

Development and implementation of preventive-maintenance practices in Nigerian industries

M.C. ETI*, S.O.T. OGAJI**⁺ and S.D. PROBERT**

*Mechanical Engineering Department, Rivers State University Of Science And Technology, PMB 5080 Nkpolu, Oroworukwo, Port Harcourt, Rivers State, Nigeria

** School Of Engineering, Cranfield University, Bedfordshire MK43 OAL, United Kingdom.

⁺ Corresponding author

Abstract.

A methodology for the development of PM using the modern approaches of FMEA, root-cause analysis, and fault-tree analysis is presented. Applying PM leads to a cost reduction in maintenance and less overall energy expenditure. Implementation of PM is preferable to the present reactive maintenance procedures (still prevalent in Nigeria).

Keywords: PM, changes, challenges, Nigerian industries.

Abbreviations

CBM	Condition-based maintenance
CM	Corrective maintenance
FMEA	Failure modes and effect analysis
JIT	Just-in-time
MMP	Maintenance-management process
MTBFs	Mean-time between failures
OR	Operational research
PM	Preventive (or proactive) maintenance
RCA	Root-cause analysis
RCFA	Root-cause failure analysis
RCM	Reliability-centred maintenance
REP	Reliability-engineering principles
RM	Reactive maintenance
RTF	Run-to-failure
TPM	Total productive-maintenance
TQM	Total quality-maintenance

GLOSSARY

Reliability

Higher plant-reliability leads to reductions in the (i) frequency of equipment failure and (ii) wastages of energy. Failures decrease production as well as erode profits. Hence it is desirable to:

- deal effectively with each type of failure;
- move towards a more proactive-maintenance approach;
- address how to extend the run length between shut-downs i.e., the mean-time between failures (MTBFs); and

- harness the cooperation of all those involved in or affected by the maintenance functions

So consideration is focused on equipment condition, operation standards, reasons for deteriorations, the quality-management approach to improve the output, while simultaneously significantly reducing the overall operational cost. Hence ways are sought to install maintenance methodologies that will significantly reduce operational and maintenance costs by focusing on the root cause of failure through creating a sense of ownership in each of the plant-equipment operators, maintainers and support staff so as to encourage 'a prevention of problems at source' attitude. Two compatible processes, namely, reliability-centred maintenance (RCM) and total productive maintenance (TPM) are likely to help confront and overcome these challenges. A strategic framework methodology will be developed for developing a cost-effective maintenance plan by identifying:-

- what is wanted of the plant/equipment?
- what the plant/equipment can do?
- in which way may it fail to meet the requirement?
- what can be done to ensure that the equipment meets expectations in a safe and cost effective manner?

Preventive Maintenance (PM)

In PM, the system which is highly likely to exhibit a demobilising fault is replaced before that failure is allowed to occur. The most common forms of this policy are scheduled PM and condition-based maintenance (CBM). In the former approach, the PM action is performed on the item at a scheduled time regardless of its actual condition. Because the schedule is often drawn up on the supplier's recommendation, but made with either only limited local knowledge of the actual use conditions or from past experience, it is seldom an optimal procedure. PM schedules that minimize resource consumption or maximize availability can be determined through the use of quantitative decision-models, based on factual information such as time-to-failure distributions, cost of intervention (e.g. for inspection, repair or replacement) and consequences of failure. Models for the optimization of PM decisions have been published [1-3].

Condition – based maintenance (CBM)

Under the regime of a scheduled PM policy some components may be over maintained, that is replaced prematurely. However, if the condition of the item can be monitored continuously or even frequently, PM actions will be implemented only when failure is judged to be imminent. This is the basic concept of CBM. Performance-parameter analysis, vibration monitoring, thermography, oil analysis or ferrography are some condition-monitoring techniques that are involved in CBM. Each of these methods will reveal a specific type of fault. For example, vibration-monitoring can be employed to detect wear, imbalance, misalignment, loosened assemblies or turbulence in plant with rotational or reciprocating parts. For optimizing replacement decisions, an operational-research (OR) models which takes into account the information obtained from monitoring, has been described by Markis and Jardine [4]. A survey of the recent CBM models can be found in Tsang [5].

