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Analysis of Total Productive Maintenance for Competitive Advantages in Electric Power Industry

T.D. Bestmann, A.O. Odukwe, J. C. Agwunwamba and K. Orima

1.Maintenance Department, Nigerian Agip Oil Company Ltd, Kwale-Delta State, Nigeria
2. Faculty of Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria

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ABSTRACT

This study assessed the role of TPM in electric power industry to hold emergency and reactive maintenance to barest minimum, using Afam and Sapele power stations as case study. Overall equipment effectiveness (OEE) was used as quantifiable performance indicator. Maintenance records of installed equipment provide data for computation. The availability, performance efficiency, and quality rate of equipment were used to calculate the overall equipment effectiveness (OEE). Statistical computation yield of 2.756 for 29 degrees of freedom at 5% confidence level, a value less than calculated t-value of 4.9267, and TPM reliability value of 78%, taking OEE observations for sixty production months with threshold value of 80%, indicates that TPM may bring positive change to process development. Comparison of modified TPM model with other existing maintenance models using quantitative data showed that the modified TPM model has the following inclusive advantages indisputably: low cost implication kt value of less than 7.5%, ability to reduce system failure rate Dt value greater than 97% and low equipment failure rate Di value less than 10%. Hence, this work affirms that, using TPM will avert system failure, maintain steady power production capability, achieve industry competitiveness and stimulate the economy.

Keywords: electricity, analysis, competitive advantage, power industry, TPM, RCM, availability.

I. INTRODUCTION

Total productive maintenance (TPM) has been recognized as one of the significant operation strategies to reduce production losses due to equipment inefficiency. Many organizations have implemented TPM to improve equipment efficiency and to obtain competitive advantage in open market environment in terms of cost and quality. Reliable and stable supply of electric power is fundamental to the economic development and social security of a society. Power plant is the core power generating unit of an electric utility, and any break down of the generating unit would lead to expensive social and economic consequence to society. In the past, electric power plant maintenance was regarded as a necessary evil by various management functions. However, this in recent times has changed. The development which contributed to this change include environmental concerns, safety issues, warranty, reliability factors, customers' expectations and satisfaction, regulatory matters, aging plants and equipment, drive for cost reduction and need for quality and values [4].A proactive maintenance system provides a solid basis for the availability and reliability of electric power supply through the implementation of TPM. Given the day-to-day pressure faced by the electric power plants, the question is what can be done; buy a new maintenance system and reorganize; invest in a load of condition monitoring equipment and rebuild. The answer lies at the beginning of the mission statement which states that the mission is to preserve the functions of the assets. It is only when these functions have been defined that it becomes clear what the next maintenance step is trying to achieve.

Once failure causes and effects have been identified, it is then possible to assess how management options should be used to manage each failure mode. At this point it should be decided on what must be done to preserve the functions of the assets. Different organizations attempts to deploy different strategies to build a level of proficiency in accordance with business level conditions in the TPM philosophies and goals aiming at total quality maintenance management (TQMM). The objective of TQMM is to provide a methodology or framework for improving maintenance effectiveness continuously. .

1.1 Background of study

Efficiency and effectiveness of equipment determines the performance of organizational productivity function as well as the level of success achieved in modern power industry. Power industry with poor performance poses social insecurity and severe economic problems and loss of competitive advantage in electric supply market in terms of cost and quality. The market oriented competitive environment in electric utilities has forced many power plants to become more conscious of the role of maintenance management in enhancing equipment performance and consequently improving the quality of services. Good equipment maintenance practice which can improve the reliability of the power system maintenance has become the prominent issue for electric utilities. The use of optimum method for maintenance management practice can improve the overall effectiveness of the operations and maintenance of the power plant. By adopting the TPM practice appropriately, the electric power plant could become more cost-effective in maintenance. However, for plants looking for breakthrough improvement in maintenance, should adopt alongside TPM; CMMS and PMMS. All these are needed to transform the system and `achieve quality in energy production [4].

1.2 Scope of work

This is strictly focusing on the use and application of globally accepted total productive maintenance (TPM) model in the maintenance activities of the electric power industry. The scope focuses on:

- maintenance management in the electric power industry;
- maintenance modeling, scheduling, optimization and standardization; and
- TPM implementation, philosophy and advantages/benefits to electric power industry.

II. LITERATURE REVIEW

The modern view of maintenance management is that it is all about preserving the functions of productive equipment. In other words, carrying out tasks that serve the central purpose of ensuring that equipment are capable of doing what the users wants them to do, when they are required to do so [7].

Several works relating to maintenance management have been done in the past, which includes that of Warrendale [1], [4] who identified and defined maintenance to mean ensuring that equipment continue to do what their users want them to do. Furthermore, said that the major challenge facing maintenance people nowadays are not only in learning what the techniques are, but to decide which are worthwhile and which are not in their own organizations.

2.1 Strategic maintenance policies

In many factories in Nigeria and most developing nations, the valuable operating time is less than 25% of the gross available hours per year (Eti et al, 2006; Lezlo, 2005; and Mobley, 2004). Hence, it becomes obvious that the plants are not operating optimally to be cost effective. Part of this problem is as a result of high downtime, planned production not realized; inadequate spares to cope with volume flexibility. To keep a plant in running, it needs to receive primary care, which includes cleaning, lubrication, periodic inspection and calibration. In addition, maintenance policies and strategies have to be established to maintain plant availability [5].

