Applied Energy, Volume 83, Issue 11, November 2006, Pages 1235-1248.

Reducing the cost of preventive maintenance (PM) through adopting a proactive reliability-focused culture

M.C. ETI[a], S.O.T. OGAJI[b+] and S.D. PROBERT[b]

[a] Mechanical Engineering Department, Rivers State University Of Science And Technology, PMB 5080 Nkpolu, Oroworukwo, Port Harcourt, Rivers State, Nigeria
[b] School Of Engineering, Cranfield University, Bedfordshire MK43 OAL, United Kingdom.
[+] Corresponding author

Abstract.

The economic and political realities of the 1990s forced managers to reverse long-standing organizational cultures in order to reduce costs and energy expenditures in their organisations. For instance, these can be achieved, with respect to maintenance, by replacing a reactive repair-focused attitude by a proactive reliability-focused culture. Thereby far less (i) human effort is expended and (ii) energy would be wasted, both of which lead to increased profitability.

Keywords: Cost reduction, PM, Culture, best practice, Nigerian industries.

Abbreviations

CBP	Current best-practice
CM	Corrective maintenance
CMMS	Computerized maintenance management systems
FTM	Fixed-term maintenance
HR	Human relations
JIT	Just-in-time
PDM	Predictive maintenance
PM	Preventive maintenance
RCA	Root cause analysis
RCFA	Root-cause failure analysis
RCM	Reliability-centred maintenance
ROFA	Return on fixed assets
TPM	Total productive maintenance
TQM	Total quality management

Glossary

Downtime	The period during which a system (e.g. a machine or factory) is not operational, due to a malfunction or undergoing maintenance
Uptime	The period when the system is functioning properly

Introduction

Within many large-scale plant-based industries, maintenance costs can account as much as 40% of the operational budget [1], and therefore improving maintenance effectiveness is a potential source for making financial savings. Today‘s competitive environment

requires that industries try to sustain full production capabilities, while minimizing capital investment. From the maintenances perspective, this involves maximizing equipment reliability (i.e. uptime) including prolonging the equipment's life. Wise operation and careful maintenance should together deliver cost-effective production reliability and this should be the basis for shrewd management decision-making. Unfortunately many industries have been slow to implement PM initiatives. For instance, in Nigeria:-

- ~80 percent of maintenance costs are spent on facilities with a mean time between failures of 30 days or less
- 30 to 40 percent of PM costs are spent on assets with negligible failure track-records, i.e. incorrect priorities are chosen and implemented.

Overall, the goal for an organization is to increase profitability. The maintenance and asset-management function can increase profits in two main ways, i.e. by decreasing running costs and increasing capability. If the annual maintenance cost exceeds 5 percent of the asset value, the organization is probably in financial difficulties. The total maintenance cost depends on the quality of the equipment, the way it is used, the maintenance policy and the business strategy. The wise business owner buys equipment that will subsequently need little maintenance, i.e. is highly unlikely to fail [2].

By automatically monitoring multi-functional printers (displaying the behaviour parameters of the components being assessed), eMaintenance programs can continually track the performance of each component. eMaintenance can provide a customised solution and implement the corresponding preventive process, which can be tailored to satisfy the individual needs, by providing highly-accurate 'prior' information, as and when required, about the performance (i.e. degradation) of each component. With this information, maintenance costs can be reduced, and the production process become more effective.

Maintenance

This should preserve components so that they fulfil their function(s). However continuing operation depends on designers of the equipment, as well as its constructors and its operators, i.e. not just the maintainers.
Developing and executing a maintenance strategy consist of three steps:

- formulate a plan of what needs to be done for each component.(i.e. work identification);
- acquire the resources (skilled personnel, spares and tools) needed to executive the proposed procedure effectively
- implement the strategy (i.e. acquire and deploy the systems needed to manage the resources effectively) [3].

