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Design of a total productive maintenance model for effective implementation: Case study of a chemical manufacturing company

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Abstract

In today's industries, the concept of Total Productive Maintenance (TPM) has been widely accepted and implemented yet it's still possible to find industries facing maintenance challenges. The focus of this paper was to develop an effective TPM model to improve the maintenance system at a chemical manufacturing company in Zambia. The researchers set objectives to assess the current maintenance system, to determine the overall equipment effectiveness and to identify key performance indicators and success factors of TPM. Data relevant to the research was collected using designed questionnaires, structured interviews, direct observations and company records. The results of the research came double folded by reviewing that, the maintenance department employed 67.6% breakdown maintenance, 24.3% preventive maintenance and 8.1% not applicable. The research also reviewed that 78% of the time the operators were not involved in maintenance activities with only 14% operator involvement. As regards to the effectiveness of the maintenance technique(s) used, 19% was recorded poor, 65% fair, 8% good and 8% not applicable. Overall equipment effectiveness (OEE) was calculated at 37% which was below the world class standard by 50%. Equipment downtime was a major cause of plant under utilization with 52% caused by shortage of spares, 32% shortage of raw materials, 8% due to power problems and 8% not applicable. TPM awareness deduced 70.5% of the employees been aware of the TPM concept while 14.7% indicated the concept of TPM would help improve the current maintenance system and 14.7% were not sure. 29.5% of the employees were not aware of TPM with 64.3% not sure that the TPM concept can help improve the current maintenance system. Based on these results, knowledge and information sharing, operator involvement and training should be considered. The researchers then designed a TPM model which would result in effective implementation of TPM for higher competitiveness in the dynamic business environment.

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1. Introduction

Total Productive Maintenance (TPM) is a productivity improvement practice analogous to the use of total quality management (TQM), [1] while [2] describes it as a Japanese concept of equipment management that allows a facility to improve decisively the equipment performance in the manufacturing area with the help and involvement of all employees. Nakajima [3] concludes that TPM activities focus on eliminating the six major losses; equipment failure, set-up and adjustment time, idling and minor stoppages, reduced speed, defects in process and reduced yield. According to [4], the objective of TPM is to continuously improve the availability and prevent the degradation of equipment to achieve maximum effectiveness and these objectives require strong management support as well as continuous use of work teams and small group activities to achieve incremental improvements. TPM is analysed into three words;

- **Total:** This means every individual in the company, from top management level to the shop floor workmen level.
- **Productive:** This means no wasted activity or the production of goods and services that meet or exceed customer's expectation.
- **Maintenance:** keeping equipment and plant in good working order i.e. in as good as or better than the original condition at all times.

TPM is designed to maximize equipment effectiveness (improving overall efficiency) by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields (planning, use, maintenance, etc.) and, with the participation of all employees from top management down to shop-floor workers, to promote productive maintenance through motivation management or voluntary small-group activities [5]. The company under study is a manufacturer of fertilizer products. It manufactures and supplies the following products; anhydrous ammonia, ammonia solution, liquid carbon dioxide, liquid oxygen, methanol, nitric acid, sulphuric acid, NPK compound fertilizers, ammonium fertilizer, ammonium sulphate and porous ammonium nitrate. As a result of a poorly integrated maintenance system, the company had been experiencing high rate of equipment breakdowns, prolonged downtime and therefore reduced equipment utilization. The significance of this paper was to develop a TPM implementation model for the company in order to improve the organization performance through reduced equipment breakdowns. According to [6], a positive strategic outcome of TPM implementations is the reduced occurrence of unexpected machine breakdowns, which ultimately results in enhanced profits in the organization while [7] and [8] recommend four key components for successful implementation of TPM in an organization as: worker training, operator involvement, teams and preventive maintenance.

Maintenance has been largely considered as a support function which is non-productive since it does not generate cash directly. However for an industry to produce goods of the right quality and right quantity for the customers and able to deliver them at the right time, its plant or equipment must operate efficiently and accurately [9]. The purpose of this paper was to assess the existing maintenance system of the company, determine the current overall equipment effectiveness (OEE) and determine the key performance indicators and success factors of TPM to be incorporated in the model for effective implementation.