2.1.1Inspection optimization models-Exact Algorithms

Over the years many useful PM related mathematical models have been developed, here some of these models are presented. The following modeling approaches as enumerated are used to find optimal preventive and replacement schedules. These models provide a framework that can be applied and used in a preventive maintenance scheduling and are not restricted to manufacturing or service systems. It is expected that the presentation of these models will put in proper focus and promote better understanding of maintenance practice in the power sector. (a) Barlow et al, 1963; (b) Nakajima, 1989; (c) Aven and Goarder, 1997 and (d) Wortman et al 1994.

a. **Barlow et al (1963):** Inspection optimization model I

Inspections are often disruptive, but usually reduce downtime because of lesser number of failures. This model can be used to obtain the optimum number of inspections per facility per unit of time. Total facility downtime is expressed as [9];

$$TDT^{*} = 2\left(CT_i \times T_b\right)^{\frac{1}{2}}$$

TDT*= total optimal downtime per unit of time for a facility.

b. **Nakajima (1989):** Inspection optimization model II

Reliability and mean time to failure (MTTR) determination model of a system with periodic maintenance. This mathematical model can be used to calculate the reliability and mean time to failure of a system subject to periodic maintenance. The model is subject to the following assumptions:

$$MTTFpm = \frac{\int_O^Y R(T)dt}{1 - R(Y)}$$

c. **Aven and Goarder (1997):** Inspection optimization model III

This model is similar to inspection frequency model of Barlow et al. It can be used to determine optimum inspection frequency in order to minimize the per-unit-of-time equipment downtime. In this model equipment (per-unit-time) total downtime is the function of inspection frequency.

$$n^* = \ln\left[\frac{f\theta}{\mu}\right]$$

Where n* = optimal inspection frequency.

d. **Wortman et al (1994):** Inspection optimization model IV

This is a useful mathematical model that can be used to calculate optimum inspection frequency to maximize profit. The model is developed on the premise that the equipment under repair lead to zero output; thus less profit. Furthermore, if equipment is inspected too often, there is danger that it may be more costly due to factors such as loss of production, cost of materials, and wages than losses due to breakdowns.

$$\frac{d\lambda}{dn}(n) = \frac{\frac{P}{\theta} + \frac{C_i}{\theta}}{\frac{P}{\mu} + \frac{C_r}{\mu}}$$

Therefore, the value of n will be optimal when left and right hand sides of the equation are equal. At this point the profit will be at its maximum value.

2.3 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) has become an industrial standard and it is an approach to optimize the effectiveness of production means in a structured manner. It is a maintenance methodology, which focuses on people and is an integral of total quality management (TQM). The methodology was developed in Japan's manufacturing industries, initially, with the aim to eliminate production losses due to equipment breakdown in just-in-time (JIT) production system [2].

2.3.1Benefits of TPM

[5],[10] have redefined TPM as the organization of maintenance work by applying the following;

- cultivate a sense of ownership in the operators by introducing autonomous operator maintenance, where the operators takes responsibility for the primary care of plant;
- the tasks involved include cleaning, routine inspection, lubrication, adjustments, and minor repairs as well as cleanliness and tidiness of the operator's workshop;
- use Cross-Functional teams consisting of operators, maintenance staff, engineers and managers to improve people and equipment performance;
- better understanding of the performance of their equipment (what they achieve in terms of OEE and what the reasons are for non-achievement); and
- improved teamwork and less adversarial approach between production and maintenance etc.

2.3.2 TPM as a Business focus

[3], [5] and [6] conclude that TPM being maintenance focus is a necessary and vitally important part of business, continuing, they maintained that it is no longer regarded as a non-profit activity. Downtime for maintenance is scheduled in some cases as an integral part of manufacturing process. It is no longer squeezed wherever there is failure. The goal is to hold emergency and unscheduled maintenance to barest minimum.

[8], [9], [3] and [7] pointed out that, the profit-focused approach to maintenance has its tools in the elements of productive maintenance, such as: training to improve skill of all personnel; improving equipment efficiency; and improving maintenance organization and efficiency.

Today, with the competition in industry at all-time increasing, TPM may be the only thing that stands between success and total failure for power industries [8].

2.3.3 TPM Impact on business process

Most of the operational and maintenance costs of physical assets are linked to decisions taken at an early stage of the equipment. Therefore, it is easier to reduce future maintenance costs at the design stage than at the operational stage [6]. Capital investment in the plant are influenced by factors such as equipment/component useful life, equipment redundancy, extra spare parts inventory, buffer inventory, damage to equipment due to breakdown, extra energy consumption. Maintenance affects the technical performance and cost-effectiveness of the production department, according to [1]. The technical performance of the production function can be assessed by Overall Equipment Effectiveness (OEE) in TPM [7]; or modified version of OEE, i.e. The Overall Process Effectiveness (OPE) [2]. Efficient maintenance contributes by adding value through better resource utilization (higher output), enhanced product quality, and reduced rework and scrap (lower input production costs). Maintenance can have impact on customers, society, and Shareholders [10].

[6] showed that organizations try to capture new customers, satisfy them and retain existing customers by giving them assurance of supply on time, which in turn depends on adequate production capacity with a minimum of disturbances and with high quality products. The impact of maintenance on society can be traced through its effects on safety, on the environment and on ecology. Finally, the impact of maintenance on Shareholders can be traced by analyzing the effects of maintenance on the generated profit, which is usually measured by indexes such as Return on Investment (ROI) percentage, [8].

2.3.4 The critical factors of Total Productive Maintenance (TPM)

I. senior executives assume active responsibility for evaluation and improvement of maintenance management system, and leading quality drives;
II. clear, consistent communication of mission statements and objectives defining quality values, expectations and focus;
III. visibility of senior executives commitment to total quality maintenance and customer satisfaction;
IV. the entire workforce understands and is committed to vision, values and total quality goals of the organization; and
V. the organization understands that each individual and process has internal and external customers and suppliers etc.