To increase the equipment's uptime, at least cost, is the aim. A proactive profit-focused approach is needed to narrow the gap between actual costs and ideal costs. Downtime seriously bedevils the productive capability of Nigerian industries, so reducing average rate of output, increasing operating costs and interfering with customer service. Downtime can so easily increase as a result of the ineffective implementation of just-in-

time (JIT) and lean total-quality management (TQM) procedures. Hence, the applications of total productive maintenance (TPM) and reliability-centred maintenance (RCM) as company-wide improvement processes are highly desirable. TPM requires operators and maintainers to work together as a team in order to reduce waste, minimize downtime, enhance product-quality, and improve equipment effectiveness.

RCM involves determining what must be done to ensure that any physical component continues to perform in the way that its user wants it to do [3]. Two objectives, must be met:- (i) determine the maintenance requirements, and then (ii) ensure that they are met as cheaply as possible. RCM relies on using pertinent skills, regarding the operation and maintenance of a piece of equipment, through a small multi-disciplinary team. Several root-cause analysis (RCA) techniques have prompted the use of such teams to solve and eliminate one-off, catastrophic and chronic failures. The secret of success is to ensure that all involved personnel are properly trained in these techniques, then to establish the organizational disciplines and procedures that ensure that they are used whenever an appropriate situation arises. It is vital that ownership of the problem is accepted by all involved. Lezlo [4] pointed out that managing people consists of more than controlling their activities: effective management requires appropriate leadership with clear vision and mission, and must make available the funds necessary for implementation of the mutually-agreed programme. The evolutions of TQM, lean management and JIT, brought about TPM. Unfortunately these concepts have not been widely embraced, as yet, in Nigeria. In order to achieve success, the basic principle of a quality-maintenance programme must permeate the entire organization. A factual numerate approach to decision making, respect for other personnel, encouragement of innovation and emphasis on continual improvement rather than focusing on blame when mistakes arise are what is needed, i.e. these are signs of a learning organization.

The Maintenance Challenge

Business leaders increasingly realise the strategic importance of the maintenance function for organizations, which have significant investments in physical assets, and so is a necessary expense in the operating budget. In order words, reliability has become a critical issue in capital-intensive operations.

Unfortunately, in many Nigerian industries, effective maintenance is usually not a high priority and the consequent cost of failures, as a percentage of the total cost, keeps rising. Businesses today need innovation, to break the inherent moulds of perception and redundant patterns of behaviour [5]. Organizations should be changing from a repair-focused to reliability-focused culture. Hence the set goals must provide “something in it for us” for all within the organization, thereby “building-in” commitment. So the leader should formulate these goals with reference to the needs of those working within the organization, and use the goal to shape the future of that organization [1]. Individual rewards must be aligned with the achievement of the company’s strategic goals. These rewards can be both financial and non-financial: the most successful change-initiatives incorporate a blend of the two. The leader must create opportunities for teamwork and organizational learning. The challenge facing Nigerian maintenance mangers today is not

solely to find the appropriate methodologies to apply, but in understanding how they fit together. It also lies in making sure that the application of this approach is not regarded as the latest fad or "flavour of the month", but is fully adopted and internalized within the organisation and simply becomes "the way we do things around here". If wise leadership emanates from the top of the organisation, then the speed of cultural change will be much greater and far wider ranging.

A vision statement should describe what the organization aspires to, whereas the resulting mission statement should explain how the vision is to be achieved. The vision statement for maintenance should be governed by current best-practice (CBP) as the benchmark. PM is usually based on an old-fashioned premise, namely fixed-time maintenance (FTM) overhaul or even replacement of components. This approach is seldom justifiable, because less than 20 percent of all components fail within the usually prescribed periods, and hence the relatively high costs incurred as a result of implementing PM. Thus, if adopted, PM activities should be primarily individual component-condition based, and implemented via a more wisely-scheduled corrective maintenance procedure.

By a comparison of USA and Nigerian industries, it is concluded that more than one-third of all maintenance expenditures in the latter are wasted through ineffective utilization of maintenance resources.

Preventive Maintenance Contribution to Profitability

An important criterion for investment in a company is the financial return on its fixed assets (ROFA). Asset management focuses on achieving the lowest total life-cycle cost to produce the required product or provide a sought-after service. The goal is to achieve a higher ROFA than ones competitors in order to be the lower-cost producer of a product or service. The maintenance management impacts on the ROFA because maintenance costs are a significant contributor to manufacturing costs. If the maintenance cost as a percentage of manufacturing cost fluctuates, then the effectiveness of maintenance should be examined to find the cause of the variation.

