Development Of An Optimal Planning And Maintenance System (A Case Study Of Shell Petroleum Development Company, Obigbo Node)

Temple Temple Amachree, M. T. Lilly, Adanma Cecilia Eberendu

Abstract: Preventive and breakdown maintenance system for a gas compressor plant were analyzed and appraised using established maintenance tools. To determine this, comparative cost benefit analysis of preventive and breakdown maintenance activities on Agbada gas compressor plant of the Shell Petroleum Development Company was carried out. The cost of achieving 20,000 run hours overhaul preventive maintenance with some disused repaired parts was analyzed and compared with the cost of carrying out the same activity with all new parts. Comparative studies showed that carrying out preventive maintenance with repairable parts, which were recovered in the 'as new state', is more cost effective than using all new parts. A cost saving of 14.63% was achieved. The same trend was also observed when the cost benefit analysis was carried out in breakdown maintenance option. This again gave a cost savings of 7.51 % when repaired disused parts were used. The results showed that the rate of return on investment if breakdown maintenance is adopted is 24% as compared to the rate of return 01: 26% that was obtained when preventive maintenance system was used. An NPV of ₦6,703,491,725.00 and ₦5,371,346,424.00 were obtained for preventive maintenance and breakdown maintenance respectively. It is therefore observed that preventive maintenance system strategy presented a better NPV over breakdown maintenance.

Keywords: Optimal Planning and Maintenance System

1. INTRODUCTION

The late 1990s brought with it declining earnings from O & G activities yet the world is yet to see another resource with such a price earning capacity as crude oil. The Nigerian oil industry, being a key player in the global oil economics and politics has suffered tremendously from poor maintenance strategy in this core sector of the economy. The need for an optimal maintenance system method for O & G facilities can hence not be over emphasized. Maintenance has been changing for a long time. Until recently, however, the pace of change was relatively slow. The first phase of maintenance took place between 1920 and 1940. It was characterized by the fact that maintenance was a lot simpler due to low level mechanizations. The degree of mechanization was much lower, so the unavailability of a machine did not matter so much. Equipment was to a large extent over designed and therefore tended to be fairly reliable when it was working and fairly simple to repair. Complex systems brought with it stringent maintenance system requirements if the plant must be profitable. In Nigeria, the oil boom of the 1980s was characterized with poor maintenance system.

2. STATEMENT OF THE PROBLEM

The current global economic downturn has forced operating companies to seek for better maintenance strategies. Awareness of the immense benefits of optimum equipment maintenance systems has also increased. Such benefits include maximization of economic life of plant equipment, improvement of the utilization of maintenance man-hours, reduction of downtime, minimization of repair costs, optimized spares holding, higher level of equipment availability, safety, integrity and assurance of the plant system, and environmental protection associated with the prevention of failure of a system in use. It can also be attributed to the increase in the level of automation and sophistication of systems and the consequent sharp increase in the amount of capital required for procurement of systems. High capital input has forced operating companies to seek ways to optimise systems and plant availability. For systems in which preventive maintenance is carried out, the assumption is that each time a maintenance action is carried out, the system is restored to as - good as - new condition. In such cases, the reliability of the system is computed using the reliability equation for an idealized maintenance. In more realistic situations, the improvement in reliability is brought about by maintenance and must be weighed against the possibility that faulty maintenance will lead to system failure. This may be as a result of less-than-perfect human reliability in which case, maintenance its carried out unsatisfactorily and may cause the system to fail immediately afterwards. Various maintenance system methods are currently in use in the O&G industry. However, this thesis aims at developing an optimal method for crude oil flow station facility maintenance system. An optimal maintenance system is needed to ensure the followings:

1) The efficiency and integrity of O & G facilities.
2) Safety of life of the operators in the installations.
3) Cost effective methods for the maintenance of O & G facilities.
4) Increase in the earning capacity, by reduction in unit cost of oil production.

Objectives of the Study

This thesis aims at studying the current maintenance practice in the oil industry particularly in SPDC with a view to recommending an optimal method. This study will aid O&G companies to make good management decision on the best option for facility and installation maintenance using management decision tools.