The emphasis of the Total Productive Maintenance (TPM) is on the importance of productivity, reliability and effective use of maintenance resources as well as the use of industrial engineering and systems management characteristics for ensuring failure-free operations of electric power stations. Total Productive Maintenance characteristics must be considered during the planning phase of electric power station and must take cognizance of the core business aspect as well as customer expectations and needs to facilitate economic and social well-being of the people [10], [3].

2.4 Comparison between TPM and other maintenance policies

Maintenance management strategies have been evolving slowly overtime and starting from the concept of breakdown maintenance, varied strategies like Conditioned Based Maintenance, Total Productive Maintenance and Reliability Centered Maintenance are in practice. The use of TPM has been chosen deliberately for power industry to deliver in the context of this work. Each of these strategies has distinct advantages as well as few limitations. A method of comparison of these strategies is done on the basis of established method and drawing on the capability maturity method. The salient features of CBM, TPM and RCM have been enumerated and presentation of a qualitative comparison of these strategies is also done, so as to provide implementers, primarily from the power and process industries, with a ready guide that may help in deciding on the adoption of one of these strategies, [9], [2].

2.4.1 Methodology of comparison

Any strategy implementation is also a simultaneous management of change. Change impacts people and processes. In selecting a particular strategy for implementation the user must be aware of what are the various levels of maturity of the strategy and the various factors that are present in each stage that decided the success of the strategy. The following are being used for the comparison:

A. Method

- simplicity of method;
- standardization of method process;
- scalability of method;
- degree of change from existing process;
- Prioritization of effort;
- effort required; and
- Built-in- continues improvement.

1.4.2 Summary of salient features

The section described each of the strategies in detail. Before undertaking a comparison, the salient features of these strategies are summarized and tabulated in Table 1 summary of salient features of strategies.

Table 1: Summary of salient features of strategies

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SUMMARY OF STRATEGY			
PARAMETERS	**CBM**	**TPM**	**RCM**
Core intent	Detection of failure	Cultural change, long term gains, scaling up. Operations improvement.	Failure prevention,
Focus of implementation	Monitoring	Planning for different conditions	Coverage of all possible failure modes.
Program initiation	Deciding on parameters, procurement of equipment.	Top management announcement, launch training program, collection of failure history/ team assembly.	Assembling team, training.
Program support	Separate section For monitoring and recommending actions.	Creation of organizational support structure. Polices implementation happen concurrently.	Post training implementation can begin immediately.
Presumed existing system	PM	PM, PDM, RCFA	PM, RCFA
Process changes	CBM section becomes initiator of maintenance jobs	Autonomous maintenance by operators.	No changes to maintenance process. PM/ PdM plan generation based on RCM outcome
Major maintenance activity	Breakdown maintenance. PM largely stopped	Preventive and predictive maintenance. Operator level monitoring	Predictive. Preventive where predictive does not work and Design change where both fail.
Measures of effectiveness	Number of failures without notice	Equipment effectiveness. MTBF (Weibull)	MTBF, beta (Weibull)

B. Goals

- goal Complexity; measurable goals; andgoal realization time frame.

C. Employee

- skill required;employee participation;focus on individual;training requirement; andlong term sustainability.

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The final comparison is based on the above 15 criteria, cost of implementation has not been considered as this will be highly dependent on the implementing organization and the extant state of maintenance maturity. Based on the criteria shown, a qualitative comparison of the strategies is carried out using the base as shown in Table 2

Table 2:Comparison between TPM and other maintenance policies

COMPARISON OF STRATEGIES			
Criteria	**CBM**	**TPM**	**RCM**
A. Methods			
simplicity	Straight forward implementation	Simple method	Complex method, FMEA
scalability	Partially scalable. Plant–wise implementation possible	Partially scalable but preferable organization wise implementation	Fully scalable, equipment-wise and plant–wise implementation
Effort prioritization	Criticality, dependent	No same method for all	No same method for all.
Standardization	No standards	International and TPM standards are available	International standards are available
Degree of change	Minor change, limited to a small section	Major change, spread across section	Minor change/ few process change
Built-in-continual improvement	None	Continual improvement focus and built-in but no prescription.	Cyclical process, periodic improvement.
Effort required	Minor effort to setup and maintain	Major effort required for setting up and maintaining	Major one time effort required for setting up. moderate effort for maintaining
B. Goals			
Goal complexity	Simple goal-prevent breakdown	Complex and multiple goals improves availability	Singular goal improves reliability.
Measurable goals	Yes-number of failure	Yes-organizational and cultural change measurable.	Yes-MTBF
Time frame	Short-immediate authorization of derived benefits	Long-term, benefits take a longtime to accrue but sure wins possible	Long term, benefits accrue after program implementation
C. Employee			
Skill required	High skill in detection and analysis	Low skill	Medium and low skill, High skill analyst
Employee participation	Low-limited to few people for core CBM	High-organization wide participation	Low core analyst group only.
Individual focus	Low- system driven	High individual and system driven	Low only for the analyst
Training required	Low-for the analyst	High-training for all	Low-for the analyst
Sustainability	Sustainable as it is system driven	Sustainable as it is both system and individual driven	Sustainable as it is system driven

I. Condition Based Maintenance (CBM), with its simplicity of methods and goals may appear as the ideal strategy. However, due to the static nature of the strategy, continual improvement

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is not possible. Further, the strategy limits itself to monitoring and correcting the issues causing failures, but does not extend to the preventing these from occurring in future. Even with a RCFA program, this strategy fails to address the need for across the board reliability improvement due to its inability to address potential and hidden failures.