Downtime increases the industry's financial expenditure because of the costs of:

- idle production/operations personnel
- late deliveries
- overtime to make up for lost production in order to meet promised deliveries on time
- lost sales as a result of products not being made on time.

However Japanese studies relating to TPM have concluded that "inefficiency" losses tend to exceed downtime losses. In Nigerian industries, most inefficiency losses are never measured and reported. Also, many chronic problems, that have a dramatic impact on equipment effectiveness, are never even comprehended. Only if accurate maintenance records are kept are these problems realised. Then, utilizing the maintenance data, combined with pertinent financial data, a worthwhile estimate of the resulting costs can be achieved. As maintenance is regarded as an expense, any maintenance saving will

contribute directly to the profit achieved. As the effectiveness of maintenance improves and downtime is reduced, there is less need for investment in standby (but otherwise) redundant plant. This will contribute to an overall rise in the ROFA for any organization.

Cost of Maintenance

In the chemical industry, the world's best-performance maintenance processes annually cost 1.8 to 2.0 percent of the current replacement value of the plant. In poorly-managed operations, maintenance costs per year exceed 5 percent of asset-replacement value, i.e. a wastage of $30,000 yearly is typical for every M$ 1 of asset value. The effect of compounding the maintenance cost, taken as $ 30,000 annually, over a twenty-year life at the business average annual rate of 12 percent for the sake of calculation, then the lost opportunity cost would be $2,162,000 because of (i) poorly designed-or-built equipment and (ii) ineffective operating and maintenance practices. In the example cited, for each 1 percent of replacement asset value spent annually on maintenance over a 20-year period, $ 75,000 of every $1M of the original capital invested will not lead to any financial return. The lost-opportunity cost will then be assessed - see Table 1 [2].

Table 1: Features that should be taken into account when evaluating the lost-opportunity

Annual maintenance cost as % of asset replacement value	Current replacement value of assertion ($)	Length of asset life (years)	Weighted average cost of capital (%)	Accumulated value of 20 years maintenance opportunity-cost at the average cost of capital rate	Present value of capital. Year of maintenance opportunity cost as a weighted-average cost of capital without inflation.

In recent years, some Nigerian industries have gradually shown increasing concerns about (i) higher maintenance costs and (ii) maintenance productivity. Maintenance is often the largest single management expenditure in Nigerian plants: in many industries, it exceeds the annual net profit. Although strategies such as PM and PDM have produced savings of up to 25 percent, some studies have suggested that more than one-third of maintenance costs can be saved without decreasing uptime. Therefore, it is important for organisations to maximize their maintenance effectiveness and thereby their equipment uptime. In Nigeria, most maintenance departments showed productivities of around 25→35 percent of ideal productivity. However, wiser planning and scheduling of maintenance activities could significantly improve on this. The objectives should be to:

- Increase the effectiveness/efficiencies of plant/equipment.
- Boost the profit achieved
- Reduce maintenance and operating costs.
- Improve availability and reliability
- Raise the financial return on asset investment
- Introduce an inspiring corporate culture amongst maintenance personnel
- Implement a continual-improvement paradigm

The overall aim is to maximize the value achieved by maintenance investments, i.e. profit optimization with maintenance excellence.

Scope

Lean manufacturing and optimal maintenance require the identification and elimination of waste through continual improvement. Over-maintaining of an asset squanders precious resources. Nigerian industries have been conservative in setting PM intervals. Both excessive frequency of maintenance or under maintenance increase downtime, and so reduce production output. Maintenance personnel should adopt a proactive focused-approach to narrow the gap between manufacturing actual costs and what could be achieved by reducing waste and inefficiencies. A profit-focused approach to maintenance has its roots in TPM [6].

