

Applying Total Productive Maintenance for Machinery Failure Prevention and Optimal Performance

T.D. BESTMANN, A.O. ODUKWE and J. C. AGWUNWAMBA
Maintenance-Mechanical Department, Nigerian Agip Oil Company, Kwale Gas Recycling Plant, Kwale Delta State, Nigeria.
Faculty of Engineering, University of Nigeria, Nsukka

Abstract
The functional Total Productive Maintenance TPM role of holding emergency and unscheduled maintenance to barest minimum and reduce the amount of reactive maintenance which affects productivity in terms of cost and performance; using Overall equipment effectiveness (OEE) as key quantifiable performance indicator to determine machinery performance as measuring tool. To achieve optimal level, industries should do the right thing; use Maintainability, Availability and Safety enshrined (TPM) policy and do it right by ensuring that right competences are available. Furthermore, applying the never-ending improvement cycle: Plan-Do-Check-Act (PDCA) alongside will enable identify problem areas, to apply the policy to avoid premature replacement cost, maintain steady production capabilities and prevent systems failure and its components deterioration.
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1.0 Introduction

To perform effectively, use of TPM as a maintenance tools will emerge as an important strategy to:

- add-value and quality to the maintenance function;
- make changes in the employee mind-set toward their job responsibilities;
- bring maintenance into focus as part of the business, and taken as profit activity; and
- reduce unavailability and cost.

Maintenance becoming a prominent issue for effective performance in most industries requires industries managers and owners to resort to best option practices TPM, using it with reliability centred maintenance (RCM) in line with condition based maintenance (CBM) and computerized maintenance management system (CMMS). All these are needed to transform company operating philosophies and practices to embrace a quality culture. Maintenance is the combination of all technical, administrative and managerial (TAM) actions intended to retain an item in or restore it to a state in which it can perform its required functions, [12].

When an asset is maintained, the state in which it is preserved must be one in which it continues to do whatever the user wants it to do. If things do not fail then there would no need of maintenance, so the technology is all about finding and applying suitable ways of managing failures. Failure management techniques include preventive and predictive maintenance, failure-finding, run-to-failure and one-time changes to the design of the asset in the way it is operated. Each category includes a host of options, no more effective than others. Maintainers not only need to learn what these options are, but to decide which are worthwhile. If right choices are made, it is possible to improve asset performance, and at the same time contain and reduce costs, while if the wrong choices are made, new problems are created while the existing problems get worse.

1.1 Background to the problem

Efficiency and effectiveness of machinery plays a dominant role in modern Industry to determine the performance of the organizational productivity function as well as the level of success achieved. The modern industry confronted with wide range challenges that includes quality improvement, reduced lead times, set up times, and cost reduction, capacity building and expansion, managing complex technology and innovation and improving the reliability of the systems, [4]. The challenges of intense market competition have also placed enormous pressure on maintenance system to improve efficiency and reduce operational costs. These challenges have forced maintenance managers to adopt tools, methods and concepts that could stimulate performance growth and minimize errors and to utilize resources effectively toward making the organization a world-class or high-performance plant.

[13], review in to most manufacturing industries showed that 80% of problem is about availability, 5% safety and 15% maintainability. The major issue associated with analyzing and finding solution to these problems he asserted is directly related to absence of an effective centred asset management approach, inadequate, and delayed maintenance of facilities at any of the stages enumerated e.g. obsolete equipment, bad tools and poor operational planning.

2.0 Maintenance approaches

The maintenance concept has passed through several major developments stages. Consequently, several maintenance approaches i.e. various maintenance strategies, policies, methodologies or philosophies, have been implemented by practitioners or suggested by intellectuals, [9] [10] [14].