Review of Related Literatures

Optimal Maintenance System includes unscheduled and scheduled maintenance. Scheduled maintenance; whereas is achieved via predictive and preventive maintenance system, while unscheduled maintenance refers to breakdown or corrective maintenance system. Lewis (1987) in his study on maintenance systems stated that relatively few systems are designed to operate without maintenance of any kind, and for the most part, they must operate in environments where access is very difficult, in outer space or high-radiation fields, for example, or where replacement is more economical than maintenance. He classified maintenance into two - preventive and corrective maintenance, one or both of which may be applied to any maintained system. Rao (1992), supported this classification and also went further to compare the two classes. He stated that in preventive maintenance, the system is periodically inspected, some components are replaced, lubrication checked, and adjustments are made before the system fails. Whereas preventive maintenance is intended to eliminate costly repairs involved during the corrective maintenance stage when the system fails, corrective maintenance is used after the system fails. While the aim of preventive maintenance is to increase the reliability and prolong the life of a system by overcoming the effects of aging, fatigue and wear, the objective of corrective maintenance is to bring the system from the failed state to an operating state as soon as possible in order to increase its availability. Stitt (1992), emphasized that many "traditional" maintenance programmes use preventive maintenance as a means to ensure reliable system operation. He quoted Patton (1980) as having defined preventive maintenance as "actions performed in an attempt to keep an item in a specified operating condition by means of systematic inspection, detection, and prevention of failure". He added that a subset of preventive maintenance is scheduled maintenance, which as its name suggests, is maintenance performed at a fixed point in time. It is this scheduled maintenance that "traditional" maintenance programmes use as a means to prevent failure. He further suggested one alternative to the "traditional" maintenance approach which uses reliability and logistics engineering analyses to evaluate the predicted reliability of the system/equipment, and to determine the maintenance programme necessary to achieve this level of reliability. Contrary to Stitt's view, Nowlan and Heap (1978) discovered through the years that many types of failures could not be prevented or effectively reduced by such maintenance activities, no matter how intensely they were performed. In response to this discovery, airplane designers began to develop design features that mitigated failure consequences - that is, they learned how to design airplanes that were failure "tolerant". Even in the aviation industry, which shares the same level of expected reliability as the oil industry, several investigations has been carried out by operators and owners. In 1960, The United States Federal Aviation and Airlines (FAA) operators investigated the capabilities of preventive maintenance, and established the FAA/Industry Reliability Program. The introduction to the authorizing document states thus, "The development of this program is towards the control of reliability through an analysis of the factors that affect the reliability and provide a system of actions to improve low reliability levels when they exist, in the past, a great deal of emphasis has been placed on the control of overhaul periods to provide a satisfactory level of reliability and overhaul time are not necessarily directed at associated topics; therefore, the subjects are dealt with separately". In an attempt to organise what has been learnt from the various reliability programs, a rudimentary decision-diagram technique was devised in 1965 and presented in a paper at the Commercial Aircraft Design and Operations meeting in 1967. It expressed the development of a logical and generally applicable approach to the design of preventive maintenance programs, now known as reliability-centered maintenance. Blanchard (1986), defined reliability-centered maintenance as "systematic analysis approach whereby systems design is evaluated in terms of possible failures, consequences of these failures, and recommended maintenance procedures that should be implemented". Stitt (1992) went further to state that "the objective of reliability-centered maintenance is to develop a preventive maintenance program (including scheduled maintenance) by evaluating maintenance for an item according to possible failure consequences". Okomoto and Osaki (1977), considered preventive maintenance policies for a standby system where preventive: maintenance for an operating unit is possible but corrective maintenance for a failed unit is not. They discussed the optimum preventive maintenance policies minimizing the expected cost per unit time by introducing corrective replacement and preventive maintenance cost. Elwood and Rakesh (1987), discussed the decision concerning the choice between repair and major overhaul which normally occur at time of breakdown. According to them, these major preventive maintenance actions are meant to anticipate breakdowns to avoid the occurrence of downtime at inconvenient times and perhaps to minimize downtime costs. In their work, Tapiero et al (1979), considered simultaneous maintenance and replacement under uncertainty with the effects of maintenance and deterioration assumed to have a probabilistic effect of the Markovian type on a machine's salvage value. The application of the tools of optimal control theory to determine a "certainly equivalent" maintenance program and the optimum replacement date of the machine was considered

