equipment wise for production, the more effective the maintenance strategy and vice-versa.

2.2 Plant Availability Equipment Wise

Availability of a machine is a key performance indicator (KPI) in evaluating the effectiveness of the maintenances strategy in the sense that the higher the percentage of plant availability equipment wise for production, the more effective the maintenance strategy and vice-versa.

2.3 Maintenance Cost Due To Downtime

Maintenance cost due to downtime is a key performance indicator (KPIs) in evaluating the effectiveness of maintenance strategy and the lower the total maintenance cost due to downtime, the more effective the maintenance strategy.

2.4 Mean Time To Repair (MTTR)

Mean time to repair is accounted as a key performance indicator (KPIs) in evaluating the effectiveness of maintenance strategy, in that, the shorter the mean time to repair, the more effective the maintenance strategy.

2.5 Mean Waiting Time

Increased mean waiting time (MWT) helps management in identifying the areas for improvement such as organizing of trade force or improving the stores systems & procedures or improving the spare part control systems therefore, MWT was also a key performance indicator (KPIs) in evaluating the effectiveness of the maintenance strategy in the sense that, the shorter the MWT for material, spare parts or labour, the more effective the maintenance strategy.

2.6 Effectiveness of Maintenance Planning

Scheduling was considered to be a key performance indicators (KPI) in evaluating the effectiveness of the maintenance strategy for this research as it shows the total number of hours that have been planned to restore the equipment or machine to its operational conditions and also the amount of maintenance work that have been completed within that scheduled time.

3. Hypothesis Development

The researchers' developed the following hypothesis tests to explain and interpret the relationship between maintenance effectiveness evaluating factors and the effectiveness of the maintenance strategies on overall equipment utilization.

3.1 Plant utilization equipment wise

H_0: Not more than 90% is plant utilization equipment wise in the observed period.
H_a: More than 90% is plant utilization equipment wise in the observed period.
H_0: $P \leq 0.90$ not effective
H_a: $P \geq 0.90$ effective
If p-value is less than α=0.05, reject the Null hypothesis.

3.2 Plant availability equipment wise

H_0: Not more than 90% is plant availability equipment wise for production in the period.
H_a: More than 90% is plant availability equipment wise for production in the period.
H_0: $P \leq 0.90$ not effective
H_a: $P \geq 0.90$ effective
If p-value is less than α=0.05, reject the Null hypothesis.

3.3 Maintenance cost/lost sales due to downtime

H_0: maintenance cost is more than 10% of the budgeted total revenue in the period.
H_a: maintenance cost is less than 10% of the budgeted total revenue in the period.
H_0: $P \geq 0.10$ not effective
H_a: $P \leq 0.10$ effective
If p-value is less than α=0.05, reject the Null hypothesis.

3.4 Mean time to repair (MTTR)

H_0: MTTR is more than one hour/breakdown in the observed period for each machine.
H_a: MTTR is less than one hour/breakdown in the observed period for each machine.
H_0: $\mu \geq 1$ hour not effective
H_a: $\mu \leq 1$ hour effective
If p-value is less than α=0.05, reject the Null hypothesis.
In this research paper, the plant utilization for the company was set at the level of 90% and above, plant availability was set at the level of 90% and above, the cost of maintenance/lost sales due to downtime was set at 10% or less

of the total sales and finally the level of MTTR was set at one hour per breakdown. The entire hypotheses were tested at 95% confidence level.

4. Methodology

A conceptual research design was adapted for this research. Quantitative and qualitative approaches were used in the analysis of the data that was collected using on site observations and personnel interviews. Under on-site observations, the researchers visited the plant and directly observed and monitored the processes of physical activities. Machine operating time and the effectiveness of the operators on failure identification were observed. Under personal interviews, face to face interviews were conducted with the Plant Manager, the Engineering maintenance supervisor, the Production Manager and a small group of employees in the maintenance department in order to obtain information on maintenance systems with particular attention on the, maintenance procedures, how maintenance personnel scheduled their work, and how repairs were done. The accountant department was also interviewed to obtain information regarding the cost of the scheduled maintenance work and the selling price per bag.