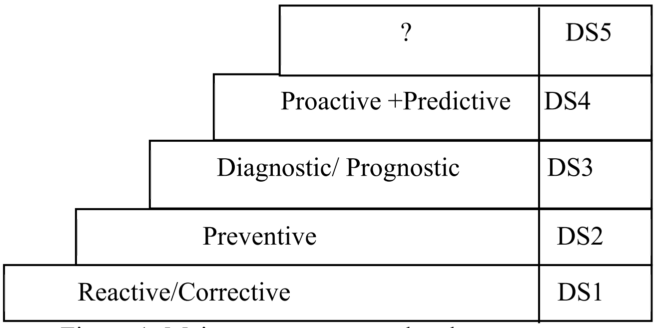

Figure 1: Maintenance concept developments

Maintenance strategy involves the identification, researching, and execution of many repairs, replacement and inspection decisions. Maintenance strategy describes what events i.e. failure, passing of time and condition that triggers what type of maintenance (inspection, repair or replacement). It is a matrix of policies/techniques which varies from facility to facility, [16].

2.1 Maintenance concepts and selection method

Making decision is not an easy task, especially when the system consists of several different components with different maintenance characteristics and the maintenance program combines technical requirements with the firm's managerial and business strategies.

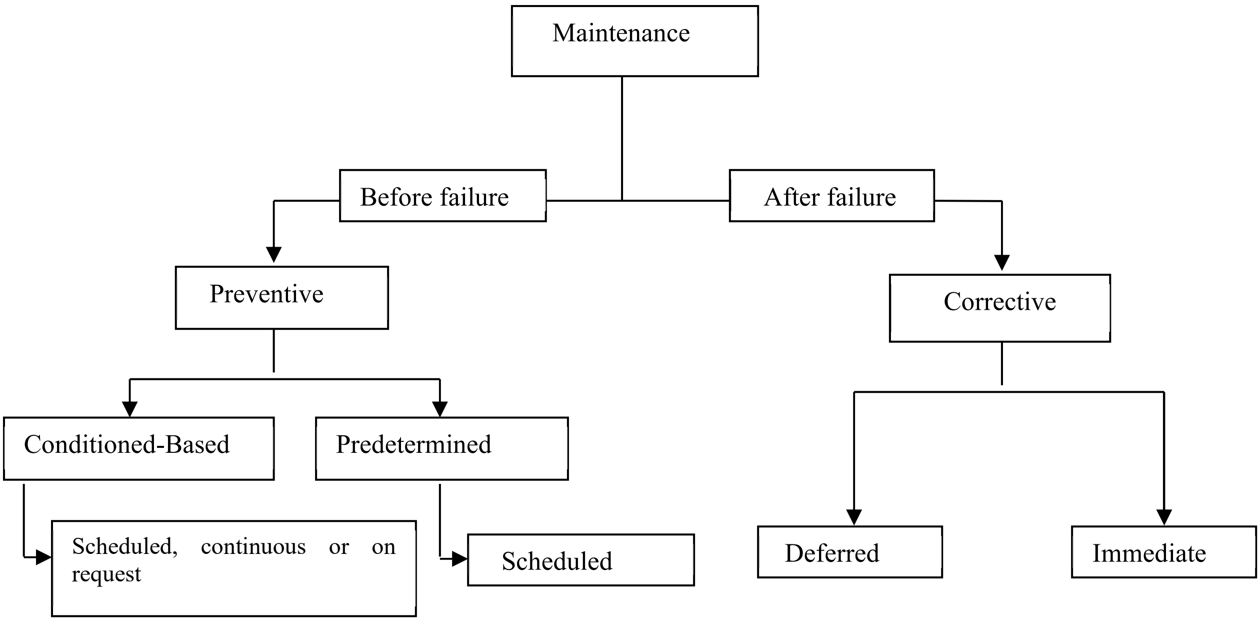

Figure 2: Basic maintenance classifications

Maintenance actions take several forms and makes use of various approaches as shown above in figure.2; corrective (breakdown) maintenance, preventive maintenance (PM) i.e. replacing components at pre-specified time using statistical model based on collected historical failure data, or condition-based maintenance using data from monitoring the condition of the machinery through using one of the condition monitoring (CM) techniques. In each of the cases the decision maker needs to select from all the applicable maintenance policies the most cost effective one for each component, module, or equipment that suits the operating context.