The way maintenance is performed will influence the availability of plant as well as the safety of its operation. These, in turn, will determine the profitability of the enterprise [7]. Maintenance usually remains one of the few business sectors via which significant increases in company profits can be achieved [8]. The common problems include (i) its high cost; (ii) underutilization of plant and equipment; (iii) it being poorly valued in house and so not an exploited opportunity for competitive advantage; and (iv) too often it is undertaken by insufficiently skilled operatives.

Maintenance in Nigeria can account for up to 40% of total production costs. The effect of poor maintenance can result in less production, poorer quality end-products and customer dissatisfaction. Part of the solution to the besetting problems in maintenance is not technical: rather a more business-based approach to maintenance is needed resulting from a top-management commitment. In a poorly-run company, the maintenance manger can control up to 40 percent of production costs and this has a direct effect on profitability.

A cost and cash-flow budget needs to be drawn up with normal forecasting formats, which, in conjunction with other pertinent documents, will form a maintenance business-plan. In this way, maintenance concern will be embodied in the management-decision process [8].

Culture

A dictionary definition of culture is “the total of the inherent ideals, beliefs, values and knowledge, which constitute the shared basis for social action”. Continual business change is inevitable in a global economy. A successful business environment should reflect the way people live. Thus it is desirable, within the industry, to provide an environment and a culture which contribute to the welfare of all personnel. Considering staff as individuals, rather than as a generic workforce, is seen by enlightened companies as a prerequisite to achieving a positive company culture. Desirable human motivations, attitudes and behaviour are determined by a culture based on addressing human needs. Such a culture is therefore an aid to management in efforts to make their personnel “creators and wise doers” rather than parasitic “done-fors” [9]. The factors (see ISO 9001: 2000) that significantly contribute to a high-quality culture in an industry, are:-

- Top-management involvement
- Customer focus
- Wise management of human relations (HRs)
- Providing an inspiring management and work environment
- Measurement, analysis and improvement of all activities
- 360^{o} loyalty

Success in business is not determined by the executives' skills alone, or by the visible features, the strategy, the structure and the reward system of the organization. Rather each organization has an espirit de corps, a certain style, a character, a way of doing things that influences new entrants as well as existing personnel. The pervading corporate culture provides the social benchmarks that inspire or fail to drive successfully the organization: much of what goes on in an organization is guided by the cultural quality of shared meaning, hidden assumptions, and unwritten rules [10]. " There are no rules here, but if you break one of them, you've had it" in the words of a famous manager – Giles Alington.

Organization culture is defined as the personality of a company! It represents a set of common perceptions such as: norms, guiding beliefs, values, customs and modes of behaviour [11, 12]. Although corporate culture is usually classified under headings such as degree of empowerment, tasks undertaken or personnel responsible [13], it is common for sub-cultures to exist within individual departments, groups or teams. Hofstede [14] defined these as (i) the "boss" distance, (ii) uncertainty avoidance and (iii) individualism or collectiveness. Tenant et al [15] stated that an organization's desirable culture can be developed through company policy and operational practices, with an appropriate management style. The management leadership should implement measures to ensure that the organisation has a more open and supportive culture to encourage relevant learning, cooperation and teamwork in order to improve performance.

Organizations influence the behaviours and values of its individuals and vice-versa [16]. Over time, there is a tendency towards uniformity of individual behaviour within an organization and a corresponding tendency towards uniformity of organizations within the business environment. Hence regular transfusions of 'new blood' are desirable especially if the industry is faltering. Each organization is a society unto itself and has its own internal culture or social system. An organization adopts values that reflect the administration in charge and the environment with which it has to cope. New personnel soon become aware of the value system of the organisation, either consciously or unconsciously, and most guide their actions accordingly [16]. These resulting actions can manifest themselves as company policy. The culture of an organization comes through the development of norms and values that help it to survive given the environment in which it was created and subsequently exists.

The organisation's culture should endow individuals with rules or principles that provide guidance when making decisions. A learning organization needs a clearly-stated purpose, effective communications, training about all aspect of the business, flexible structures and processes that facilitate introducing innovations, creativity, and risk taking [17]. Accompanying this effort should be systematic problem-solving experimentation,

learning from past mistakes and experience, acquiring know-how from others, and transferring ‘modern’ reliable information from the outside world [18].