THE CHALLENGE

Proactive maintenance (PM) should reduce the need for reactive maintenance (RM). Effective PM activities enable a company to achieve a ratio of more than 80 percent PM to less than 20 percent RM. Once the ratio complies with this, other maintenance practices become more effective. However, less than 1 percent of those employed in industries in Nigeria understand that PM programmes are effective.

Today's competitive environment requires that industries sustain full productive capacities while minimizing the required capital investment. From the maintenance perspective, this means maximizing equipment reliability (and hence up-time), by extending each individual component's life. This proactive shift requires total quality-maintenance (TQM), that is the planning and implementation of preventive maintenance involving both operational and maintenance staff. TQM is based on:-

- having a maintenance organization and administration
- maintenance-management information process
- technical documentation
- logistics support
- measures of effectiveness
- work control
- multi-skill workforce
- maintenance tasks
- maintenance and reliability engineering.

As production systems have had to become more competitive, reducing downtime has grown in importance. In refineries, the maintenance and operation departments are often among the largest and each may require about 30 percent of total staffing [6]. Maintenance preserves the functions of assets, and affects issues such as product quality, customer service, economy of operation, compliance with environmental regulations, and even the physical appearance of the asset [7]. Routine maintenance is about reducing the occurrence of failure and diverting energy expenditures away from activities, which have little or no effect on the overall operation.

Maintenance policies should be formulated by personnel involved in the production and maintenance operations. The role of management is to provide the tools to help operators make the right decisions and to ensure that those decisions are sensible and defensible. A successful, sustainable maintenance programme will probably only be developed by maintenance personnel and the users of the assets working together.

Improving maintenance procedures usually require [7]:

- a change of attitude; and
- getting maintenance personnel to apply the resulting proposed changes one at a time, ensuring each time that an improvement occurs.

Maintenance has recently become ever more challenging [8] because:

- The conventional wisdom-embracing "economics of scale" is losing followers. An increasing number of organizations have switched to lean

manufacturing, just-in-time production and/or six-sigma programmes. These highlight a shift of emphasis from achieving a high volume rate of output to a quick response, elimination of waste and defect prevention. Because of the elimination of slack in such ever more demanding environments, then breakdowns, speed loss and erratic process yield will create occasional crises for the timely supply of products and services to customers. Optimizing the maintenance of the production system and the effective development of manpower to perform the maintenance activities are crucial to support these emerging operation strategies.

- Rapid technological changes

In the past, companies tended to produce adequate, standard goods and services to satisfy the insatiable demands of customers: these companies were protected from the onslaught of outside competition through regulation or the imposition of trade barriers in their home market. Production runs tended to be long due to technological changes being implemented only poorly and the tolerance of customers who would accept what was available. Most people perceived work merely as a means of earning a living. However, especially in affluent societies, even then personnel tended to want to improve their quality-of-life at work. Improvements in available education and increased loyalty in progressive organizations has led to highly successful horizontal management-structures, self-managing teams, virtual organizations and strategic alliances: some of these would be appropriate for improving today's maintenance services in Nigeria.

MAINTENANCE IN NIGERIAN INDUSTRIES

Effective maintenance ensures that the equipment is capable of doing what it was designed to do, when required. In Nigerian industries, maintenance is not given a high priority and hence plants are often under utilized and run at high costs. The problems are that:-

- Not many senior managers have pertinent knowledge and maintenance experience.
- There is no maintenance education course in Nigeria universities
- Maintenance budgets are inadequate
- Many organizations regard maintenance as a cost centre rather than a business centre.

These challenges are difficult to overcome but nevertheless maintenance is often the major activity, accounting for up to 40% of total costs, in some Nigeria companies. Poor maintenance can result in lost production, poor end-product quality and customer dissatisfaction. The following pertinent problems have been identified within Nigeria industries.

- Maintenance is not regarded seriously even at local management level
- Maintenance lacks a business culture (e.g. undertaken without business plans, ineffective budget allocation; and unfocused reports produced.)
- Maintenance supervisors and team leaders frequently lack management skills.
- Maintenance often remains isolated, with little integration with the functions of other departments (e.g. production)
- Only low levels of planned maintenance are implemented.