Unscheduled Maintenance

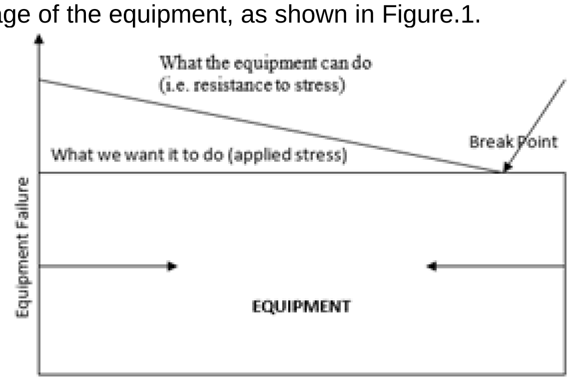
Some schools of thought have argued that breakdown maintenance is a good option, just because it keeps maintenance labor and materials cost that comes out of current operating profit to a minimum. On the face value, it may seem to be less expensive, but the cumulative expenses and damaging effect may however outweigh that emanating from scheduled maintenance strategies. The following discourse highlights the pros and cons of unscheduled maintenance:

Breakdown Maintenance System

According to Ogbonnaya (1998), no repairs or services are carried out while adopting the breakdown maintenance except a failure occurs. He described it as repair/replacement maintenance policy. Breakdown maintenance also called corrective maintenance is an unavoidable maintenance in old plants as machine/equipment, even a whole production system can fail. However, an effective preventive maintenance will minimize the rate of occurrence of corrective maintenance. It is cheaper to perform a planned activity than an unplanned one. Preventive maintenance reduces unplanned corrective maintenance and as well as the monitoring of plants equipment while in operation helps early identification of component failure, before the failure result into a breakdown. With the failure report, the maintenance department can now plan in advance, whereas preventive maintenance assists condition monitoring of equipment while in operation. The primary objective of breakdown maintenance system is to keep equipment running without maintenance until they breakdown. The essential parameters for measurement are: The cost of lost machine- hours in terms of production units and the effect on profit. The breakeven point - even the difference between the costs of a preventive maintenance program and continued breakdown repairs. When the combined costs of breakdown repairs and reassemble costs exceed the cost of a preventive maintenance program, and the breakeven point has been reached. Minimisation of loss of direct labor productivity: Smith et al (1982) pointed out the various techniques for measuring the effectiveness of a break down maintenance program, they include:

(a) Equipment Utilization Recording (EUR): This involves recording all breakdowns through the use of a work order system. These work order are analysed by an equipment coding system to determine if breakeven point has been reached. The primary concern is the continual use upon direct labour performance.
(b) Direct Labour Variance Analysis: This is a process whereby detailed reports of labour variances are analyzed to determine the effect of breakdown on direct labour costs.
(c) Work Samplings: This is used to determine the casual factors of down time.
(d) Information System: This is used to analyze performance of direct labour operations (Smith et al. 1982)

Applications in many industries involve the use of all the techniques mentioned above. The maintenance system techniques described are effective and proven and allow maintenance of the equipment to meet the objective established for availability, reliability and cost. Any physical asset which is required to fulfill a function was subjected to variety of stresses. These stresses cause the asset to deteriorate by lowering its resistance. Eventually its resistance drops to a point at which the asset can no longer deliver the desired performance. When this happens, breakdown is said have occurred; hence the equipment is worked on to bring it up to its initial state by carrying out breakdown maintenance. Breakdown of equipment is influenced by a number of factors; these include output, calendar time, distance traveled/run hours. All these units are related to time, so it is common to refer to total exposure to stress as age of the equipment. This connection between stress and time suggests that there should be a direct relationship between the rate of deterioration and the age of the item. If this is so, then it follows that the point at which the item fails also depends on the age of the equipment, as shown in Figure.1.