Evolution often needs the transfer of a culture: the advantages of the learning organization are that it provides internally an intrinsic motivation for change [19]. Further energy for achieving the desirable change can be obtained through the “creative tension” between the desired vision of the future and the current reality.

Learning Organization

Life-long learning is a highly worthwhile process that is found in almost every facet of society. At work, we learn to accomplish certain tasks, e.g. how to (i) make wise decisions, (ii) treat other people professionally within the organization, and (iii) cope with rapid changes. If a company is to develop the ability of continual self-improvement, its main challenge lies in ensuring that its individual members’ behaviours and actions [20] adapt successfully to the changing circumstances.

Best Practices in Maintenance Management

These enable a company to achieve a competitive advantage over its competitors, and include:

- PM
- inventory and procurement
- work flow and control knowledge
- CMMS
- operational involvement
- PDM
- RCM
- TPM
- financial optimization
- continual improvement attitude

Preventive Maintenance

PM reduces the amount of reactive maintenance to a level that allows other practices in the maintenance process to be cost effective. Nigerian industries need to focus more on the basics of PM if they are to achieve “best-in-class” status, with a ratio of more than 80 percent proactive maintenance to less than 20 percent reactive maintenance.

PM is performed to retain the equipment in a satisfactory operational condition: it is divided into time-based and condition-based maintenance. Time-based maintenance is performed after fixed time intervals, whether a problem is apparent or not, in order to avoid failure of the items during operation. Time-based maintenance incurs a large cost for the user in maintaining the required level of reliability, because the majority of items are replaced prematurely despite still having useful lives remaining. Condition-based maintenance is applicable to components which tend to deteriorate rapidly with time.

However, it is usually not cost effective to monitor the condition of each component: some will be relatively inaccessible for monitoring.

Inventory (stores) and Procurement

There should be a focus on providing the right parts at the required times without having large financial outlays on stocks lying idle for prolonged periods.

Work Flows and Controls

A work-order procedure should be used to initiate, track and record all maintenance activities. The process will start as a request that needs approval. Once approved, the work is planned, then scheduled, performed and finally recorded. All the maintenance activities are tracked through the work system. At least 80 percent of all maintenance work should be planned on a weekly basis: the scheduled compliance should be at least 90 percent on a weekly basis.

Maintenance management systems in most companies are so complex as to require computerizing the collection, processing, and analysis of the data. The CMMS software manages the functions of PM and provides support for some excellent practices.

Technical and Personal Training

This should ensure that all maintenance staff (i) possess the necessary technical skills to understand and maintain the plant and equipment, (ii) are able to communicate intelligently with other departments within the organization about pertinent matters, and (iii) be able to work in teams or as a group.

Operations Department Involvement

There should be better integration between production and maintenance operatives; hence, all operational personnel should receive basic maintenance training.

Predictive Maintenance

The focus should be on investigating and purchasing the technology that solves or mitigates chronic equipment-problems. PDM inspections should be planned and scheduled utilizing the same techniques that are used to schedule the PM tasks. All data should be integrated into the CMMS.

Reliability-Centred Maintenance

RCM consists of structured processes to determine the equipment maintenance strategies required for any physical asset to ensure it continues to fulfil its intended function(s) in present operating conditions. The goal of RCM is to determine what the critical components in any process are and, based on this information, design a customized preventive/predictive maintenance strategy. Another strategy is the root-cause failure analysis (RCFA), which is based on failures that have occurred previously .RCFA should

lead to corrective actions beyond the component stage into the system's deficiency or latent root stage.

Total Productive Management

TPM, which focuses on people and is an integral part of TQM, defines the organization of maintenance work by applying the following actions [21]:

- Cultivate a sense of ownership in the operator by introducing autonomous operator maintenance, whereby the operator takes responsibility for the primary care of his/her plant. The tasks involved include routine inspection, lubrication, adjustments, minor repairs, as well as the cleanliness and tidiness of his/her work space.
- Optimize the operator's skills and knowledge of his/her plant in order to maximize operating effectiveness. The operator is thus mobilized to detect any early signs of deterioration, wear, maladjustment, oil leaks, errant chips or loose parts. He/she should regard it as his/her duty to propose improvement suggestions to eliminate losses due to a sub-optimal or breakdown performance of the plant.
- Use cross-functional teams consisting of operators, maintainers, engineers and managers to improve personnel and equipment performance.
- Establish a schedule of clean – up and PM to extend the plant's life span and maximize its uptime.