- Recently, however there has been a preoccupation with the introduction of advanced maintenance methods, which fail due to a lack of basic maintenance ethos existing.
- Regular scheduled overhauls (i.e. usually the current practice) are incompatible with achieving recommended maintenance practice as implemented by the worlds leading industries.

In most companies in Nigeria, repairs and replacement only ensue after a breakdown. Also failure data are rarely available. In the traditional general management of companies, maintenance is regarded as an expense that can easily be reduced in relation to overall business costs, particularly in the short term. This is a misguided opinion. However, to increase the availability and reliability of equipment, more commitment is needed to maintenance. It is now increasingly realised that achieving high-quality maintenance requires prevention at source and a focus on identifying and eliminating the cause of equipment deterioration rather than the more traditional approach of either letting the equipment fail before repairing it or “fire fighting” in the case of an emergency. Maintenance practice improves with the adoption of benchmark standards arising from the worlds best, and having pertinently trained personnel with commitments to continual professional development.

Two proactive maintenance practices (RCM and TPM) have been identified and their implementation recommended [9]. RCM is a structured, logical process for developing or optimizing the maintenance requirements of a physical system to realize its “inherent reliability”. This reliability depends on both the equipment’s design, construction and how it is used. RCM is a methodology based on the following precepts;

- failure is an unsatisfactory condition;
- the consequences of failure determine the priority of the maintenance effort to be expended;
- equipment redundancies should be eliminated;
- CBM or predictive-maintenance tactics are favoured over traditional fixed-period schedules methods; and
- where warranted, run-to-failure is accepted.

The high-quality approach of prevention at source was translated to the maintenance environment through the concept of TPM [9]. This results in superior availability, reliability and maintainability of the equipment and also in significant improvements in capacity with a substantial reduction in both maintenance costs and total operating cost. TPM is focused on applying preventive/predictive strategies to identify and repair equipment before deterioration ensues.

- Total productive maintenance (TPM) involves all production personnel in appropriate maintenance tasks via the use of self-directed small work groups [10].
- Root-cause analysis (RCA) classifies the problem into associated categories, such as people, procedures or hardware, and tries to prevent recurrences of the problem.
- Reliability-engineering principles (REPs) are applied to solve problems so leading to reductions in the overall cost arising from unreliability.

Visser [11] modelled maintenance as a transformation process encapsulated in an enterprise system such as shown in figure 1. The way maintenance is performed will influence the availability of production facilities, the rate of production, quality of end-product and cost of production, as well as the safety of the operation. These factors in turn will determine the profitability of the enterprise.

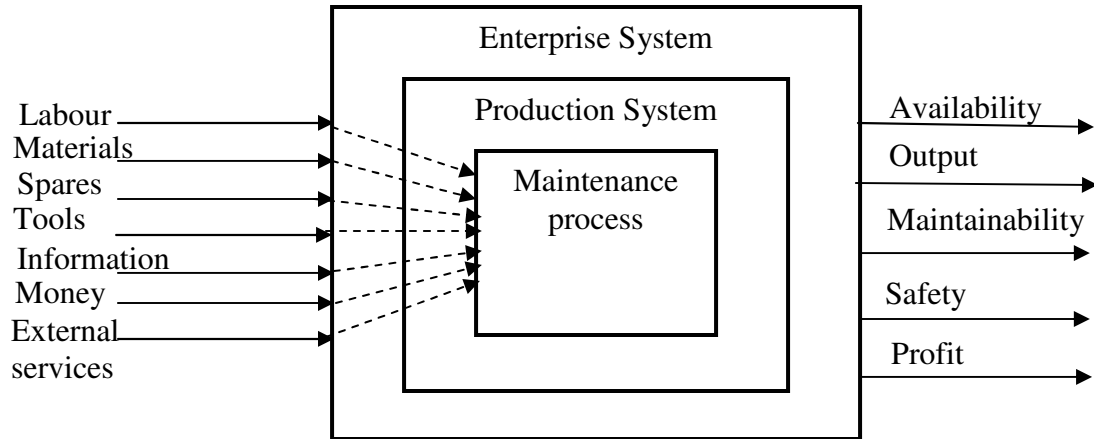


Figure 1. Input-Output model for an activity

The four strategic dimensions of maintenance [8] are:

- Service-delivery options i.e. the choice between using an in-house capability and an outsourced service.
- Organization of the maintenance function and the way the task is structured.
- Maintenance methodology, i.e. the selection of the preferred maintenance policy or policies.
- Design of the infrastructure that supports the maintenance function.