[Source: Dresser-Rand Planning Department]

Figure.1 *is based on two key assumptions:*

(1) Deterioration is directly proportional to the applied stress, and
(2) The stress is consistently.

If this is true of all assets, we would be able to predict the life of most equipment with great precision and breakdown was eliminated. The classical view of preventive maintenance suggests that this can be done; all that is needed is enough information about failures. In reality, however, the situation is much less clear cut.

Computer-Aided Maintenance Management Systems

The type of maintenance management required on any facility depends on the activities of the organization. Industries making use of separation, heat exchange and rotating equipment require peculiar computer aided systems in their maintenance system plans. One of such systems is the Event Activated Servicing of Equipment (EASE). The EASE system operates as detailed below: A planned arid predictive approach is a highly desirable alternative to so-called 'crisis management' or 'putting out fires'. If breakdowns are continually dealt with as they occur, without collecting any data which can be used for preventive maintenance, little or no control over equipment reliability and maintenance costs was achieved.

Types of Maintenance System

Most maintenance activity falls within two broad categories of maintenance; unscheduled maintenance and scheduled maintenance. Scheduled maintenance is achieved via predictive and preventive maintenance system, while unscheduled maintenance refers to breakdown maintenance system. Unscheduled maintenance is brought about by one of the following occurrences:

(a) Failure of equipment to continue operation in an acceptable manner.
(b) An automatic shutdown by an equipment safety system(s), following failure of a critical component or resulting from a condition in excess of limit.
(c) An operator initiated shutdown to avoid an unsafe condition.

Table.1: Preventive maintenance programme job description sheet

DATE		PLANT ITEM		
ISSUE NO				
REFERENCE NO		MANUFACTURER		
ISSUED BY		TYPE		
APPROVED BY		LOCATION		
JOB TITLE				
JOB NO. OR STEP	DESCRIPTION OF WORK	(MTH) IN INTERVAL	NO. OF (M) MEN	NO. OF MXN MAN HOURS

[Source: Dresser-Rand Planning Department]

The above occurrences are highly undesirable and the resulting unplanned downtime is very costly. The role of scheduled maintenance activity is therefore to eliminate such unwanted downtime through the use of preventive and predictive maintenance techniques.

Maintenance Planning of Oil Equipment

The key to all satisfactory maintenance activity is planning. The ability of the maintenance personnel to carry out inspection and overhauls expeditiously requires a major planning effort to ensure that all the equipment; manpower and materials necessary are available on site as required. Maintenance planning for rotating equipment can be grouped under one of the followings:

(i) Maintenance Programme
(ii) Maintenance Resources Planning
(iii) Maintenance Materials Planning.

Maintenance Program

The planned maintenance program (PMP) for rotating equipment covers a variety of maintenance engineering activities. Preventive maintenance schedules can for convenience be divided into the following categories:

(i) Routine inspection jobs within specified intervals to be carried out by the operating staff.
(ii) Planned inspection/surveys/adjustments/settings to be carried out by the maintenance staff.
(iii) Planned servicing (Lubrication, cleaning, painting etc.)
(iv) Repairs/Overhauls.

The Routine inspection activities are basically visual inspections and checks of the equipment at weekly and monthly intervals and are normally carried out by the plant operator with the plant in operation or on standby duty. A detailed checklist is formulated for centrifugal pumps, compressors and gas turbines in the job description sheets of this work. The planned inspections and planned servicing activities in the preventive maintenance program are the key to reliable and economical operation of the equipment between major inspections and overhauls. The activities are usually carried out at half-yearly intervals and a number of the activities will require a short outage of the plant. Major repairs and overhauls are normally designed based on the original equipment manufacturers recommended running hours. However, these intervals may be increased if the equipment, (as in gas turbines and compressor) component parts are found in satisfactory condition after the yearly inspection and from condition monitoring.