2.2 TPM starting history

Owing to recent globalization of business activities development of information-based technology, increasing attention of the customer orientation as a strategic choice, the relevance of maintenance scheduling and planning activities have significantly increased. The plan based approach to preventive maintenance (PM) evolved the concept of maintenance, availability and safety (MAS) culture. It was developed gradually from maintenance programme with wholesome quality management policy, as a direct result of Deming's influence on manufacturing industries in Japan shortly after the World War II.

When the problems of plant maintenance were examined as part of TQM programme, some of the general concept of PM did not seem to fit or work well in maintenance environment. Using PM techniques, maintenance schedules designed to keep machines operational were developed. However, these techniques often resulted in machines being over-serviced in an attempt to improve production. The need to go further than just scheduling maintenance in accordance with manufacturer's recommendation as a method of improving productivity and product quality was quickly recognized by those who were committed to the TQM programme. To solve these problems and still adhere to TQM concept, modifications were made to the original TQM concept. These modifications elevated maintenance to the status of being an integral part of overall quality programme. The Japanese Institute of plant engineers (JIPE), which was the predecessor to the Japanese Institute of plant maintenance (JIPM) in 1969, started working closely with automotive component manufacturing company on the issue of preventive maintenance (PM) and when the company decided to change the role of operators to allow them to carry out routine maintenance this was the beginning of TPM.

It was a severe economic situation in the early 1970s that accelerated adoption of TPM policy, propagated by the seven pillar steps of TPM in 1988, in Tokai-Rubber industry. The seven pillars of TPM focused on (i) Improvement maintenance (ii) Autonomous maintenance (iii) Planned maintenance (iv)Training (v) Early equipment maintenance (vi) Quality maintenance and (vii) safety and environment. The study highlights the initial house keeping using the 5S, all the seven pillars are critical to successful application of TPM and its successful implementation in an industry requires total employees' engagement in extra role behaviour and change of attitude- a new thought wave and dedication.

3.0 System's performance

The overall performance of production system is determined by the quantitative and qualitative properties of the system. These properties are found in all the different components of the system, also in the organization or structure of the system. The relation between the qualitative properties of the most important sub-system of a production system may be illustrated as shown in Figure 3.