Unprecedentedly high business-performance can be achieved if the available skills and resources are focussed on a limited set of core competences, i.e. a bundle of skills and technologies that enable one to provide a particular benefit to customers [12]. Thus, maintenance activities for which the company has neither a strategy nor the special expertise required are prime candidates to be outsourced. Maintenance activities, which the company can typically outsource, include the maintenance and repair of electronic and environmental equipment, mobile vehicles and buildings [1].

The appropriate maintenance approach can be determined using RCM methodology, which provides a structure for determining the maintenance requirement of any physical asset, with the primary object of reducing the system's function-cost [7, 1]. Performing a system's function failure analysis, for the first time, is labour intensive and time consuming. RCM draws on the operators' intimate knowledge about the deteriorating equipment and requires their resourcefulness to develop innovative, more cost-effective ways of performing the PM tasks. The collaboration should nurture teamwork spirit between operational and maintenance personnel, replacing the adversarial relationships and disputes arising from the perceived boundaries of responsibilities, which commonly

exist. Furthermore the learning, deductions and communications arising from RCM studies will enhance the intellectual base of the organisation [8].

The optimization of inspection, maintenance and replacement-decisions depends on the availability of high-quality pertinent data [8]. E-maintenance, an emerging concept that exploits the potential of digital technologies, offers new options to deal with this challenge. An important restraint that inhibits the rapid adoption of e-maintenance is the security concern associated with transactions over the internet. Risk management in e-maintenance activities involves a trade-off between production on the one hand and functionality, performance and ease-of-use on the other [13]. Careful requirement-identification, ensuring a systematic approach with clear aims and goals, is needed when performing a risk analysis [14]. Each study should establish the importance of a well-planned requirement specification and the need to analyze and interpret risk-analyses before making maintenance decisions. Prioritization within maintenance has become increasingly important in several branches of industry due to the increased competition. In order to maintain at least adequate profit-margins, organizations have to control maintenance costs. However, in doing so, they need to minimize or eliminate risks to individuals, the environment and utilised physical assets. In order to identify faults in terms of where they are located in a system and how serious their consequences are, a risk analysis should be a prerequisite to any major operation. This will provide guidance as to where maintenance actions should be directed. RCM uses function analysis, in combination with risk analysis, in prioritizing the required maintenance actions [7].

Through the 1980s, in the USA and Japan, the developed corporate maintenance strategies involved significant paradigm shifts, such as uptime maintenance, inter-trade flexibility within the maintenance workforce, as well as the amalgamation of the roles of plant operators and front-line maintenance personnel. This paved the way for the introduction of autonomous maintenance, a key element of TPM [15], which required the implementation of following procedures:-

- Cultivating a sense of ownership in the operator by introducing autonomous maintenance, i.e. the operator takes responsibility for the primary care of his/her plant.
- Optimizing the operator's skills and knowledge of his/her plant in order to maximize operating effectiveness: the operator is thus mobilized to detect early signs of wear, maladjustments, leaks, errant chips or loose parts. He/she is also involved in making improvement suggestions to eliminate losses due to the breakdown or sub-optimal performance of the plant.
- Using cross-functional teams, consisting of operators, maintainers, engineers and managers to improve the overall-plant's performance.
- Establishing a schedule of clean-up and preventive maintenance to extend the plant's life-span and maximize its uptime.

RCM is an asset-centred methodology, with a primary focus on making decisions with respect to the type of maintenance tasks to be undertaken. TPM, on the other hand, focuses on people and is an integral component of total quality-management (TQM). The methodology was developed in Japan's manufacturing industries, initially, with the aim

of eliminating production losses due to machine breakdowns in just-in-time (JIT) production processes. TPM usually requires changes in employees' attitudes and their standards of behaviour, which may take a long time to accomplish. Senior managers must demonstrate their commitments to TPM by devoting and allocating sufficient resources to create and sustain cultural changes, e.g. to provide the necessary training for all involved personnel to achieve autonomous maintenance.