Job Description Sheet

The job description sheet is a compilation of each activity on the preventive maintenance program. This sheet gives a step-by step work sequence and list all reference drawings, instruction, tools and spare parts required for each activity as shown in Table.1.

Causes of Equipment Breakdown

Also included are special safety precaution, component weights, and torque tightening levels and instrument settings. This system will minimize the briefing time required by the maintenance staff and also reduces the plant outage time. Failure of equipment can be attributed to a number of factors, and they include wrong design, poor manufacturing and installation procedures, commissioning, wrong routine maintenance and poor workmanship.

Spare Parts Planning for Effective Maintenance System

Spare parts planning function is very important. Lack of adequate on-site spare can have a major effect on plant availability; therefore prior to a planned scheduled maintenance, adequate spares should be on-site. Planning for the purpose of industrial management with respect to economic activity was defined by Adeyinka (1998) as the preparation of manufacturing inventory with respect to the cost involvement of such process. The heart of spare parts planning tasks is the ability to forecast accurately, spare requirement over an extended time period. Spare part forecasting must cover requirement due to equipment failure. Care must be exercised in estimation of spare parts requirements. An over-estimation could lead to excess inventory and large amounts of capital tied up in spare parts, while an underestimation can lead to protracted forced outages and lower unit availability and profitability. The high cost of oil field equipment parts, like turbine parts places considerable pressure on users to determine recyclable parts. The parts can be sent to the manufacturer's facility for repairs and returned to the spare parts recovery. This procedure is economic in term of price versus life expected. Finally the spare parts planning group needs to maintain a close relationship with field personnel. The advantage of this is that their performance is greatly improved by accurate information from field maintenance personnel on pattern and anticipated long term needs.

Contributions of Maintenance to Terotechnology

The definition of terotechnology evolved between 1970 and 1975. However, in 1968, a company by name, PA Management Consultants Limited was commissioned by the Ministry of Technology of the United Kingdom to carry out a study of engineering maintenance in British manufacturing industry. It reported that the total direct cost of engineering maintenance was approximately £1billion per annum. The report also specifically revealed that improved productivity of maintenance staff could have led to a reduction in maintenance expenditure of around 250 million per annum (Abdul, 1998). Using this and other information, the working party on maintenance engineering of the department of industry reporting in 1970 emphasized, amongst other things, the important of the link between maintenance costs and feedback of information to the designers of the plant. A steering committee was set up to examine the broader findings of this report and in 1972 published their conclusions, central to which was the statement: "The nature of maintenance activity was determined by the manner in which plant and equipment was designed, selected, installed, commissioned, operated, removed and replaced." Major benefit could come to the Nigeria oil industry if a broad based technology which embraced all this area is adopted. This is basically what is referred in the engineering technology world as 'Terotechnology' It is a word that is based in the Greek word "terein" meaning to guard or look after. The British committee for Terotechnology defined terotechnology as 'a combination of management financial engineering and other practices applied or physical assets in pursuit of economic life cycle costs.' The scope and interrelationships of terotechnology are shown in Figure 2

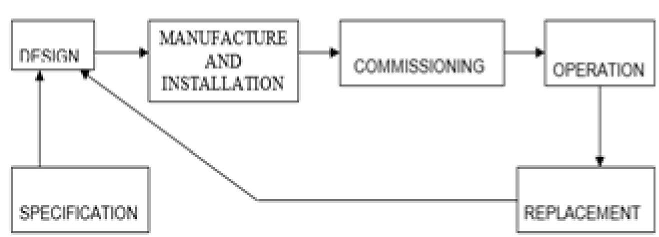


Figure 2 Equipment life cycle and factors affecting maintenance costs

[Source: Dresser-Rand Planning Department]

According to maintenance techniques and analysis, in Wolfson Maintenance, (1998), terotechnology can be defined as the technology of conceiving, designing, manufacturing, installing, commissioning, operating, maintaining and feeding back to design and manufacture of plant, machinery or equipment, system or subsystem, as well as related subjects and practices.