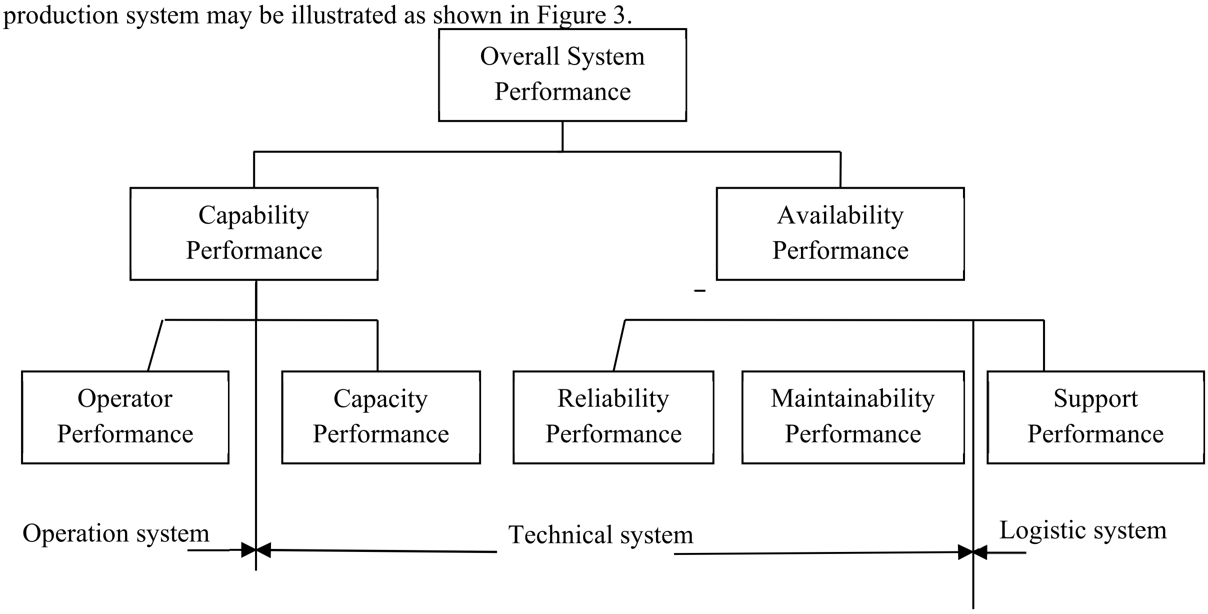

Figure 3: System Performance
Source: [9]

These can be explained as follows:

- Overall system performance: the total production result over along period of time, in principle the lifetime of the system. It can also include the economical result.
- Capability performance: the average production result per unit time, normally related to the rated capacity. If a plant is operated at 100% capacity and the product is 100% perfect in quality the capability performance is 100%.
- Availability performance: the part of the total calendar time the equipment is in economic production condition. If the condition does not permit production at full rate capacity and with the product quality at the specified level the equipment has one or more failure and needs maintenance the equipment is not available for production.

- Operator performance: the ability of the operating system to utilize the equipment capacity and availability. It depends on production planning and control, the personnel and the safety. Motivation of the personnel involved, has major influence on the operational performance.
- Capacity performance: the ability of the equipment to produce at the rate capacity with specified product quality.
- Reliability performance: the ability of the equipment to perform the requested function when operated. If the function obtained does not meet the specification the equipment has a failure and needs maintenance. Normally measured in probability function-The Weibull reliability function R, or mean time between failure = MTBF, by [2].

  Failure rate = λ = 1/MTBF, t = specified period of failure:

$$\text{Re}\,liability = (t) = (\lambda \times t) = e^{-}\left[\frac{t}{MTBF}\right] = \left[\frac{-t}{MTBF}\right]$$

$$R(t) = \exp\left[\frac{-t}{MTBF}\right] = \exp(-\lambda t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

- Maintainability performance: The properties determining the mean time to repair measured in 'mean-time-to-repair', MTTR, which has little to do with the performance of the maintenance resources but more dependent on the design and installation of the production equipment relative to time. Where μ = the repair rate = 1/τ, and τ = the restoration time or duration outage, i.e. MTTR (= τ)

$$(Mt) = \exp\left[\frac{-t}{MTTR}\right] = \exp(-\mu t) \ldots\ldots\ldots\ldots(2)$$

  Maintainability
- Support performance: the ability of the logistics support system, or maintenance system to provide support to the equipment when maintenance is required. It depends on the organization of the maintenance procedures and the resources available (e.g. tools, personnel, skills and spares). The performance is measured as the mean waiting time (MWT) or mean logistic down time (MLDT). The theoretically correct method for computing the availability performance, A, is to use the calendar time as 100%. This approach is mostly used for systems that are supposed to work round the clock, such as the process industry. [2].

$$MLDT = \frac{Down\ time}{Number\ of\ failures} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

MLDT = MTTR - MWT

Availability = the ability of a power plant to be in a state to perform a required function under given conditions at a given time over a time.

Therefore,

$$Availability(A) = \frac{PPT - DT}{PPT} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$Or\ Availability(A) = \frac{MBTF}{MBTF - MDT} \times 100\% \ldots\ldots\ldots\ldots\ldots(5)$$

Since MLDT = MTTR + MWT

$$Therefore,\ (A) = \frac{MBTF}{MBTF + MTTR + MWT} \times 100\% \ldots\ldots\ldots\ldots(6)$$

Absolute availability is based on calendar time (8760/annum = 730h/month = 183h/week). Planned production time includes all the available hours in a year (8760h).