2. Methodology

2.1. Research design and approach

An explanatory research design was employed as the research involved an in-depth understanding of TPM on topics such as the implementation plan, TPM modes, challenges and benefits of TPM implementation and finally TPM key performance indicators. The researchers employed both a quantitative and qualitative approach to assess the maintenance systems, determine the key performance indicators and to calculate OEE. Collected data was analyzed using SPSS.

2.2. Data collection

Research data was collected using designed questionnaires, interviews, company records and direct observations.

2.2.1. Interviews

Interviews were conducted with the maintenance personnel, operators and other employees outside the maintenance and production departments. The researchers focused on the following;

- Type of losses the company experienced
- Causes of maintenance problems
- Whether the TPM concept existed in the company
- Factors that can facilitate the implementation of TPM

2.2.2. Direct Observations

The researchers observed the maintenance and production activities. They observed how the inspection and lubrication activities were conducted. Direct observations enabled the researchers collect data without relying on the respondents’ willingness and abilities.

2.2.3. Questionnaires

A total of 40 employees were sampled out of 160 employees using stratified sampling method. A sampling intensity of 25% was used as it minimizes the sampling error. According to [10] 25% sampling intensity is recommended and acceptable for selecting samples from each population. The representative sample was based on Boyd formula, (see equation 1).

$$\frac{n}{N} \times 100 = c \tag{1}$$

Where;

C = represents a figure greater or equal to 5% of the target population.

N= overall population

n = sample size

Determined Sample size:

$$\begin{aligned} \frac{n}{N} \times 100 &= c \\ n &= 160 \times 25/100 \\ n &= 40 \end{aligned}$$

3. Results

The research data was collected using designed questionnaires, structured interviews, company records and direct observations. This data was then analyzed using SPSS and Microsoft excel.

3.1. Maintenance techniques

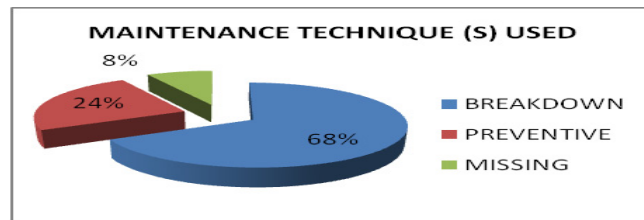


Fig. 1. Maintenance technique(s) used

Fig. 1. above shows the maintenance techniques employed in the company. 67.6% breakdown and 24.3% preventive maintenance (inspection, lubrication and change of oils) and 8.1% of the responses were not applicable.

The data was collected using questionnaires distributed in the maintenance department. This data was then analyzed using SPSS.

3.2. Operator involvement in maintenance activities

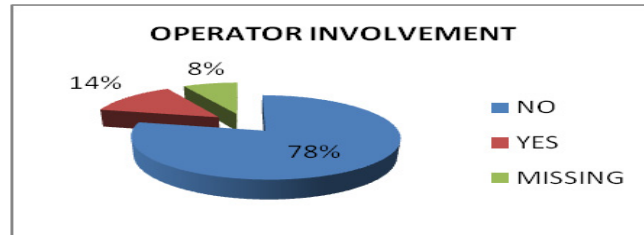


Fig. 2. Operator involvement in maintenance work

Fig. 2. depicts the results from the assessment of whether operators were involved in maintenance activities. The results showed that, 78% of the respondents indicated operators were not involved in maintenance activities. The reasons for their lack of involvement were; lack of appropriate knowledge and skills for maintenance, specialization, unwillingness to take more responsibilities and the prevailing culture in the company. 14% of the respondents indicated operators were involved in maintenance activities. Reasons for their involvement were; operators understand the operation of the equipment better than the maintenance personnel thus detect abnormalities easily and earlier than the maintenance personnel.