II. Reliability Centered Maintenance (RCM) is a very systematic strategy with goals. It demand high skill from only few people and hence can be easily or quickly started. The basic focus is on uncovering all potential modes of failures and addressing these through the three actions of Preventive, Predictive and Default action. The process requires extensive analysis, through an FMEA of all equipment and is time consuming. The analysis is a time consuming activity, therefore the major problem associated with a conventional RCM process is that in the period of the study, there will be no benefit accrued and at times this can lead to loss of management support, and miss crucial recommendation.

III. Total Productive Maintenance (TPM) is a strategy that aims to empower individuals. This approach is best suited for effective operations i.e. operators and maintenance staff working together as a team to reduce waste, minimize downtime, improve product quality, and effectiveness of equipment. The goals are simple and measurable, the entire process is both system and people driven and training requirements are higher and this strategy is directed towards building a minimum level of competency across all employees. On the positive side, the strategy results in increased skill of all employees, greater participation and hence improved morale, [5], [1].

III. MATHEMATICAL MODELS FOR SYSTEM PRODUCTIVITY

The relationship below was expressed mathematically by [11].

$P_r = f(A, P, C)$ (1)

$A = g(R, M, P, C)$ (2)

Where P_r = Productivity

A, P, C, = Availability, Performance, Cost

R, M, = Reliability, Maintainability;

Availability is expressed in this case as a function of reliability and maintainability subject to the constraints of performance requirements and cost.

3.1 Availability goal

The operating availability of an existing power plant can be obtained from historical data with the following relations of equation [9].

$$Availability = \frac{Uptime}{Uptime + downtime}$$ (3)

The first task in setting up an availability goal is the construction of a simple model to provide insight into the significance of the goal. These are series models since the failure of one system will result in shutdown.

The availability is given by

$$A = A_1 A_2 A_3 - - - - - A_n = \frac{n}{\pi} A_i$$ (4)

or $A = 1 - \overset{n}{\Sigma} U_i$ (5)

Where A_i = Availability of major equipment or system

U_i=Unavailability=1–A_i (6)

Mathematically this is expressed 1 minus availability. Availability can be treated respectfully, with simple representation, as the ratio of the expected value of the uptime of a system to the aggregate of the expected values of up and downtime, or:

$$A = \frac{\Sigma[Uptime]}{\Sigma[Uptime] + \Sigma[Downtime]}$$ (7)

If the status of function X (t) is defined as:

$X(t) = \int_0^1$ (8)

Therefore, the availability A (t) at time t > 0 is represented by

$$A(t) = P_r[X(t) = 1] = \Sigma[X(t)]$$ (9)

Average availability must be defined on an interval of the real line. If we consider an arbitrary constant c > 0, then average availability is represented as

$$A_c = \frac{1}{c}\int_0^c A(t)\, dt.$$ (10)

Limited or steady-state availability is represented by

$$A = \lim_{c \to \infty} A_c. \quad (11)$$

Limiting average availability is also defined on an interval [0, c] as

$$A_\infty = \lim_{c \to \infty} A_c = \lim_{c \to \infty} \frac{1}{c}\int_0^c A(t)\,dt, c > 0 \quad (12)$$

3.2 Statistical analysis and reliability estimation of TPM

TPM is an effective tool to improve productivity and reliability. OEE is an indicator that shows the effectiveness of TPM. Number of failures by a productive system indicates the system condition. Thus, the failure reduces the rate of quality and also affects the OEE. It is therefore necessary to measure the effectiveness of TPM.

Statistical analysis is made to measure the effectiveness of TPM. The inferential statistics is concerned with estimating the unknown parameter by using sample statistics. If a claim or assumption is made about the specific value of a parameter then it is expected that the corresponding sample statistics is close to the hypothesized parameter value.

In this work TPM effectiveness is measured. The effectiveness is measured in comparison with before and after TPM implementation to know whether TPM would help to reduce the failure rate in production process.

A statistical hypothesis is a claim and is useful to analyze such claim or assertion statistically. The sample data are collected and analyzed on the basis of sample findings; the hypothesized value of the parameter is either accepted or rejected. The process that enables a decision maker to test the validity or significance of claim by analyzing the difference between the value of sample statistic and the corresponding hypothesized parameter value is called hypothesis testing.

The estimation of TPM effectiveness for a power production process is an essential activity. This activity involves computations, analytical skills and also large amount of time. If the effectiveness of TPM is determined analytically, it helps the maintenance engineer to predict the percentage of failure over the specific period of time. To measure the effectiveness of TPM, the hypothesis test will be conducted using OEE as TPM parameter. The methodology involves;

- null hypothesis Ho and alternate hypothesis Ha are formulated;
- required confidence level is selected;
- test statistic is computed;
- the critical value of the test and obtained value of the test are computed; and
- decision is made regarding accepting or rejecting Ho based on above results.

Testing of hypothesis entails data collection for computation i.e. installed capacity, working capacity, number of failures for different years before and after TPM installation. The difference between failures is computed for hypothesis testing.

3.2 Formulating the Null hypothesis (Ho) and Alternate hypothesis (Ha)

Basically the formulation includes the following details:

- Ho: there is no change that has taken place as an effect of TPM implementation,
- Ha: there is a positive change that has taken place as an effect of TPM implementation.

Let, µA denote the mean failures after the implementation of TPM; and let µB denote the failures before the implementation of TPM.

Therefore, Ho = µB - µA =0 and Ha = µB - µA >0.

95% of confidence level and 5% significance level are set.

Student's t-value is calculated using average of deviations and standard deviation.