$$A_{abs} = \frac{Calendar\ time\,(8760h/a) - down\ time}{Calendar\ time} \times 100\% \ldots\ldots\ldots(7)$$

$$MBTF_{abs} = \frac{Calendar\ time\,(8760h/a) - down\ time}{Number\ of\ failures\ over\ Calendar\ time} \times 100\% \ldots\ldots(8)$$

$$A_{abs} = \frac{MBTF_{abs}}{MBTF_{abs} + MDT} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Relative availability is based on a planned production time. The values are real and they indicate the real failure behavior state of isolated identical equipment in any process plant.

$$A_{rel} = \frac{PPT(8,16,24\,h) - DT}{PPT} \times 100\% \qquad (10)$$

$$MTBF_{rel} = \frac{PPT(8,16,24\,h) - DT}{Number\ \ of\ \ failures\ over\ calendar\ time} \times 100\% \qquad (11)$$

$$Therefore, A_{rel} = \frac{MTBF_{rel}}{MTBF_{rel} + MLDT} \times 100\% \qquad (12)$$

The method chosen for processing data depends on the amount of data, availability of computer-data based system and the parameters that are to be estimated. If measures of reliability and availability such as mean time between failure (MTBF) or µ and the mean time to repair or mean repair time (MTTR) or ϴ are to be found. The values of these are defined directly as:

$$\mu = (MTBF) = \frac{Total\ \ Operating\ \ time}{Number\ of\ \ failures} \qquad (13)$$

$$\theta = (MTTR) = \frac{Total\ \ repair\ \ time}{Number\ of\ repairs} \qquad (14)$$

For example, if a process plant has M identical units in operation over a total period of time T, during which N failures occurs, then the estimated values of these parameters becomes:

$$\hat{\mu} = \frac{1}{N}\sum_{i=1}^{N} tf_i \qquad (15)$$

$$\hat{\theta} = \frac{1}{N}\sum_{i=1}^{N} tr_i \qquad (16)$$

Where tf_i and tr_i are the individual times to failure and repair; in many cases the total repair time is relatively small and since

$$MT = \sum_{i=1}^{N} tf_i + \sum_{i=1}^{N} tr_i \qquad (17)$$

$$Then, \mu = \frac{MT}{N} - \theta \approx \frac{MT}{N} \qquad (18)$$

Alternatively using the mean time between failure (MTBF) and then mean time to repair (MTTR) for N failures.

$$Time\ \ Lost = N\hat{\theta}$$

$$Availability\,, A = \frac{N\hat{\mu}}{N\hat{\mu} + N\theta} \qquad (19)$$

$$Time\ \ elapsed = N\hat{\mu} + N\hat{\theta} \qquad (20)$$

$$Therefore,\ \ Availability = \frac{Uptime}{Uptime + Downtime} \qquad (21)$$

$$A = A1, A2, A3 \ldots\ldots An = \frac{n}{\pi} A_i$$

$$A = 1 - \sum_{i=1}^{n} U_i \qquad (22)$$

Where Ai = Availability of major equipment or system
U_i = Unavailability = I - A……………………………… (23)

3.1 Overall Equipment Effectiveness OEE

Equipment performance and reliability have become major concerns as business reorganize, down size and aggressively pursue “lean” principles. In order to streamline the industry there are some certain salient cause of actions: first, to find out why the equipment is not doing what they ought to do every time; secondly, find the causes of poor performance and thirdly, to find what should be focused on.

Measuring and improving machinery performance is presently a typical issue in facilities, manufacturing and processing plants. The basic measure associated with TPM is OEE. It incorporates the basic indicators of equipment performance and reliability.

- Availability or uptime (downtime: planned or unplanned);
- Performance efficiency (actual versus design capacity); and
- Rate of quality output (yield).