Top management should demonstrate their commitment to TPM by devoting sufficient time and allocating adequate resources to create and sustain any necessary cultural changes and to provide training for employees to achieve autonomous maintenance.

Financial Optimization

This statistical technique combines all of the relevant data about an asset, such as the costs of downtime, maintenance, lost efficiency or poor-quality end-product. It then assesses the data against financially optimized decisions, such as when to take the equipment off-line for maintenance, whether to repair or replace an asset, and how many critical spare-parts should be immediately available. Financial optimization requires accurate data: making the associated decisions incorrectly could have a devastating effect on a company's competitive position.

Continual Improvement

Continually seeking for better methods of accomplishing a task is characterized by determining incremental as well as radical improvements to existing processes. Focusing on existing processes differentiates continual improvement from other approaches, such as re-engineering, which disregards existing procedures and develops new ways for accomplishing the task [22].

Continual improvement as part of asset care is an ongoing evolution that includes continually looking for the "little things" that can make an organisation more

competitive. One of the key tools for achieving continual improvement is best-practice benchmarking, which examines the maintenance process presently employed and compares it with those in organisations that are world leaders in this respect, and so highlight the changes necessary to improve the process.

Costs and Benefits of TPM

To appreciate the benefits, which could result from the implementation of a wise maintenance policy, it is important to appreciate the various costs involved. Priestly [23] suggested that, on average, 25 years ago, 70% of maintenance time was spent on dealing with emergencies (i.e. fire-fighting), and 15% on planned preventive maintenance. If a policy of "fire fighting" is adopted, a high proportion of the costs are always unavoidable. Emergency repairs mean that high inventory levels of replacement components, particularly critical parts, have to be carried all the time. Also reactive maintenance has a negative impact on the production time. The cost of downtime, if determined from possible sales/production lost opportunities, can be assessed accurately.

In Nigerian industries, it appears that, too often, maintenance costing is conducted in a cavalier non-comprehensive manner. This is due to the disparaging management attitudes towards the role of maintenance in relation to the business operation. Hence, in most industries in Nigeria:

- there are no detailed records of maintenance costs
- maintenance is not always considered at company executive level
- most companies ignore the real cost of downtime in terms of lost sales, despite more than 20 percent of annual sales revenue being spent on maintenance.

With good maintenance management, costs can be drastically reduced in Nigerian industries: plant availability could be increased and so lead up to 30 percent increases in profitability being achieved. The costs of maintenance can be represented by a curve, such as figure 1. A change of attitude toward PM from the implementation of routine maintenance such as inspections, lubrication, etc. to fault diagnosis and predictive studies will lead to a drastic decrease in repair costs, thereby minimizing production downtime and losses of sales revenue [24].

To obtain the optimal impact achievable from a TPM programme, it is important for maintenance/production managers to calculate or obtain estimates of all the costs involved –see table 2. The impact of TPM on productivity levels can only be fully appreciated once the various costs and their impacts have been understood and calculated. TPM has a direct impact on the productivity arising as a result of manpower, capacity and availability, as well as on the utilization and productivity of capital assets. It also has a direct impact on the number of replacement components held in store for maintenance purposes (for emergency repairs) and the amounts of raw materials in stock. TPM would facilitate manufacturing companies getting it right first time, and having significantly reduced inventory levels. In addition, a TPM programme, which is effective, can lead to the implementation of a successful TQM philosophy and therefore enable the

companies concerned to meet customer requirements first time and every time more often [24].