Mean differences of failures, $\bar{A} = \Sigma \frac{d}{n}$ (13)

Therefore $\bar{A} = \sigma$

Standard Deviation, S = $\sqrt{\frac{\Sigma d^2}{(n\text{-}1)} - \frac{(\Sigma d)^2}{n(n\text{-}1)}}$ (14)

S =ϕ

Standard Error = $\frac{S}{\sqrt{n}}$

Student's t-value is given by $t = \frac{\bar{A} - \mu_{\bar{A}}}{S/\sqrt{n}}$

Where, $\mu_{\bar{A}=}$ total failures, which is targeted as zero

Therefore, $\mu_{\bar{A}=0}$ and $t = \frac{\bar{A} - \mu_{\bar{A}}}{S/\sqrt{n}}$ (15)

The verification of result of hypothesis testing from the t-table for a given degree of freedom at certain percentage of significance is known, which should be less than calculated t-value. Hence, the Null hypothesis Ho is rejected. Therefore, it may be concluded that TPM implementation brings positive change to the process.

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3.3 Reliability based estimation of Total Productive Maintenance (TPM)

TPM improves the maintenance system in the context of operations management. To succeed in demanding market electric power companies have to fulfill several requirements. One such crucial aspect is a reliability of the maintenance system. TPM has potential to increase the process efficiency, quality of the process, product and hence the reliability are important factors to gain the competitive advantages of the operations management.

Further, the reliable production and maintenance is necessary to meet quality specifications of the product and process. To enhance the high process capability, maintenance performance must be systematic and reliable. Reliability estimation helps in quantifying OEE and assists production by reducing the downtime due to breakdowns.

The reliability estimation helps to determine the behavioral pattern of TPM over the time period. The basic method adopted in estimating the reliability of TPM over a given time period is by generating a process parameter using the Monte Carlo simulation technique for large number of production months and the corresponding OEE is estimated.

The estimation of TPM for a production process is an essential activity of OEE validation. This activity involves computations and analytical skills. The estimation of TPM requires large amount of time and cost. It is not possible to conduct the study very often if the behavioral pattern of TPM is determined analytically. It helps the maintenance engineer to predict the OEE over the specific period of time. The methodology involves the following steps:

- computation of OEE values using random numbers; and
- computation of OEE for large number of production months.

Using the above computation and considering threshold value of OEE as 80%, reliability of TPM is estimated. The 80% threshold value of OEE was chosen, because it is the standard expected value of system performance. The collection of data for one year period for availability, performance efficiency and rate of quality is done and hence OEE for the given period is estimated and presented in a table. The Monte Carlo simulation procedure has been adopted to simulate the random numbers for the other five (5) years.

The simulated values for availability, performance efficiency and rate of quality are prepared and presented in other following tables respectively. The random numbers are obtained from standard random table.

To calculate the reliability of TPM, threshold value of OEE has been taken as 80% since 80% is the standard expected value, Kennedy, (2003). The OEE observations above and below 80% are recorded. The reliability of TPM is estimated by considering the ratio of observations above threshold value to the total number of observations i.e.

- Numbers of observations above 80% are n value;
- Total number of observation is considered u value; therefore
-

$$\text{Reliability of TPM} = \frac{\text{No.of observations above threshold value}}{\text{Total no.of observations}} \quad (16)$$

$$= \frac{n}{u} \times 100\% = \mu\%$$

The above reveals that, the reliability of TPM is µ% taking into account OEE observation over the number of production months.

IV. MAINTENANCE SYSTEM AND STATUS IN CASE STUDY POWER STATIONS

Electric power plants that operate with low downtime or failure rate levels can maximize the productive capacity of the power station and the lifespan of equipment. Data were collected from two electric power stations in Nigeria namely Afam and Sapele power stations for investigative analysis. It was found that the power stations have deplorable maintenance strategy, still reactive rather than proactive from facts gathered. The power stations have maintenance department that is organizationally independent of the production; while some sections are organized as part of the production department. The power stations operate both centralized and decentralized maintenance organization management system; spends time on planned tasks at least 60% and 30% on unplanned tasks, allocating 10% for planning. However, Figures 1 show the causes of planned maintenance actions were distributed on average so that 45% is the recommendation of the original equipment manufacturer (OEM), 40% the use of condition monitoring (CM) techniques, 5% the use of statistical modeling of failure data, 2% the use of key performance indicators or measures and 8% other factors such as those based on the industry's own experience as illustrated in Figure 1 adopting basic procedure utilized by (Alsyouf, 2004).

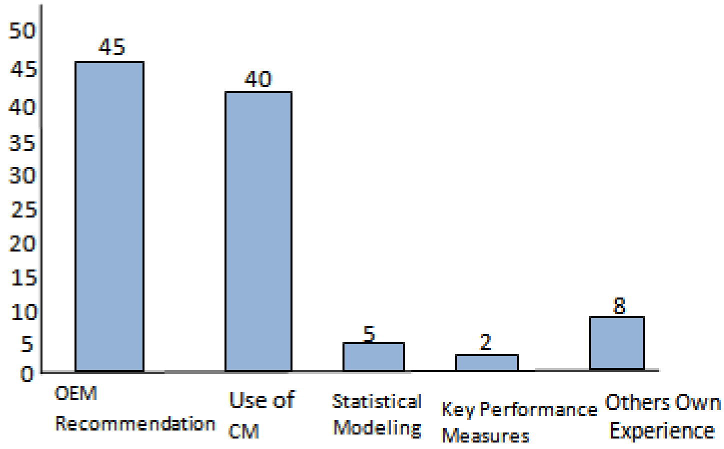
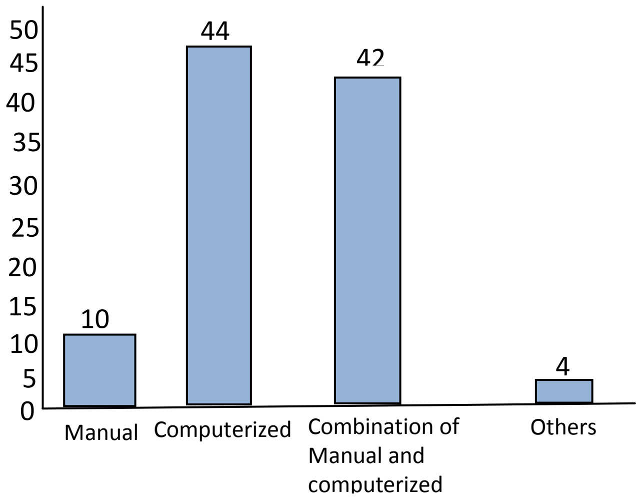