A sample size that was used in this research was taken in form of the period in days. In a period of eight months a sample of 200 days was taken. An evaluation of the effectiveness of the maintenance strategies based on a population of the fifteen (15) machines in the plant was then conducted.

The data was analysed using Microsoft Excel, manual calculations and Statistical package for software (SPSS) MegaStat was used to test and prove the hypothesis.

5. Results

5.1 Equipment Availability

The company comprised of fifteen (15) machines, one extruder, laminating machines, six (6) looms, printing machine, slitex machine, convertex machine, two bag maker machines, recycling machine and air compressor. From the data that was collected in terms of the type of maintenance systems used, breakdown maintenance was predominant therefore its effectiveness was evaluated. The results also reviewed that, the maintenance department did not have maintenance schedules, no backup spares and the maintenance department had no order in which spare parts were replenished. Table 1 is a summary of the figures used in the analysis of the data.

Table 1: Summary of Figures used in Data Analysis

Budgeted number of bales/output per day/shift	1,000 bales
Quantity per bale/output	500 bags/bale
Number of days observed in the period	200 days
Total hours during the period	2000 hours
Working hours per day/shift	10 hours
Actual bales/outputduring the period (646.5 bales* 200days)	129,300 bales
Budgeted bales/output during the period (1,000 bales*200days	200,000 bales
Bales/output per hour (1,000bales/10hours)	100 bales/hour
Bags per hour (100bales/hour * 500bags/bale)=	50,000 bags/hour
Selling price per bag	K 2.5/ bag

From the analysis of the data collected on causes of machine breakdown and down time, this is illustrated in table 2.

Table 2: Causes of machine breakdown

Machine name	Reason for breakdown	Counter measure
EXTRUDER	Due to weak suction and suction outlet broken	Replace the missing unit
LAMINATING	Due to rubber roller stiff and rubber roller bearing ceased	Replace the bearing
SLITEX	Due to chain holder broken, weight of the chain and machine design	Hold back the chain holder
PRINTING	Separation of rubber and its holder (shaft)	Replace the rubber roller with a new one
CONVERTEX	Jamming in the delivery unit and belt lost its position	Proper adjustment of the chain and belt
AIR COMPRESSOR	No diesel and filling diesel	Put more diesel
BAG MAKER 1	Knife blades not cutting and long- time use	Remove knife blades and take for sharping
BAG MAKER 2	Blades come out of position and sweeping sensor not flashing	Remove and clean the sensor
RECYCLE	Shaft moving on one side and bearing worn out	Replace the bearing
LOOM 1	Bearing worn out and stiff bearing	Stop the machine and blow
LOOM 2	Increased load or loose connection	Replace 20A mcb
LOOM 3	Bronze bush worn out and friction between solid pin and bronze	Implement PM and TBM
LOOM 4	Swinging lever worn out and friction between lever and pin	Replace the lever
LOOM 5	Friction and wear out of the belt	Implement PM and TBM
LOOM 6	Swinging lever worn out and	Implement PM and TBM

5.2 Plant Utilization Equipment Wise

Table 3 illustrates how the total available hours analysed during the period was divided into two categories, total machine running time during the period and total downtime during the period. The table also shows the actual number of bales produced, the number of bales lost due to breakdown and the budgeted number of bales during the period.

Table 3: Plant utilization values

Total machine running time in the period	Total downtime in the period	Total available hours in the period	Actual bales produced in the period100 * 1293	Lost bales due to breakdown 100 * 707	Budgeted bales in the period 100 * 2000
1,293 hours	707 hours	2,000hours	129,300 bales	70,700bales	200,000bales

5.3 Plant Availability Equipment Wise

Table 4 illustrates how the total available hours in the period were analysed and categorised into total machine running time, total non-productive time and total machine breakdown time in the period. The values shown in the table are used to calculate plant availability in the stated period.