Method and Materials

Maintenance of equipment is good, but between preventive and breakdown maintenance, which one is economically better? Oil field equipment are numerous, but because of the contribution of gas compressors and turbines in the re-injection of gas necessary to boost crude oil production. The scope of the project will include the followings:

(1) Comparative analysis of preventive maintenance and corrective breakdown (corrective) maintenance of gas compressors.
(2) Determination of the maintenance alternative for oil field equipment, especially gas compressors.
(3) Ascertain the return on investment using preventive maintenance approach in comparison with adopting breakdown maintenance option.
(4) Determine a maintenance system option to adopt in order to minimize maintenance costs and increased equipment uptime.
(5) Study the effect of ergonomics on equipment maintenance system.

Data Analysis and Discussion

Cost benefit analysis of carrying out maintenance, whether preventive or breakdown, with new spare parts and repairing some of the repairable spares and re-using them was carried out. The result of the analysis was used to decide whether to discard all damaged parts or to repair some of them and reuse. To determine the optimal maintenance strategy to adopt, the two best options after the cost analysis was identified and then an economic appraisal of the two options carried out the Discounted Cash Flow (DCF) technique was used in the appraisal, to determine the earning rate of each of the options. The option with the highest rate of return was chosen as best appraisal maintenance option.

Effects of Ergonomics on Optimal Equipment

Maintenance System (OEMS)

The optimal purpose of maintenance is to keep the maximum number of equipment in the highest degree of material readiness at all times. Riggs (1979) remarked that the ample responsibility involved in maintenance is quite obvious but the difficulty of carrying out the work is not so apparent and in most companies, few employees receive less recognition than maintenance personnel. The researcher having worked as a maintenance engineer has also personally observed this trend. The good work of maintenance personnel is often taken for granted but an occasional failure, often not their fault, may attract disciplinary action. The quality and personal commitment of maintenance personnel have a direct bearing on the operating performance of the equipment. Selection and training of personnel has been recognized as an important feature in setting up an effective team for equipment **Survey on Equipment and People Management**. In a survey of people working for SPDC, a number of supervisors (Process Engineer, Mechanical Engineers and Electrical Engineers), technicians, and mechanics were asked key question on the essential implementations of an optimal maintenance programmes and the benefits gained (if any or none). The results of the survey are striking. A clear message on the essential benefits from the proper implementation of an optimal maintenance programmes for rotating machinery and other oilfield equipment was received.

A) Awareness in Prevention Maintenance

To determine the level of awareness of the various maintenance options available, staff were asked whether they have participated in any preventive inspection/checks on rotating equipment. Further, staff were asked to indicate if they have participated in any preventive maintenance inspection in the last two years. To determine if currently enough resources are being devoted to preventive maintenance activities, respondents were told to comment on the level they perceive SPDC is devoting resources to preventive maintenance.

B) Causes of Slow Breakdown Maintenance Response

Staff were asked the obstacle they encounter in carrying out on time repairs, checks / inspections on equipment, 72% of the staff pointed out that lack of materials is the major obstacle in carrying out on time repair maintenance in the company. Another 15% blamed poorly equipped workshop while 13% pointed at lack of tools. Based on their capacity as experienced maintenance personnel, respondents were asked further to recommend the best method for equipment maintenance. 100% of the sampled staff recommended preventive maintenance. None recommended breakdown as a better strategy. Respondents were asked to suggest any method better than preventive maintenance. The respondent suggested the below method:

1) Routine checks (i.e. condition monitoring)
2) Diagnosed maintenance
3) Scheduled oil sampling (S.O.S)

Many did not respond to this question, but the answers given are still part of what may be regarded as preventive maintenance.

C) Training and Optimal Maintenance: Any Relationship?

Staff were asked of what they think are the major obstacles to execution of an optimal maintenance system programmes. The factors in Table 2 were presented during the questionnaire session on the relationship between training and maintenance.