Introducing the strategic initiatives, such as multi-skill, inter-trade flexibility, outsourcing, RCM, TPM, as well as the redesign of work processes and structures, often fails to deliver the expected benefits [8]. The main reason for this is that the required ethos, management behaviour and processes (including pertinent information collating and use, training, performance management and rewards) were not in place when the paradigm change programmes were implemented.

MAINTENANCE MISSION

It is wise to develop a formal mission-statement to help maintenance personnel perform well [16]. "Maintain" means "cause to continue". Maintenance exists because we have physical assets which deteriorate. The function we wish to preserve must be one the user wants it to be. Maintenance affects three distinct sets of customers - the owners of the system, its users (usually the operators) and society as a whole. Owners are usually satisfied if their system generates a satisfactory financial return on their financial investment. Users are satisfied if their system continues to operate at the required standard of performance. Society as whole is satisfied if the system does not fail in any way that threatens public safety or damages the environment.

The technology of maintenance is concerned with finding and applying suitable ways of managing or preventing failure. Failure management includes predictive and preventive maintenance, failure-finding, run-to-failure and necessary one-time changes to the design of the system or the way it is operated. Each category includes a host of options, some being more effective than others. Maintainers not only need to learn what these options are, but also have to decide which are worthwhile applying in their own organizations. If they make the right choices, it is possible to improve a system's performance and simultaneously contain or even reduce the cost of maintenance. If they make wrong choices, new problems arise while existing problems get worse. So the mission statement should stress the need to make the most cost-effective choices from the full array of options.

Failure can affect output, safety, environmental integrity, product quality, customer service, protection and operating cost in addition to incurring repair costs. The severity and frequency with which a failure occurs make these consequences dictate the type of failure-management technique that is worthwhile applying. So the mission statement should acknowledge the key role of consequence avoidance on the maintenance procedures employed. The most effective maintainers are those who apply the required available resource – people, spares and tools – at minimum cost, but not so cheaply as to reduce the long-term functionality of their system. In other words, the lifetime cost of ownership must be minimized.

Finally, the mission statement must recognize that maintenance depends on people including designers, constructors and operators. Everyone involved should share a common and correct understanding of what needs to be done, and to be able and willing to do whatever is required right first-time, every time. Hence the mission statement should emphasise;

- Preserving the function of the physical system throughout its useful life.
- Satisfying the system's owners and users, as well as ensuring the safety of the society.
- Selecting and applying the most cost-effective techniques for managing the consequences of failure
- The active support of all the personnel involved

MAINTENANCE STRATEGY

It is usually far more difficult to develop and implement a strategy that enables the maintenance enterprise to accomplish a mission than to devise that mission. There arise such questions as Where do we start? Do we buy a new maintenance-management process (MMP)? Reorganize? Invest in condition-monitoring equipment? Pull down the whole system and rebuild? The answers lie at the beginning of the mission statement, i.e. to preserve the functions of our equipment. It is only when these functions have been defined that it becomes clear what maintenance is trying to achieve and so what is meant by "failed" or "failure".

Once the failure causes or failure modes and their effects have been identified, we are in a position to assess how and which matter: this, in turn, enables us to determine which of the full array of failure-management options should be used. This is termed work identification [16]. When the maintenance requirements have been identified in detail, the next step is to decide what resources (people, tools, energy, materials, etc) are needed to undertake each task. Then the following questions should be answered:-

- Who is to undertake each task? A multi-skilled maintainer? The operator? A contractor? The training department (if it exists)? The engineering department (if the equipment has to be redesigned)?
- What spares and tools (including condition-monitoring equipment) are needed to complete each task?

It is only when the resource requirements are fully understood that we can decide exactly what is needed to manage the resources in such a way that the tasks are completed effectively. Looking at the maintenance requirement, in the context of the function of each system (by seeking to understand what it does), transforms the way in which the requirements are perceived.

The development and execution of a strategy consists of three steps:-

- Formulate a maintenance programme for each component (i.e. work identification).

- Acquire the resources (i.e. skilled personnel, spares and tools) needed to execute the procedure effectively
- Execute the campaign (i.e. acquire, deploy and operate the systems needed to manage the resources effectively).