Some loses involved in OEE includes:
Availability losses: where breakdowns and changeovers indicate situation where the line is not running, whereas it should.
Performance losses: where speed loses and small stops/empty positions indicate the line is running, but not producing outputs.
There are also losses due to start ups. These losses lead to the OEE indicator, which shows how efficient the process or system is.
The overall equipment effectiveness (OEE)
Calculation of OEE: [8].

$$Availability = \frac{Operating\ \ time}{Planned\ \ production\,time} \text{...}(24)$$

Availability takes into account downtime losses. It is the amount of time the equipment actually was running as a proportion of time it could have been running.

$$Performance = \frac{Actual\ output\ of\ the\,equipment}{Ideal\ output\ \ of\ the\ \ equipment} \text{...}(25)$$

The equipment performance is the actual output of the equipment as a percentage (%) of the theoretical output running at its rated speed and actual run time.

$$Quality = \frac{Good\ \ \mathrm{Pr}\,oduct}{Total\ \ product} \text{..}(26)$$

The quality takes into account quality loss.
OEE = Machinery Availability x Performance Efficiency x Quality Rate... (27)
Where,
Availability = Percent of scheduled production or calendar hours (24/7/365) that the equipment is available for production. It measures the percent of time that the equipment can be used, usually total hours per annum of (61320) hours divided by the equipment uptime (actual production).
Performance rate = Percent of parts produced peer time frame; it is the percentage of available time that the equipment is in use at its theoretical speed for the individual context. It measures speed losses.
Quality rate = Percent of good products/service produced out of total parts produced per time frame. The OEE Percentage is obtained by multiplication of the three ratios: Availability, performance rate and quality rate, [5].

4.0 TPM application method

Thomas Clarke, 2001 argued that knowledge management initiatives are unlikely to be successful unless they are integrated with business strategy and related to the development of the capabilities of the organization. Similar claims noted by [3], that knowledge is only authentic if it can be put to work. Therefore, the learning to know pillar is not enough in existing TPM. Hence this study will follow the four pillars of life learning. (Learning to know, do, be and live together) should be built into TPM. Wisdom could be described as the best use of knowledge, [6] [7]. Knowledge processes are always to be objective. After the members learn to know what TPM is, they have to learn how to do and implement it in the work place wisely.

The goal of all TPM members should be creating competence. Top management and shareholders should be committed to the policy as ultimate goal. They have to communicate clearly this new direction to all employees and to make sure that everyone within the organization understands the TPM strategies thoroughly and acquires the competence not only the skill. [15], affirms that top management must have passion for successful application of the policy and without the sustained passion, management direction and energy maybe diverted to another pressing need. Again, he stated that successful application occurs in organization where executive “walk the talk” teaching new behaviour by examples. The determinants of success of enterprise are ever more reliant upon their effectiveness in gathering knowledge and inventory that is competence. In applying TPM, organizations require coordination of complex activities: planning and inventory, therefore competent employees are all needed to operate the system. Top management should be monitoring, pay visits, training and provision of adequate resources and high morale for the employees and making room to strengthening personal relationship and usual circles to discuss common problems. The TPM as a policy is uncovered when an organization conducts an analysis of its current maintenance policies and practices and benefits are gained by following a disciplined process;

- conduct an internal audit of the process or processes;
- education of key personnel in TPM processes is critical at this point; they must fully understand and support the process;
- highlight potential areas for improvement: this requires understanding the cost of TPM compared to financial benefits that will be derived. This should be presented in an investment business issues;
- do research to find three or four organizations with superior process in this area identified; contact these organizations and obtain their cooperation for benchmarking-TPM;
- develop a pre-visit questionnaire highlighting the identified areas for improvements; this step requires a carefully planned approach toward TPM; discipline is needed to adhere to the plans;
- perform site visit to three or four partners, an interim report should be presented to the executives;
- perform gap analysis on the data gathered compare to the organization;
- develop a plan for application: the model of TPM sees people as both the source of and solution of problems. In this paradigm, solution of problems might be seen as fixing people (i.e. training employees to improve attitude). TPM emphasize that organization survival is contingent upon the effectiveness of the system of the organization. In TPM management there is a rule of the thumb which is called 85/15. Rule which suggests that the root causes of organizational problems is attributed to 85% of a faulty system and that few 15% are the result of behavior of employees.