Figure 1: Distribution of causes of planned maintenance

Maintenance personnel and records confirmed the use of manual maintenance management system since inception, only recently the use of a computerized maintenance management system (CMMS) came into being and the effective use is rated about 44% and use of combination of the manual system and CMMS is 42%, otherwise not applicable at all, in some sections is 4% and 10% for manual system.

Figure 2: Type of Maintenance management system



Regarding the attitude to maintenance, about 80% consider maintenance as a cost centre, 20% both a cost and a profit centre. Also, it was estimated that the maintenance budget between the year 2007 and 2011 as a percentage of production cost took a tiny chunk of 0.4% indicating poor interest in, and poorly managed operations and maintenance practices. However, the distribution of maintenance budget among the different tasks and resources is illustrated in Figure 3

Figure 3: Maintenance budget distributions

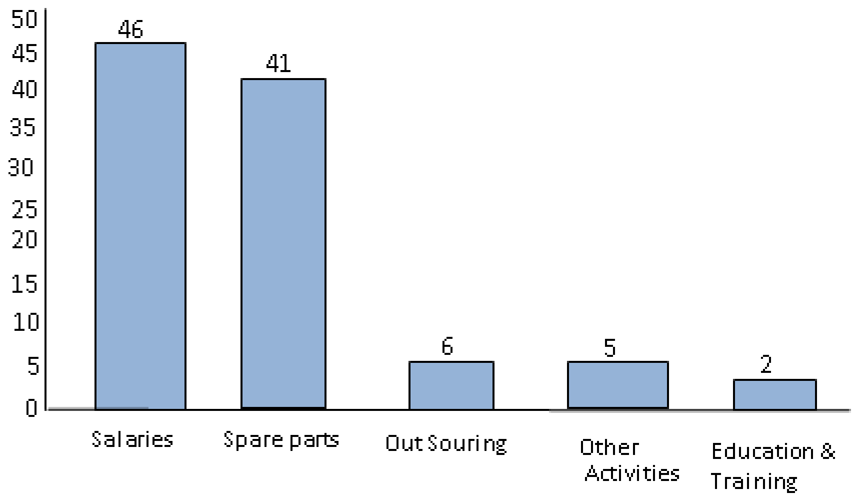


Table 3: Comparison of Results of Afam and Sapele Power Stations

Plant Name	Cause of Planned maintenance		Maintenance Management System		Maintenance Budgets distr.	
	OEM Rec.	KPM	Computerized	Automation	Salaries	Educ. & Training
Afam Power Station	High >75%	Poor <17.5%	High >90%	Poor < 0%	High >85%	Low < 25%
Sapele Power Station	High> 90%	Poor <17.5%	High> 80%	Poor < 0%	High > 90%	Low < 15%

Comparison of the two case study investigative power stations (Afam and Sapele) in Table 3 evidently showed that basic factors that could have helped the power plants reduce failure/downtime rate, improve performance, and become more competitive were treated with high ignominy i.e. KPM < 17.5%, Automation < 0%, and Education and Training < 20%.

4.1 Results from the optimum policy –TPM

Measuring the effectiveness of TPM requires hypothesis test using OEE as TPM parameter. Using the methodology described by collecting data for computation of the hypothesis testing. The working capacity (produced amount of power in MW) and failure are noted for before and after TPM difference between the failures is computed for the hypothesis testing and presented in the Table 4.

Table 4: Statistical measurement of TPM effectiveness

S/N	**Capacity (MW)**	**Working Capacity (MW)**	**No. of Failure**	**Before TPM % rate of Failure**	**Working Capacity**	**No. of Failure**	**After TPM % rate of Failure**	**Deviation = d**	**d^2**
1	10.3	-	-	-	10	1	10	10	100
2	10.3	-	-	-	10	0	0	0	0
3	17.5	-	-	-	15	1	6.7	6.7	44.99
4	17.5	-	-	-	15	0	0	0	0
5	23.9	20	20	4.0	20	0	0	4	16
6	23.9	15	40	6.0	15	1	6.7	6.7	0.49

7	23.9	-	-	-	15	0	0	0	0
8	23.9	-	-	-	15	0	0	0	0
9	27.2	-	-	-	15	0	0	0	0
10	27.2	-	-	-	20	1	5	5	25
11	27.2	-	-	-	20	1	5	5	25
12	27.2	-	-	-	20	1	5	5	25
13	75	-	-	-	60	0	0	0	0
14	75	-	-	-	60	1	1.7	1.7	2.89
15	75	-	-	-	60	1	1.7	1.7	2.89
16	75	-	-	-	60	0	0	0	0
17	75	50	2	4.0	50	1	2	2.0	4.0
18	76	50	4	8.0	50	2	4	4.0	16.0
19	138	100	6	6.0	100	0	0	6.0	36.00
20	138	100	4	4.0	100	1	1	3.0	9.0
21	120	70	4	5.8	70	0	0	5.7	32.49
22	120	90	4	4.4	90	2	2.3	2.2	4.84
23	120	90	3	3.3	90	1	1.1	2.2	4.84
24	120	-	-	-	90	0	0	0	0
25	120	-	-	-	90	1	1.1	1.1	1.21
26	120	-	-	-	90	0	0	0	0
27	75	-	-	-	50	1	2	2	4
28	75	-	-	-	50	0	0	0	0
29	75	-	-	-	50	0	0	0	0
30	75	-	-	-	50	1	2	2	4