Table 4: Plant Availability Values

Total machine running time	Total non-productive time	Total time for machine breakdown in the period	Total available time in the period
1,293 hours	88 hours	619 hours	2,000 hours

5.4 Maintenance Cost Due To Downtime

Table 5 illustrates how the total downtime lost due to breakdown was converted into the total sales revenue lost in the observed period. The table also includes; the number of bags produced per hour, the selling price per bag, and the total budgeted sales revenue in the observed period.

Table 5: Lost sales due to downtime

Total observed hours in the period(A)	Total down time in the period (B)	Number of bags produced per hour (C)	Selling price per bag in kwacha (k) (D)	Total sales revenue lost due to break down(k) B*C*D	Total budgeted sales revenue in the period (K) A*C*D
2,000 hours	707 hours	50,000 bags	K2.5/bag	**K88,375,000**	**K250,000,000**

5.6 Mean Time To Repair (MTTR)

Table 6 illustrates how the mean time to repair was determined for each machine within the observed period and it also includes the number of breakdowns per machine and the total repair time in hours during the observed period.

Table 6: Meantime to Repair per Machine

Machine name	Total repair time per machine in the period (A)	Number of break downs/machine (B)	Meantime-to repair/machine MTTR=A/B
Extruder	64.8 hours	24	2.70
Laminating	77.6 hours	32	2.425
slitex	97.6 hours	32	3.05
printing	78.4 hours	24	3.266
Convertex	48.0 hours	16	3.00
Bag maker 1	79.2 hours	32	2.475
Bag maker 2	58.4 hours	24	2.433
Air compressor	124.8 hours	40	3.12
recycling	70.4 hours	24	2.833
Loom 1	60.0 hours	24	2.5
Loom 2	87.2 hours	32	2.725
Loom 3	163.2 hours	24	6.8
Loom 4	68.8 hours	24	2.866
Loom 5	34.4 hours	16	2.15
Loom 6	71.2 hours	24	2.963
Total for all period	**1184 hours**	**392**	**45.306**

The company has a targeted MTTR of one hour (1 hr) per breakdown for each machine. However, as we can see from the table 6 above, the MTTR for each machine or rather per breakdown is greater than the targeted of one hour per breakdown. (See Table 7) it shows a summary of the level of overall MTTR.

Table 7: A summary of the calculation of the level of overall MTTR

Total time to repair in the period in hours	Total number of breakdowns in the period	Total number of machines observed in the period
1184 hours	394 breakdowns	15 machines

6. Discussion

From the calculations done, it was clearly evaluated that the plant utilization equipment wise was under-utilized. The total budgeted production in bales during the period of the research, only 64.7% was produced whilst the **35.3%** of the production was lost due to machine breakdown. Thus, in relation to the hypothesis test for proportion developed the researchers concluded that the maintenance strategy employed was breakdown maintenance and it was not effective as it resulted in under-utilization of the plant. Further analysis of the output of the hypothesis test for proportion of plant utilization equipment wise, the p-value was equal to 1.00 which was greater than α=0.05. This implied that there was a big difference between the observed percentage and the standard percentage set by the company. Therefore, the researchers did not reject the null hypothesis. At 95% confidence level the researchers did not have strong evidence against the null hypothesis to conclude that the breakdown maintenance strategy employed was effective.

From the calculation, it was clearly evaluated that the percentage of plant availability equipment wise was low. Of the total available production hours in the period, the plant was only **69.1%** available for production whilst the

30.9% of the total available production hours was lost due to machine breakdown during the period. Thus, in relation to the hypothesis test for proportion developed, the researchers concluded that the maintenance strategy employed was not effective as it resulted into a low percentage of plant availability equipment wise. Figure 2 illustrates the level of plant availability in hours per month. This indicated that the level of plant availability was decreasing as we moved from one month to the other due to increased downtime, and this had negative effect on the level of production.