3.3. Effectiveness of maintenance techniques

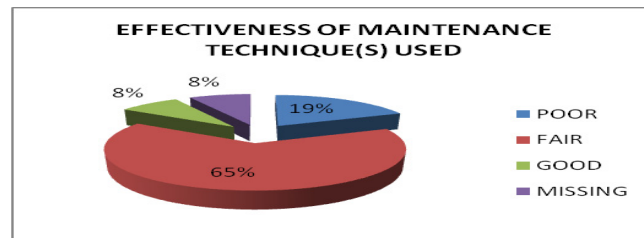


Fig. 3. Effectiveness of maintenance techniques

After data analysis of the designed questionnaires obtained from the respondents, Fig. 3. shows the results of the effectiveness of the maintenance technique(s) used, 19% of the respondents indicated poor, 65% fair, 8% good and 8% of the responses were not applicable. The significance of this question was to understand how effective the maintenance technique(s) are in achieving the maintenance objectives such as process performance and productivity performance.

3.4. Overall equipment effectiveness

Using direct observations and interviews, data related to the six major losses in TPM was collected and used in the computation OEE. The SIX Big Losses as per the TPM concept were identified and grouped with their OEE factor and OEE Loss category (Table1).

Table 1. Six Big Losses and Their OEE Factors

SI No.	OEE		Six Big Loss Category
	Factor	Loss Category	
1	Availability Ratio	Down Time Loss	Breakdowns
			Setup and Adjustments
2	Performance Ratio	Speed Loss	Small Stops
			Reduced Speed
3	Quality Ratio	Quality LOss	Start-up Rejects
			Production Rejects

3.4.1. Availability ratio

Availability takes into account Down Time Loss, which includes any events that stop planned production for an appreciable length of time (usually several minutes – long enough to log as a trackable event). Examples include equipment failures, material shortage and changeover time is included in OEE analysis, since it is a form of down time.

$$\text{Availability} = \frac{\text{Total time} - \text{Total downtime} \times 100}{\text{Total time}} \quad (2)$$

Table 2. Planned Production Time and Equipment Downtime

Month	Planned Production Time (Hrs)	Downtime (Hrs)	Downtime Percentage (%)
April	480	155.52	32.4
May	744	200.88	27.0
June	720	153.40	21.32
July	744	151.32	20.34
August	744	174.25	23.42
September	720	190.76	25.64

Using the data in table 2, the availability ratio was calculated at 0.748 (74.8%).

3.4.2. Quality Rate

Quality takes into account Quality Loss, which accounts for produced pieces that do not meet quality standards, including pieces that require rework. The remaining time is called Fully Productive Time. The ultimate goal is to maximize fully productive time.

$$\text{Quality rate} = \frac{\text{Good Pieces} \times 100}{\text{Total Pieces}} \quad (3)$$

Table 3. Off Specification Products

Month	Off Specification	Off Specification Percentage (%)
April	1,080	10.4
May	1,808	12.8

June	2,670.9	14.5
July	4,172	20.9
August	2,195	12.9
September	2,103.2	13.4

Using the data in table 3, quality rate was calculated at 0.872 (87.2%).

3.4.3. Performance efficiency

Performance takes into account Speed Loss, which includes any factor that causes the process to operate at less than the maximum possible speed, when running. Examples include machine, substandard materials.

$$PE = \frac{\text{Total Actual amount of product} \times 100}{\text{Target amount of product}} \quad (4)$$

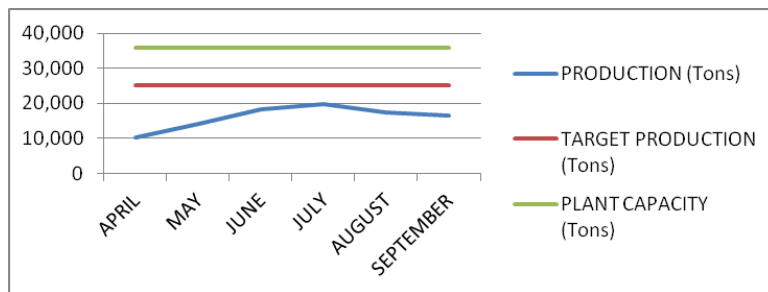


Fig. 4. Monthly production levels

Analysis of Fig. 4 shows that from April to July the production levels had been increasing at a steady rate and then after the month of July the levels started decreasing. Over a 6 month period the company had failed to achieve its monthly target production level and both the target production/ actual production was far below the plant capacity. The low production output was caused by different factors such as unplanned stoppages of the machines caused by the shortage of spare parts, shortage of raw materials and others. Using the data in Fig. 4., the performance ratio was calculated at 0.557(55.7%).