Failure-Management Policies

These fall into two categories:

- Proactive tasks: these are undertaken soon before a failure is likely to occur, in order to prevent the component from failing. Subdivisions of these tasks include scheduled restoration, scheduled discard and on- condition maintenance.
- Default actions: these, e.g. failure- finding redesign and run-to-failure, deal with the failed state and are chosen when it is not possible to identify an effective proactive task.

Planning the project requires that clear objectives are established, a detailed plan composed and adequate resources allocated. Preparation entails everyone in the organization clearly understanding what the feasible maintenance acts can or cannot achieve and what must be done. Selecting the appropriate materials requires systematically defining the function and required performance standard of each component, deciding what failures are reasonably likely to occur, assessing the effects and consequences of each failure, and selecting a failure-management policy that deals appropriately with the consequences.

RELIABILITY-CENTRED MAINTENANCE (RCM)

This is defined as a process used to determine what must be done to ensure that any physical component continues to do whatever it was designed to do under the existing circumstances. It entails asking questions about the asset under review, namely:-

- What are the functions and associated performance standards required of the component?
- In what ways does the component fail to fulfil its functions?
- What causes the functional failure?
- In what way does each failure matter?
- What can be done to predict or prevent each failure?
- What happens if a suitable proactive remedial procedure cannot be found?

Functions and performance standards

It is only when the function of each component has been defined that it becomes clearer as to what the maintenance process is trying to achieve, and also precisely what is meant by 'failed'. Thus the first step in the RCM process is to define the function of each component, together with the associated required standard of performance. The user of the asset is usually well placed to know exactly what contribution each component makes to the physical and financial well-being of the organization as a whole, so it is essential that the users are involved in the RCM process from the outset.

Functional failures

The objectives of the maintenance process are governed by the desired functions and associated performance-expectations of the system. But how does the maintenance achieve these objectives?

Failure is likely to stop any system performing to the standard required by its user. However before RCM procedures can be applied, a suitable blend of failure-management tools is needed to identify which failures are likely to occur. This is achieved by:-

- specifying what circumstances amount to a failed state
- asking what caused the asset to deteriorate to that failed state?

Failed states (i.e. operational failures) occur when the system is unable to fulfil its function to a standard of performance which is acceptable to the user. This definition encompasses partial failures, where the system still functions but at an unacceptable level of performance.

Failures

Likely failures include those that (i) have occurred with the same or similar equipment operating under similar conditions, (ii) are currently being prevented by existing maintenance schedules and (iii) have not yet happened but are considered to be real possibilities in the context in question.

Most traditional failures include those caused by (i) deterioration or normal wear-and-tear, (ii) human error (on the part of operator or maintainer), and (iii) flaws in the design of the system. These probable causes of equipment failure can be identified and dealt with appropriately. It is important to identify the cause of each failure in sufficient detail for a suitable failure-management policy to be devised.

Failure effects

The next step in the RCM process entails listing failure consequences, which describe what is likely to happen when each failure occurs. In order to support an evaluation of the failure outcomes, these descriptions should include all the pertinent information, such as:

- What evidence (if any) is there that the failure has occurred?
- In what ways (if any) does this failure pose a threat to safety of individuals or the environment?
- In what ways (if any) does the failure affect production or the operation of the plant/equipment?
- What physical damage (if any) is, or could be, caused by the failure?
- What must be done to repair the faulty component?

Failure consequence

A detailed analysis of an average medium-sized industrial undertaking is likely to yield between three and ten thousand possible failure possibilities. Each of these affects the organization, but in each case, the consequences are probably different. The RCM process classifies failure consequences into four groups as follows:

- Hidden failures expose the organization to serious consequences.
- A failure has an operational consequence if it affects production (i.e. output, product quality, customer service or operating costs in addition to the direct cost of repairs).
- A failure has a safety consequence if it results in hurting or killing somebody. It has an environmental consequence if it breaches a corporate, regional, national or international environmental standard.
- Non-operational consequence: evident failures that fall into this category affect neither safety nor operations, so they involve only the direct cost of the repair

The RCM process uses these categories as the basis for devising a strategic framework for maintenance decision-making. By imposing a structural view of the consequences of each failure, it focuses attention on the maintenance activities which have greater effects on the performance of the organization and diverts energy being expended away from those that have little or no effect (or which may even be counterproductive). It also encourages the user to think more broadly about innovative ways of managing failure rather than to concentrate solely on failure prevention.