Today the language of process industries clearly signal managerial transition to adopt a new decision making criteria and new course of action, namely corporate sustainability. However, the event in the most industry arena nowadays reveals that the currently adopted maintenance policies are not good enough and not exclusively economic in nature, but should take into account the social and environmental considerations in appraisal of machinery security.

4.1 TPM model for optimal performance

The model is based on the TPM seven pillars as previously discussed. The model for maintenance policy decision has been based on a mutual collaboration in the form of action research. Therefore, the model is based on the different perspective of practical challenges and theoretical developments thus making the model of industry and research meet. The model is hopefully incorporating the best of all models of modern innovations in TPM, thus contains the challenges experienced in the maintenance organizations and the study is seen as multi-disciplinary in nature. This is due to the problems encountered in the industry and points towards the need for action in a theme covered by this study, a cross-fertilizing so to speak between scientific disciplines of management and technology, social and business enterprise. Another challenge unearthed by this action is that of quality management inclusion. Perhaps inclusion is not the correct term indeed; but preferably could organizational change because the adaptation of the model like one in this work requires a lot of changes in organization routines and practices of the modern industry. This takes time and effort and additionally requires organizational learning on a large degree of attention, [1] [6]

Under the current definition of TPM, the term also used refer to a philosophy, or methodology to drive out waste, improve quality, cost and the time performance of any business. The concept of TPM is applied through a simple model referred to as DMAIC (Define, Measure, Analyse, Improve and Control) analogous (similar, equivalent, but appearing independent) to model as TQMEX or quality management process model. It offers tremendous potential and the more effort there is to institutionalize and restructure it properly, the more benefits can be derived in structure, strategy and system.

The greatest impact is the customer expectation and satisfaction and on time delivery and entrepreneurship. In order to appreciate the impact of TPM in innovation and optimal performance perspectives, one would have to look at the industries in the West, like Motorola, and General Electric etc. under the inter-disciplinary, encompassing all activities of a modern enterprise, TPM concepts appear to be essential to achieving global competiveness. TPM is a product of learning which can offer operational returns in practical business and a potential for radical change which makes it more attractive. The process brings excellent structure for behavioural mind-set for the behalf of continuous improvement that is essential for making concepts for value creation and ultimately to zero defects, zero downtime and zero accidents.

The challenges as we turn to 2020s is to turn to the organization vision “outside in” to measure the parameters of the customer needs and processes and work towards zero variability in service to customers needs and processes. World class studies have indicated that organizations are aroused for TPM concepts; so there is complete hope for improvement for all. The caveat here is that the focus has to be on the customer needs and process not the product. Industries embarked on TPM have to be driven by market opportunities and customers needs rather than just the need to improve profitability. The ultimate suggestion from this study on TPM is to focus on quality and continuous improvement and productivity for optimal performance shown in the Figures 4 and 5