3.4.4. Overall Equipment Effectiveness (OEE)

Overall equipment effectiveness = Availability ratio x Performance Ratio x Quality Ratio.
 Actual Plant OEE = 0.749 × 0.56 × 0.87 = **0.365 (36.5%)**

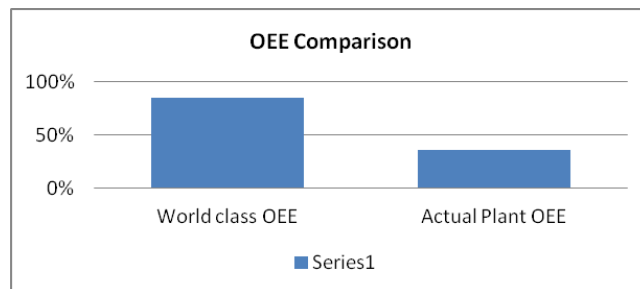


Fig. 5. Comparison of plant OEE to the world class OEE

Fig. 5 shows a comparison of the world class OEE of 85% [11] to the actual OEE of the plant under study. It shows that the actual plant OEE is much less than the world class OEE by 50 %.

3.5. Causes of downtime

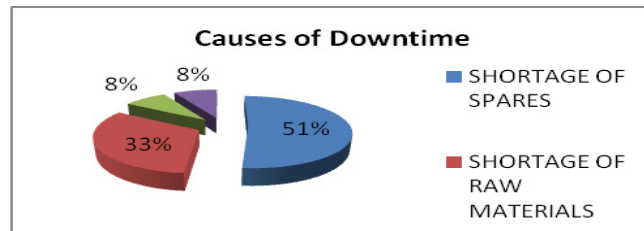


Fig. 6. Causes of downtime

Downtime is the period during which the plant or equipment was out of service. It may be due to technical failure, machine adjustment, maintenance, or non-availability of inputs such as materials, labor, or power. This data was obtained using structured interviews and designed questionnaires. Fig. 6 shows the causes of downtime. 51% of downtime was caused by shortage of spares, 33% by shortage of raw materials, 8% to power problems and 8% not applicable.

3.6. Frequency of breakdowns

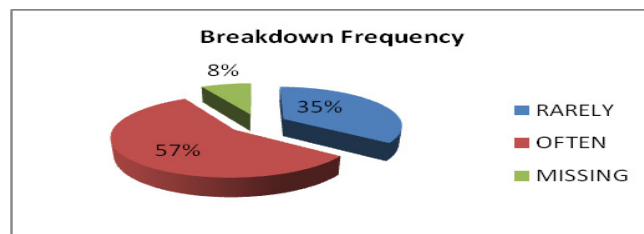


Fig. 7. Breakdown frequency

According to Fig. 7, 35% of the respondents indicated the company rarely experienced plant breakdown, 57% of the respondents indicated the company often experienced plant breakdowns and 8% of the responses were not applicable. Since more than 50% of the respondent indicated that plant breakdown is often, it would be true to conclude that the company often experience plant breakdowns.