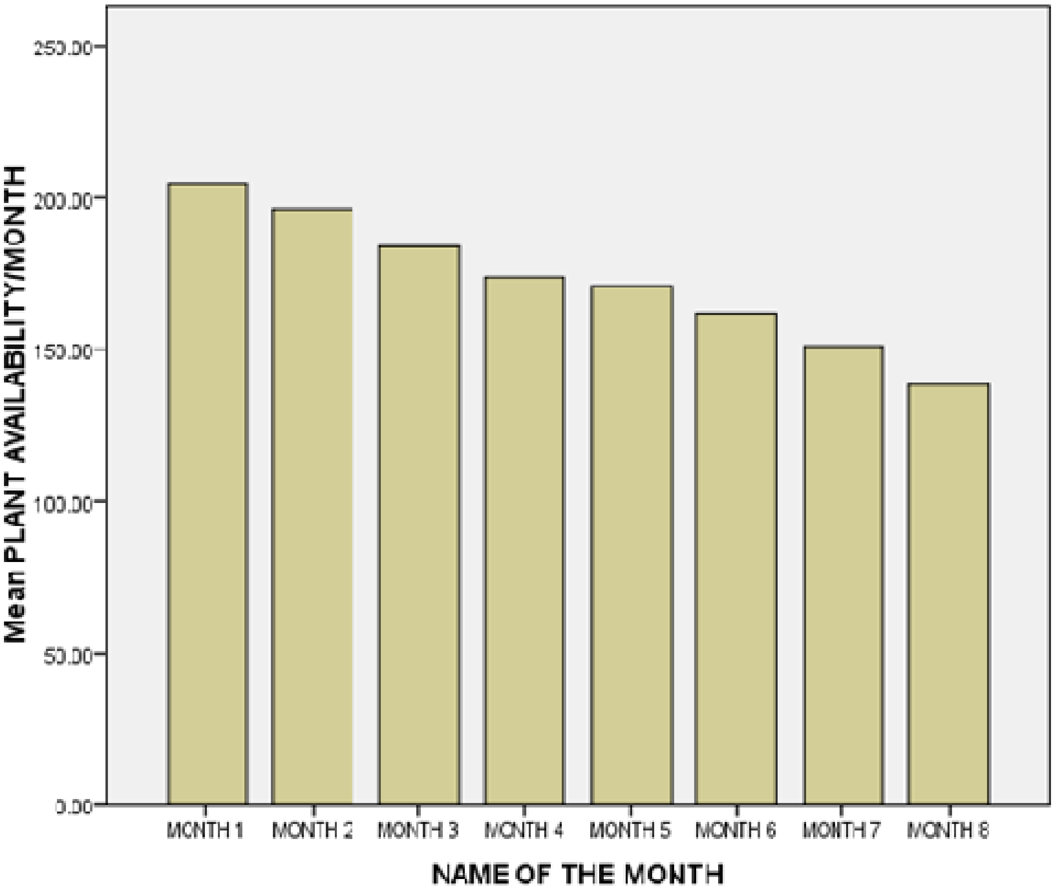

Figure 2: Plant availability per month in hours

The output of the hypothesis test for proportion of plant availability equipment wise during the observed period, the p-value was equal to 1.00 which was greater than α=0.05. This implied that there was a big difference between the observed percentage of plant availability and the standard percentage set by the company. Therefore, the researchers did not reject the null hypothesis. At 95% confidence level the researcher did not have strong evidence against the null hypothesis to conclude that the breakdown maintenance strategy employed was effective.

With reference to table 5 and the calculation, it was determined that the percentage of lost sales/revenue due to machine breakdown in the observed period was very high. This implied that, of the total budgeted sales revenue K250, 000,000, K88, 375, 000 was lost due to machine breakdown. Therefore, in relation to the hypothesis test for proportion developed, the researchers concluded that the maintenance strategy in place was not effective as it decreased profit/revenue. Figure 3 below clearly illustrates the level of lost sales/revenue per month. As can be seen the height of the bars was increasing from month one to month eight. This indicated that the level of lost sales/revenue per month was increasing from month one to month eight. This was attributed to increased downtime from one month to another which negatively affected the level of production.