Table 2: Considerations with respect to maintenance costs [25]

Type of maintenance programme	***Area for cost appraisal***
Breakdowns	Idle capacity and penalty costs
	Buffer inventories have to be established
	Lost production
	Poor quality of end-product may ensue
Reactive maintenance	Manpower idle
	Desired level of service
	Number of machine breakdowns
	Level of specialization / number of maintenance personnel used.
Regularly scheduled PM	Cost derived from PM schedule
	Manpower costs (relative on total manpower hours required for production) incurred
	Cost of repairs (determined by PM schedule)
Inspection and randomly scheduled PM	Based on total number of manpower hours required for production
	Costs based on historical manpower-usage data
Equipment back-up	Establishing a depreciation schedule (fixed expense)
	Costs of maintenance (variable cost)
Equipment upgrade	Costs can either be treated as an immediate expense or amortized depending both on their magnitudes and on the operating lifetime of the upgraded equipment.

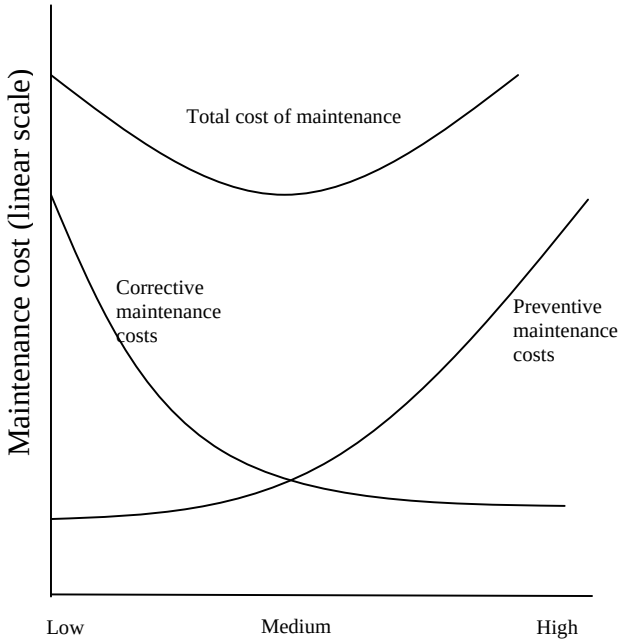

Figure1: An indication on how maintenance performance should be optimised i.e. to incur least maintenance cost **[24]**

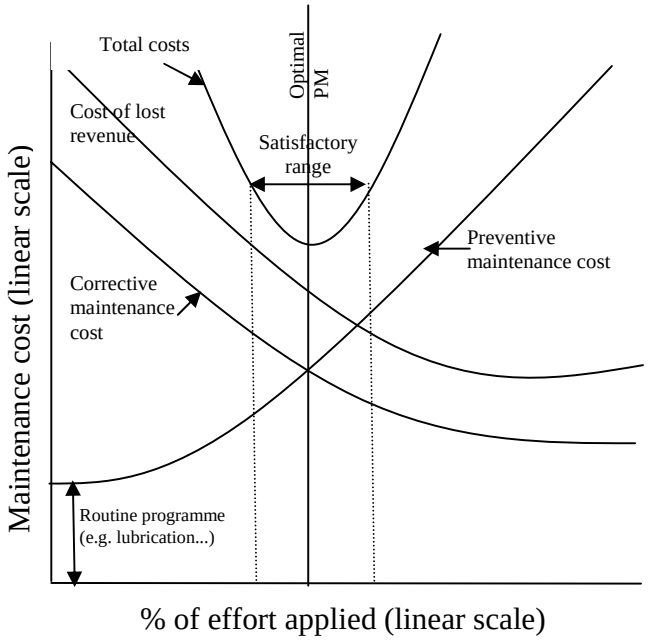

Figure 2. The impact of PM on revenue losses [24].

Conclusion

Organisations with a wise maintenance-culture usually incur relatively low running costs with respect to the end-product costs. However, this culture rarely exits is Nigeria, where industries tend to be reactive (i.e. fire fighting when failures arise), as well as employing fixed-time maintenance replacements (or overhauls of components) schedules. The latter approach is seldom justifiable, because less than 15% of all components usually need replacement at the prescribed times commonly chosen.