4. Discussion

Assessment of the current maintenance system indicated the company was facing the following problems; less availability and reliability of equipment, prolonged downtime, frequent failure of equipment, low production, worker dissatisfactions and the causes of these problems included shortage of spares, poor integration of maintenance department with other departments, lack of appropriate training and skills. 38.2% of the respondents indicated less availability and reliability of the equipment of which 20.6% was attributed to shortage of spares, 5.8% to poor integration of the maintenance department and 11.7% to others. 14.7% of the respondents indicated prolonged downtime of equipment of which 2.9% was attributed to shortage of spares, 8.8% to poor integration of the maintenance department and 2.9% to others. 23.5% of the respondents indicated frequent failure of equipment of which 8.8% was attributed to shortage of spares, 5.9% to poor integration of the maintenance department, 8.8% to

lack of appropriate training and skills. 23.5% of the respondents indicated low production of which 14.7% was attributed to shortage of spares, 5.9% to poor integration of the maintenance department, 2.9% to lack of appropriate training and skills.

The overall results show that 38.2% of the maintenance problems that the company was facing was less availability and reliability of equipment, 14.7% prolonged downtime, 23.5% frequent failure of equipment and 23.5% low production. As regards the causes of the problems, 47.1% are due to shortage of spares, 26.5% poor integration of maintenance department with other departments, 11.8% lack of appropriate training and skills and 14.7% others.

The relationship between the maintenance department and other departments in the company was rated at 22% by the respondents and rated poor, 59% of the respondents rated it fair, 11% of the respondents rated it good and 8% of the responses were not valid. The purpose of assessing the relationship between the maintenance departments with other departments was to determine how effective this relationship was as regards to issues of production, procurement and quality. Effective implementation of TPM requires a proper integration of the maintenance department with other departments in the organization as this enhances interdepartmental relationship. It was therefore necessary to assess the levels of relationship among departments. Assessing TPM awareness and whether the TPM concept would improve the current maintenance system of the company reviewed that 70.5% of the respondents were aware of the TPM concept of which 14.7% confirmed the concept could help improve the current maintenance system and 14.7% were not sure. 29.5% of the respondents were unaware of the TPM concept of which 64.3% did not confirm the TPM concept could improve the current maintenance technique and 5.8% were not sure. The overall results showed 64.3% of the respondents confirming the TPM concept could improve the current maintenance while 11.8% were not sure. The level of knowledge on TPM in the company was assessed by interviewing 10 functional heads and superintendents. Fig. 8 shows the factors affecting effective TPM implementation represented in a fish borne diagram. Management commitment was the major factor to consider in the implementation of TPM. The other factors such as total employee participation, alignment of TPM objectives to the overall objectives of the company, designing of an implementation plan, identifying the performance measures (key performance indicators) and allocating sufficient time for the implementation process are also important and should be included in the TPM model. The results from the figures above, give an indication that, TPM is not practiced. Fig. 8 shows the major factors affecting effective TPM implementation and these factors are the main challenges the Chemical Manufacturing Company is facing. Therefore, the designed TPM implementation model is based on filling the gaps that prevent proper TPM implementation.

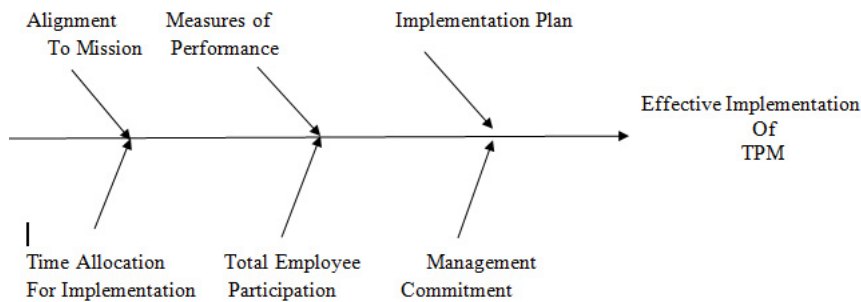


Fig. 8. Factors affecting effective TPM implementation

Fig. 9 shows the proposed TPM model for effective implementation. Effective implementation of TPM starts from top management as it is the one vested with the power to implement change in an organisation. Top management will be responsible for the formulation of the TPM strategies and policies and these should be aligned to the organisation objectives. Management commitment should be shown by their willingness to appoint a TPM company wide manager and also by investing in resources such as time, money, materials and manpower, (Patterson, 1996). The TPM manager will work under the TPM office and will be responsible for effective administration of TPM activities in the organisation, establishment of basic TPM policies and goals and formulate master plan for TPM development.