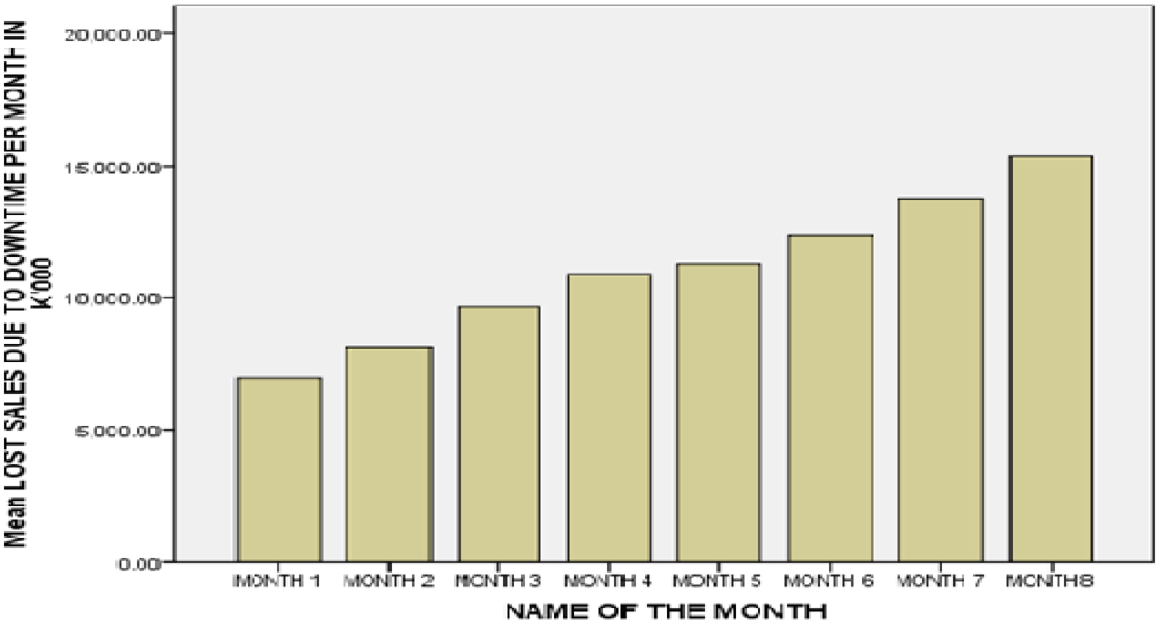

Figure *3:* The level of lost sales due to downtime per month

From the output of the hypothesis test for proportion of maintenance cost due to downtime during the observed period, the p-value was equal to 1.00 which was greater than α=0.05. This implied that there was a big difference between the observed percentage of lost sales and the standard percentage set by the company. Therefore, the researchers did not reject the null hypothesis. At 95% confidence level the researchers did not have strong evidence against the null hypothesis to conclude that the breakdown maintenance strategy employed was effective. With reference to the figures in the table 7 and the calculation above, it was determined that the level of MTTR was very high compared to targeted one set by the company. This implied that, the targeted level of MTTR was three times less than the actual MTTR per breakdown in the period. This was as a result of a number of unskilled and untrained maintenance personnel, fitters, and operators. Thus, in relation to the hypothesis test for the level of MTTR developed, the researchers concluded that, the breakdown maintenance strategy was not effective as it resulted in increased level of MTTR. The output of the hypothesis test for mean verses hypothesised value of the level of MTTR during the observed period, p-value was equal to 1.00 which was greater than α=0.05.This implied that there was a big difference between the observed MTTR and the hypothesised MTTR. Therefore, the researchers did not reject the null hypothesis. At 95% confidence level there was no strong evidence against the null hypothesis to conclude that the breakdown maintenance strategy employed was effective.