RESTORATION OR REJECTION

Scheduled restoration entails remanufacturing a component or overhauling an assembly at, or before, a specified age regardless of its condition at the time. Analogously, a scheduled discard entails rejecting an item at, or before, a specified life-limit regardless of its condition at the time. Collectively, these two types of tasks are now generally known as preventive (or proactive) maintenance (PM).

On-condition techniques

These rely on the fact that most failures give prior warning that a fault is about to occur (e.g. a component's temperature rises excessively and can be detected by thermography). Then action can be taken to reduce or eliminate the consequences that could occur if further degeneration into functional failure would ensue. This category of tasks includes all types of PM condition-based maintenance and condition-monitoring.

Failure-finding

This entails checking hidden functions to find out whether they have failed (as opposed to the on-condition task) which entails checking if something is failing.

No scheduled maintenance

This involves making no effort to anticipate or prevent failure modes, and so these failures are simply allowed to occur, and then the system is repaired. This default is also called a run-to-failure (RTF).

Redesign

This entails making an alteration to the structure of the system and possibly to the way it is used: it may require changes to hardware, procedures and, if necessary, training.

RCM TASK-SELECTION

This requires a highly-structured evaluation and policy-selection algorithm for each failure mode. It incorporates precise and easily understood criteria for deciding which (if any) of the proactive tasks is technically feasible in the present context, and also deciding how often and by whom the actions should be undertaken. It incorporates criteria for deciding whether any task is worth doing, a decision that is governed by how well the algorithm deals with the consequences of the failure. Finally, if a proactive action cannot be identified that is both technically feasible and worth doing, the algorithm should lead the user to the most suitable default action for dealing with the failure.

This approach means that proactive tasks are only specified for appropriate failures, which thereby leads to substantial diminution in routine workloads. If RCM is correctly applied to existing maintenance programmes, it reduces the amount of routine work (in other words, tasks to be done on a cyclic basis) in each period, usually by 40 to 70%. If RCM is used to develop a new maintenance programme, the resulting scheduled workload should be much less than if the programme is developed by traditional methods. Less routine work also means that the remaining tasks are more likely to be done more thoroughly. This, together with the elimination of counter-productive tasks, leads to more effective maintenance.

Planning

The successful application of a RCM procedure depends foremost on meticulous planning and preparation. The key elements of the planning process are as follows:

- Define the scope and boundaries of each project
- Define, and whenever possible quantify, the objectives of each project (i.e. describe the end-state required)
- Estimate the period (e.g. for the necessary number of meetings) needed to review the equipment for each productive process.
- Identify the project manager and required facilities.
- Identify participants (by title and by name) in the maintenance activity.
- Plan the desirable training for participants and facilitators.
- Plan the management audits associated with the RCM recommendations.
- Plan the implementation of the recommendations (i.e. maintenance tasks, design changes, and modifications to the operating procedures).

REVIEW GROUPS

Maintenance practices embody the definitions of tasks, functions and missions. A review of the maintenance requirements of any system can be undertaken by small teams, which should include the system's designers, operators and maintainers. The undertaking of this search and analysis must have the full support of the management and adequate resources. The seniority of each group member is less important than the fact that he/she should have a thorough knowledge of the system under review, i.e. have been trained in maintenance functions.

Audit

Once the maintenance review has been completed for each system, senior managers with overall responsibility for the equipment must satisfy themselves that the review is thorough, sensible and defensible. This entails deciding whether they agree with the definitions of function, mission and performance standard required of the considered system. The identification of failure modes and the description of failures affect the assessment of failure consequences and the selection of remedial tasks.

Implementation

Once the maintenance review has been audited and approved, the final step is to perform the agreed changes, tasks and procedures. These must be communicated in a way, which ensures that they will be clearly understood and performed safely by the personnel to

whom they are allocated. The maintenance tasks are then fed into suitable high – and low-frequency maintenance planning and control procedures, while revised operating procedures are incorporated into standard operating manuals.