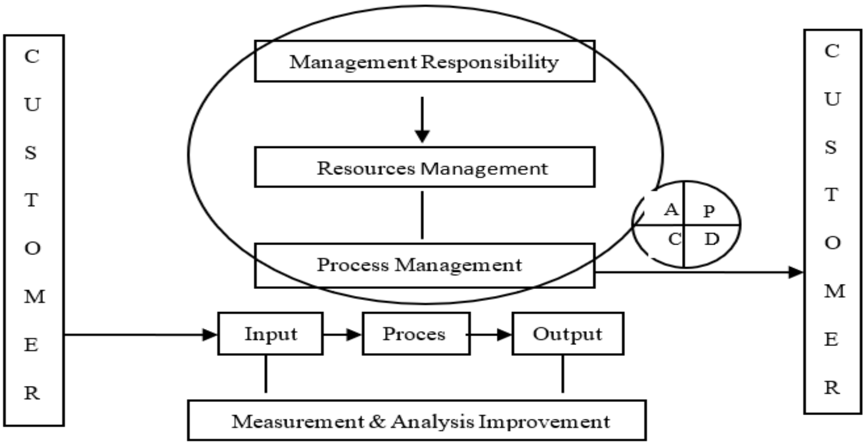

Figure 4: Quality improvement process model

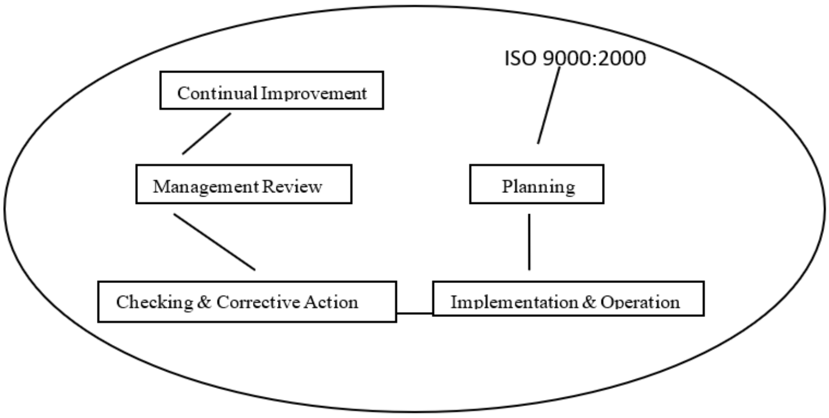

Figure 5: Corrective improvement through Deming's PDCA circle

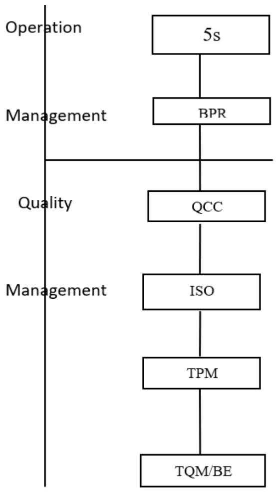

Figure 6: TQMEX – Quality management process model

5s= Seiri, Seiton, Seiso, Seiketsu, Shitsuke.
Sort, Set in order, Shine, Standardize, Sustain.
BPR: Business Process Reengineering
QCC = Quality Control Circle
TPM = Total Productive Maintenance
TQM = Total Quality Management
BE = Business Excellence
ISO = International Standard Organization. (Standardization for quality)

5.0 Conclusion remarks

Managers can see the significance of structures, strategies and systems, the connectedness of events and interpret data by participation observation i.e. principle of social organization, the distinction between development management and management development. Maintenance engineering is a complex issue that normally incorporates at least three disciplines: economics, management and accounting. In order to select appropriate maintenance techniques and design a suitable maintenance framework for a particular organization, a number of factors must be considered. The choice for suitable maintenance technique depends on a number of factors;

- purpose of the maintenance;
- level of detail required;
- time available for the maintenance;
- existence of available predetermined data and resources and;
- life cycle cost of maintenance.

This study show that TPM will indeed solved most of these limitations of traditional ways of maintenance. For examples, the use of OEE and 5S are excellent examples of strategically driven TPM. Furthermore, this modern framework is trying to raise the benchmark for maintenance to avoid information overload and guide against sub-optimization. The important requirement of TPM is that there must be a clear link between performance measures at different hierarchical levels in an organization, so that each function and department strives towards the same goals. The purpose of TPM is to link an organization strategy with its operations by translating objectives from the top down (based on customer's priorities) and measure from bottom up.

The most urgent task for modern industry today is to take a hard look at the future. To remain and sustain performance optimally, management must nurture a strong capability for self-development and strong corporate culture, both of which form part of the foundation for improvement. In order to overcome some of the limitations encountered in maintenance framework based on the seven pillars of TPM i.e. (focused improvement, autonomous maintenance, planned maintenance, quality maintenance, education and training, early equipment maintenance and safety and environment) are critical to obtaining success and each case study highlights the means of putting these pillars in place.

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