procedure has been adopted to simulate the random numbers for the next five years OEE values Sum of deviations $\Sigma d = 70$ and $\sum d^2 = 358.43$
Using the Hypothesis test; then consideration of the Null and Alternate hypothesis is as follows:
H_o = No change takes place as effect of TPM implementation
H_a = Positive change takes place as effect of TPM implementation.
μ_A = Mean failure after TPM implementation
μ_B = Mean failure before TPM implementation
Therefore, $H_o = \mu_B - \mu_A = 0$, and $H_a = \mu_B - \mu_A > 0$.
Setting 95% of confidence level and 5% significance level consideration; hence computation of test statistics, student's t-value is calculated using average of deviations and standard deviations.
Mean difference of failures, $d=\frac{\Sigma d}{n}$;

$d = \frac{70}{30} = 2.333$
Standard Deviation, SD= 2.5937
Standard Error, S.E = 0.4735
Student's t value = 4.9267
From the t-table for 29 degree of freedom at 5%, Confidence level is 2.756 which is less than calculated t-value 4.9267. Hence, the Null hypothesis Ho is rejected. Therefore, it may be concluded that TPM implementation brings positive change to process development.

4.1.1 Reliability estimation of TPM

One year data for availability, performance efficiency and rate of quality are collected and hence OEE for the given period is estimated and presented in the Table 4.8. The Monte Carlo simulation.

Table 5: OEE Value for one year

Months	**Availability %**	**Performance Efficiency %**	**Rate of Quality %**	**OEE %**
Jan	92	90	88	73
Feb	89	93	92	76
Mar	89	92	97	79
Apr	91	92	98	82
May	92	90	97	80

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Jun	94	95	100	90
July	98	89	100	78
Aug	98	85	99	82
Sept	98	89	99	89
Oct	98	92	99	89
Nov	98	93	99	90
Dec	98	94	99	91

The simulated values for availability, performance efficiency and rate of quality are prepared and presented in Tables 5, 6 and 7 respectively.

Table 6: Random number interval for availability

Availability %	**Frequency**	**Probability**	**Cumulative Probability**	**Random Number Interval**
89	2	0.17	0.17	0 – 16
91	1	0.08	0.25	17 – 24
92	2	0.17	0.42	25 - 41
94	1	0.08	0.50	42 - 49
98	6	0.50	1.00	50 – 99
	12			

Table 7: Random Number Interval for performance efficiency and quality rate

Performance Efficiency/Quality rate (%)	**Frequency** **P E-Q R**	**Probability** **P E - Q R**	**Cumulative Probability** **P E - Q R**	**Random Number Interval** **P E - Q R**
80 - 88	1 - 1	0.0833- 0.0833	0.08 - 0.08	0 – 07 - 0-07
85 - 92	1 - 2	0.0833- 0.0833	0.17 - 0.17	8 – 16 - 8-16
89 - 97	1 - 2	0.0833- 0.1667	0.25 - 0.33	17 – 24 - 17-33
90 - 98	2 - 1	0.1667- 0.0833	0.42 - 0.42	25 – 41 - 34-41
92 - 99	3 - 5	0.2500- 0.4167	0.67 - 0.84	42 – 66 - 42-82
93 - 100	2 - 2	0.1667- 0.1667	0.84 - 1.00	67 – 83 - 83-99
94	1	0.0833	0.92	84 – 91
95	1	0.0833	1.00	92 – 99
	12 -12			

The availability, performance efficiency and rate of quality are recorded and presented in Table 8. According to the random numbers, OEE has been computed for five years and presented also in the Table 9.

Table 8: Random Numbers for Availability, Performance Efficiency and Rate of Quality

Months	**Ran Numbers**	**Availability %**	**Ran Numbers**	**Performance Efficiency %**	**Ran Numbers**	**Rate of Quality %**
1	22	91	68	93	61	99
2	19	91	13	85	16	92
3	16	89	09	85	16	92
4	78	98	20	89	46	99
5	3	89	73	93	88	100
6	93	98	07	80	08	92
7	78	98	92	95	82	99
8	23	91	99	95	56	99

9	93	98	93	95	22	97
10	78	98	18	89	49	99
11	23	91	24	89	44	99
12	15	89	22	89	33	98
13	58	98	07	80	77	99
14	57	98	29	90	87	100
15	48	94	57	92	54	99
16	61	98	33	90	08	92
17	36	92	49	92	64	99
18	18	91	65	92	24	97
19	88	98	92	95	29	97
20	9	89	98	95	40	98
21	12	89	00	80	35	98
22	85	98	57	92	37	98
23	38	92	12	85	28	97
24	53	98	31	90	56	99
25	40	92	96	95	33	98
26	2	89	85	94	86	99
27	95	98	72	93	89	100
28	35	92	91	94	78	99
29	26	92	77	93	24	97
30	77	98	37	90	53	99
31	46	94	34	90	61	99
32	37	92	11	85	18	97
33	61	98	27	90	45	99
34	93	98	10	85	04	38
35	21	91	59	92	23	97
36	95	98	33	90	53	99
37	97	98	87	94	45	99
38	69	98	72	93	23	97
39	4	89	73	93	25	97
40	61	98	79	93	45	99
41	85	98	20	89	11	92
42	21	91	85	94	89	100
43	15	89	59	92	87	100
44	2	89	72	93	59	99
45	87	98	88	94	66	99
46	98	98	49	92	50	99
47	10	89	12	85	77	99
48	47	94	79	93	27	97
49	22	91	38	90	54	99
50	67	98	47	92	10	92
51	27	92	71	93	04	86
52	33	92	64	92	39	98
53	13	89	59	92	05	88
54	10	89	82	93	44	99
55	28	92	16	85	14	92
56	34	92	95	95	9	92
57	61	98	79	93	52	99
58	61	98	61	92	71	99
59	17	91	44	92	38	98
60	36	92	37	90	69	99