7. Conclusion

The maintenance system employed was breakdown maintenance and it was determined that a number of machine breakdown were due to ineffective maintenance system. The plant utilization was found at the level of 64.7%, in comparison with the established level of greater than or equal to 90%, the researcher concluded that the breakdown maintenance strategy was not effective as it under-utilized the plant. The plant availability equipment wise was found at the level of 69.1%, in comparison with the established level of greater than or equal to 90%, the researcher concluded that the breakdown maintenance was not effective as it resulted into low percentage of plant availability equipment wise. The maintenance cost was found at the level of 35.35% of the total budgeted sales in the period, in comparison with the established level of maintenance cost of less than or equal to 10% of the total sales, the researchers concluded that the breakdown maintenance is no effective as it decreased/minimized profit/sales. The mean time to repair (MTTR) was found to be at the level of 3.0204 hours per breakdown, however, in comparison with the established or targeted level of less than or equal to one (1) hour per breakdown, the researcher concluded that the breakdown maintenance was not effective because it resulted into increased MTTR. For production plant to operate smoothly, machinery should be available when needed. Thus, it is important to have effective maintenance strategies that would enable machine availability. Based on the foregoing conclusions, the researchers recommended the developed reliability centered maintenance (RCM) maintenance model (see figure 4) for the different types of equipment with respect to their critical, non-critical, subject to wear-out, and not subject to wear-out.

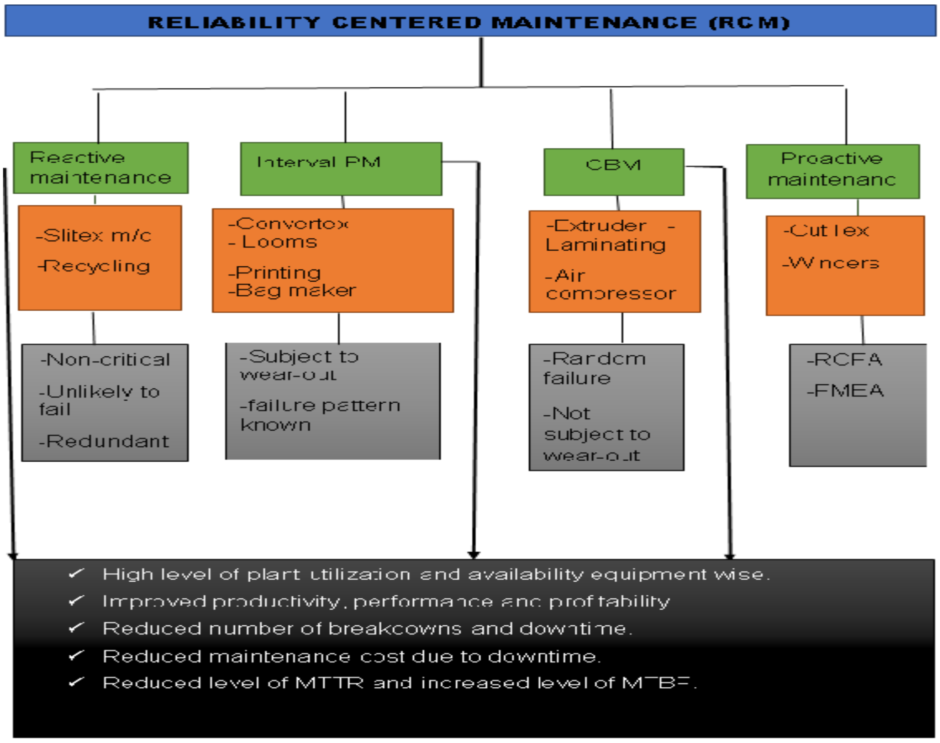

Figure 7: Developed RCM maintenance decision model.

The above effective maintenance decision diagram could be a major contributor to productivity improvement, performance and profitability of manufacturing system as far as the overall equipment utilization is concern..

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