A recommendation for Nigerian industries is to buy highly-dependable equipment that should cost relatively little to maintain. The benefits thereby gained from reliable long-lived plant extend well beyond just lower maintenance costs: for instance, smaller stocks of spare parts are needed and fewer (but probably more highly multi-skilled) operators and maintenance personnel required. These should be empowered and motivated to become even more competent. To this end, each industry should develop a wiser maintenance culture: this would require

- the industry becoming a knowledge-sharing and learning organisation;
- an understanding of the unambiguous objectives of TPM and RCM processes; and
- a comprehensive and easily accessible data-base for continual improvement, benchmarking, evaluation and analysis of each system's behaviour.

Most large companies lose between 2 and 16% of annual turnover due to downtime. In general, human error and laziness are the causes of at least 20% of downtime costs. This can be improved significantly by only using properly trained personnel and by devising and using appropriate information-technology controlled processes, thereby providing better proactive servicing.

References

1. Dunn, S. (1998), Reinventing the maintenance process: towards zero downtime, Queensland Maintenance Conference Proceedings, Queensland, Australia
2. Sondalini, M. (2000), The cost of maintenance destroys your capital-investment returns, www.feedforward.com.au
3. Moubray, J. (2000), Maintenance Management: a new paradigm, http://www.maintenanceresources.com/RCM/
4. Lezlo G P (1999) Improving a quality-management programme - the three Cs of success: commitment, culture and cost. The TQM Magazine, vol. 11 No 4, pp. 231-7
5. Pascal, R.T and Athos, A. (1992), The Art of Japanese Management. Penguin Books, London.
6. Hugh B. (2002) Business Centre Maintenance, available from: info@maintenance.com
7. Visser J.K. (1998), Modelling maintenance performance: a practical approach, IMA Conference, Edinburgh, pp. 1-13.

8. Thomas, C. (2000) Maintenance – a business approach, http://espania/cta/
9. Lawson, D. (2003), Is ISO in your system? Quality World Magazine, Sept. pp.34-36.
10. Kilman, R.H, Saxton, M.J. and Serpa, R (1986), Issues in understanding and changing culture, California Management Review, Volume XXVIII, No2, pp.87-94.
11. Daft, R.L. (1992), Organization Theory and Design, West Publishing Company, Saint Paul, MN, USA.
12. Oakland, J.S. (1998) Total Quality Management: the route to improving performance, Butterworth- Heinemann, Oxford.
13. Handy, C. (1993), Understanding Organisations, Penguin Books, London.
14. Hofstede, J.S. (1984), Culture Consequences: international differences in work-related values, Sage Publications, Newbury, CA, USA.
15. Tenant, C. Warwood, S.J and Chiang, M.M.P (2002), Continuous improvement at Severn-Trent water, TQM Magazine. Vol. 14 No5, pp284-292.
16. Krell, T.C (2000), Organizational longevity and technological change, Journal of Organizational Change Management, Vol.13 No1, pp. 8-13.
17. Garvin D. A. (199) Managing Quality, The Free Press, New York, USA.
18. Hayes, T. (1997), The Learning Organization: fashionable fad or path to progress? www.globasearchbusiness.com
19. Senge, P.M. (1990), The Fifth Discipline: the art and practice of the learning organization, Doubleday, New York, USA.
20. Stambaugh, D.M. (1995), Creating the learning organisation: an essential ingredient for attaining customer loyalty. CPCU Journal, March, pp.35-49.
21. Tsang, A. H. C. (2002), Strategic dimension of maintenance management, Journal of Quality in Maintenance Engineering, Vol. 8. No. 1. pp 7-30.
22. Hammer, M. (1990), Re-engineering work: don't automate, obliterate, Havard Business Review, Vol.68.No.4.pp104-12.
23. Priestly, C (1983), Purchasing must push for planned maintenance, Purchasing, Sept.29th pp. 29
24. Zairi, M. (1991), Total Quality Management for Engineers, Woodhead Publishing Limited Cambridge, UK.
25. Gallimore K. F. and Penlesky, R.J. (1988) A framework for developing maintenance strategies, Production and Inventory Management Journal, First Quarter, pp.16 -21.