Table 9: Availability, Performance Efficiency and Rate of Quality and equivalent OEE

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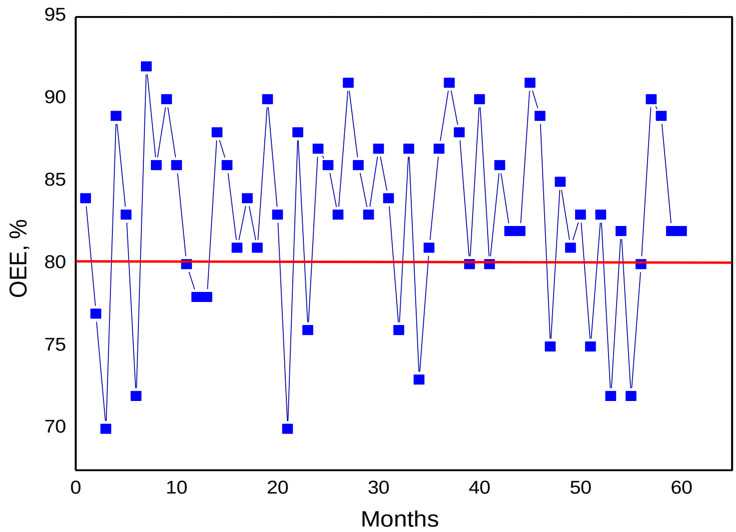
Months	Availability %	Performance Efficiency %	Rate of Quality %	OEE %
1	91	93	99	84
2	91	85	99	77
3	89	85	92	70
4	98	89	99	89
5	89	93	100	83
6	98	80	92	72
7	95	95	99	92
8	91	95	99	86
9	98	95	97	90
10	98	89	99	86
11	91	89	99	80
12	89	89	98	78
13	98	80	99	78
14	98	90	100	88
15	94	92	99	86
16	98	90	92	81
17	92	92	99	84
18	91	92	97	81
19	98	95	97	90
20	89	95	98	83
21	89	95	98	70
22	98	80	98	88
23	92	92	97	76
24	98	85	99	87
25	92	90	98	86
26	89	95	99	83
27	98	94	100	91
28	96	93	99	86
29	92	94	97	83
30	98	93	99	87
31	94	90	99	84
32	92	90	97	76
33	98	85	99	87
34	98	90	88	73
35	91	85	97	81
36	98	96	99	87
37	98	90	99	91
38	98	94	97	88
39	89	93	97	80
40	98	93	99	90
41	98	89	92	80
42	91	94	100	86
43	89	92	100	82
44	89	93	99	82
45	98	94	99	91
46	98	92	99	89
47	89	85	99	75
48	94	93	97	85
49	91	90	99	81
50	98	92	92	83
51	92	93	88	75
52	92	92	98	83

53	89	92	88	72
54	89	93	99	82
55	92	85	92	72
56	92	95	92	80
57	98	93	99	90
58	98	92	99	89
59	91	92	98	82
60	92	90	99	82

4.2 The reliability estimation

Finding the reliability of TPM, threshold value of OEE has been taken as 80% since, 80% is the standard expected value. The OEE observations above 80% are noted down. The reliability of TPM is estimated by considering the ratio of observations above threshold value to the total number of observations i.e. improving the reliability of the maintenance system (performance efficiency, quality rate and availability) by TPM. The graphical presentation of this procedure is presented in Figure 4.10.

Figure 4: OEE status over 60 months



From the Figure 4, number of observation above 80% are 47. Total number of observation considered is 60. Therefore from equation 16;

$$\text{Reliability of TPM} = \frac{\text{No. of observations above threshold value}}{\text{Total number of observations}}$$

$$= \frac{47}{60} = .78\text{ X}100 = 78\%$$

The above study reveals that, the reliability of TPM is 78% - taking into account OEE observations over the Number of production months. So far, the result in the statistical analysis method is done to measure the effectiveness of TPM. Also, the reliability estimation of TPM over the number of production months has been shown. The adopted approach helps to determine the reliability of OEE over the number of production months; helping maintenance engineers to further study the variability of OEE. Thus, the proposed TPM approach helps the maintenance plan and administers the necessary activities to achieve high level of performance and identify the opportunities to improve quality and performance.

V. CONCLUSION

TPM has a vital role to play in gaining and maintaining competitive advantages, the importance of electric power industry to adopt suitable performance measures and embrace proactive practices rather than still rely on reactive and traditional maintenance method of doing things was emphasized.

Electric power plants incorporating value based and quality maintenance methodology could be of considerable interest if the central essence is to create a good and great economy. Therefore, encouraging electric power industry to adopt or implement an innovative maintenance management strategy like the TPM could be of great benefit because it allows the industry to interpret the customer's need and expectations and relate them in term of technical requirements.

Individual equipment problems affect the entire system and hence the OEE of the power stations which is an inclusive measure of how well the maintenance system works, the design and installation of equipment as well as how it is operated and maintained. TPM therefore, if properly implemented in the power industry, will improve OEE by providing a structure to quantify losses or downtime, and by subsequently prioritizing improvements schemes. Competition in the industry all the time high, TPM may be the only thing that stands between success and failure in the electric power industry, as a proven program that works.

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