In order to implement TPM, information and knowledge on TPM is important therefore the appointed TPM manager and management will have to acquire this information and knowledge. After acquiring the knowledge and information on TPM, top management will make its decision to introduce TPM in the company.

In the TPM office headed by the TPM manager, a centralised steering committee will be formed and will comprise of personnel from various functions in the organisation such as production, maintenance, procurement, accounting, human resource etc. According to [12], a centralised steering committee is instituted to guide and control the implementation program and monitor progress.

The committees will be formed at departmental levels and will be headed by members from the steering committee. These members of the steering committee will act as coordinators of the departmental committees and will lead the employees through training and demonstration in order to equip them with information on various functional areas of the organization. Sub-committees will be formed within the department committee and will be called the pillar committees consisting of the education and training committee, autonomous maintenance committee, focused improvement committee etc. A pillar task force will be formed to monitor and enforce the progress of TPM activities.

The company will have to set a foundation before the actual implementation of the TPM pillars. This foundation is set through the application of the 5S. According to [13], 5S is an approach to keep the working areas of an organization in an organized condition in order to have an effective work place, simple working environment and less waste [13]. The TPM pillars are focused improvement maintenance, planned maintenance, educational and training, early management, quality maintenance, office TPM and safety, health and environment. The all TPM model will be directed towards achieving TPM targets of zero breakdowns, zero defects and zero adjustments using productivity, quality, cost, delivery and safety as the appropriate key performance indicators of TPM.

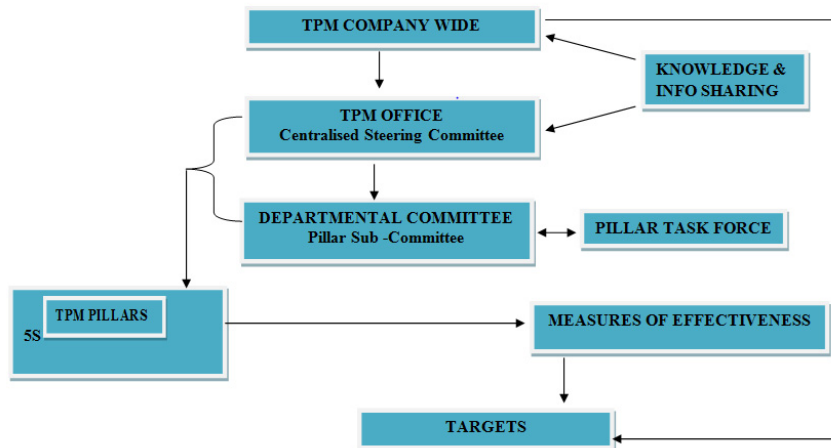


Fig. 9. Proposed TPM model

5. Conclusion

This paper assessed the maintenance systems at a chemical manufacturing company. It identified the gaps in the maintenance system, determined the key performance indicators to be included in the TPM model for effective implementation. OEE was calculated and compared to the world class OEE. The research therefore concluded that TPM can be used as a tool to enhance OEE of the company equipment. The researchers therefore recommended the following;

- Adoption of TPM can reduce losses and reduce rework to or below the acceptable levels. TPM can also help the company to increase profitability and image, both of which will ensure its competitiveness in the current economic turmoil.

- Maintenance activity shouldn't be considered any more as a separate and isolated function that makes repairs. Rather, it should be considered as the main potential area to use as a competitive advantage. Otherwise, higher cost will be incurred after the equipment deteriorate which directly affects the competitiveness of a company.
- The company should involve achieving the company goal through the implementation of operator initiated daily maintenance consisting of cleaning, adjustment, and regular inspections, as well as improvement activities and minor restoration of equipment. And the maintenance men should only participate in inspection and restoration of equipment which requires high skill and specialization.

Empowering the operators and maintenance personnel through training. This should be conducted in sustainable manner to maximize the efficiency of the equipment in order to eliminate the operators' mistakes and improper repair.

Acknowledgements

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