Planned PM

This involves the repair, replacement, and maintenance of equipment in order to avoid unexpected failures during use. The primary objective of planned PM is the minimization of the total cost (measured as the cost of production or product quality) of inspection, repair and equipment downtime. It provides a critical service function, without which major business interruptions could take place. The other component is unplanned (i.e. unexpected) maintenance [3]. Planned maintenance can be time-based or condition-based [17].

Through continuous improvement, lean manufacturing and lean maintenance one is able to target the identification and elimination of waste of resources. The problem of under-maintaining an asset is often addressed through loss-elimination and continual-improvement programmes. The problem of over-maintaining, by comparison, receives relatively little attention. Left unattended, the over-maintaining of systems continues to increase maintenance costs and squander scarce maintenance resources. Industries in Nigeria have been lax in their approaches to setting PM intervals: for instance

- a high percentage of PM costs are incurred on activities with a frequency of 30 days or less.
- 30 to 40 percent of PM costs are spent on systems with negligible failures.

CHANGING WORLD OF MAINTENANCE

Recently, the importance of proper maintenance has changed significantly due to huge increases in the number and variety of plants, equipment and buildings, which need to be maintained. Some of these systems are now of highly-complex design. New maintenance techniques and modern views on maintenance organization and responsibilities have evolved [16]. Maintenance workers have had to adapt to new ways of thinking and sometimes act as engineers and managers. Simultaneously, the limitations of maintenance systems are becoming increasingly apparent, no matter how much they are computerized!

These numerous trends have made managers everywhere look for new approaches to maintenance. They want to avoid the false starts and dead ends, which always accompany major upheavals. Instead, they seek a strategy framework which synthesises the new developments into a coherent protocol, so that they can evaluate them sensibly and apply those likely to be of significant value to them and their companies [7].

Research

Apart from growing operational expectations, research is changing our understanding about the working lives of components and associated failures. In particular, it has become apparent that there is less and less connection between the operating age of an

asset and how likely it is to fail. A growing awareness of “infant mortality” has led to the widespread belief in the upturned ‘bathtub’ curves of a component’s effectiveness versus operational duration.

New Techniques

There has been explosive growth in new maintenance concepts and techniques. The developments [16] include:

- Decision-support tools, such as hazard-studies, failure modes and effects analyses (FMEAs) and expert systems
- New maintenance techniques, such as condition monitoring
- Designing equipment with a much greater emphasis on reliability and ease of maintainability
- A major shift in organizational thinking towards participation, team working and flexibility.

Challenges Facing Maintenance Personnel

These nowadays are not only to learn what the new techniques are, but to decide which are worthwhile implementing in their own organizations. The challenges facing modern maintenance managers include [7]:

- Selecting the most appropriate techniques to deal with each type of failure in order to fulfil all the expectations of the owners and users of the assets, as well as society as a whole
- Implementing the measures in the most cost-effective and enduring fashion
- Achieving the active support and co-operation of all the personnel involved.

CONCLUSIONS

As unit fossil-fuel costs rise, effective maintenance procedures have become more important in industry in order to reduce energy expenditure and so raise profits. Maintenance efficiency can affect plant availability, costs, business effectiveness and risk, safety, environmental integrity, energy efficiency, product quality and customer service. Because of the complexity of current equipment, repairing and restoration are more difficult and special multi-skill new tools and techniques are needed. Also downtime becomes more apparent and embarrassing: so in a bid to find ways of preventing failure, the concept of PM resulted. Also, as maintenance costs have risen sharply relative to other operating costs, maintenance planning and control systems have attracted far greater interest.

Focus is not only concentrated on availability but also on the related concept of reliability. Improved maintenance procedures such as RCM, TPM, RCFA, and FMEA have been applied to achieve maintenance objectives: the focus is now shifting to highlight those aspects where the inherent design of the system yields probabilities of failure that are unacceptable and so provide some guidance and motivation for improving the effectiveness of the system.

The challenges facing maintenance managers today are not in finding methodologies and approaches to apply, but in understanding how they coalesce with one another. The approach has to be to internalize best practice within the organization, and simply become the universally accepted as the “way we do things around here”

PM activities are primarily condition-based. The condition of a component measured when the equipment is in operation, should govern its planned and scheduled corrective maintenance (CM). A standard CM procedure should be developed and documented. This should define the need for CM as part of PM.

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