Table2. *Training and its relationship with maintenance*

S/NO	FACTORS	PERCENTAGE
1.	Lack of training	83%
2.	Frequent breakdown	3%
3.	Lack of workers commitment	13%

Source: *Field Work 2008*

Asked further, if the company promotes employee growth through constant conduct of training sessions to improve maintenance worker skill, 63% answered in the affirmative while 20% said the company does not. The remaining 7% did not know if the company does that or not. Asked further if training has helped improve workers performance in maintenance activities, 98% said yes, while 2% said no.

D) Equipment Performance Level
On a scale of 5 (representing excellent) to (0 representing poor), staff were told to rate the current level of the company's equipment performance level. This was done mostly to appraise how well optimal maintenance faired in terms of equipment performance.

The Credibility Factors and its Effects on Maintenance
What do subordinates expect of their supervisors/ managers? What value (personal traits or characteristic and attitudes) do they look for in their superiors? In the survey conducted involving 31 rotating equipment mechanics and technicians the majority admire and look-forward to supervisors/managers who are job competent, inspiring, honest, intelligent, forward looking and caring. 90% of respondents rated job competence and honesty as prime essential qualities. This was closely followed by 82% who consider forward looking, inspiring and caring as some of the most essential traits. The study found out that supervisors/managers are considered honest when there is a consistency between word and deed. In the view of the mechanics and technicians, competence involved the ability to give useful and intelligent suggestion and the ideas when needed and the ability to challenge and encourage others to be more productive while forward-looking ability involves having a sense of direction and a concern for the future, to be enthusiastic, energetic and positive for the future. Opportunity consists of those factors that moderate or influence a person’s performance or tasks that are beyond the person direct control. Most people perform best in a job, which could be demanding. Jobs are to be designed to include some challenges. A job is not supposed to be allowed to stagnate to the point of no further learning or growth. Managers are always to be aware of the strength and weakness of their workers. Tough assignments are not to be issued and spread around in order to build up self-confidence thereby enabling the worker to realize his full potential and hence grow on the job. A further important feature of any maintenance department is continuity; this ensures quick efficient trouble shooting and repair of equipment. It is also important that maintenance personnel should be familiar with the equipment and have a long term personnel commitment to the overall performance of the equipment. This encourages the maintenance personnel to build up considerable knowledge of each of the individual equipment and system and can quickly trouble shoot. Several instances have occurred where the loss of an experienced technician, either by death or change in employment resulted in significant reduction of the reliability and availability of an equipment. Maintenance costs contribute significantly to the operations in most industries, hence the need to adopt an optimal maintenance system policy. For a method to be considered optimal, it must be cost justifiable. Optimal techniques heavily depend on the strategy of minimization of cost and maximization of benefits and economic viability. The maintenance strategy that would maximize return on investment of the plant was chosen as it presents an optimal method for maintenance system. This chapter presents the discussion interpretation and conclusion drawn from the results obtained from the research.

Cost Saving of Reusing Parts
From the cost analysis of the two options considered if preventive maintenance was to have been adopted, alternative 1A (Repair some parts and reuse) would cost ₦23,718,472.80 while alternative 1B (discard all disused parts and replacement with new ones) will cost ₦26,272,464.00. Consequently, a saving of ₦2,553,991.20 representing 14.63% was achieved if alternative 1A was chosen.

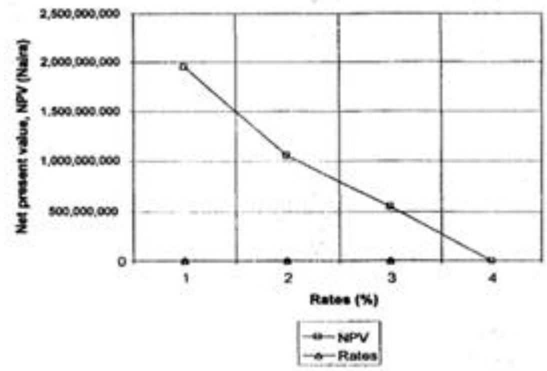
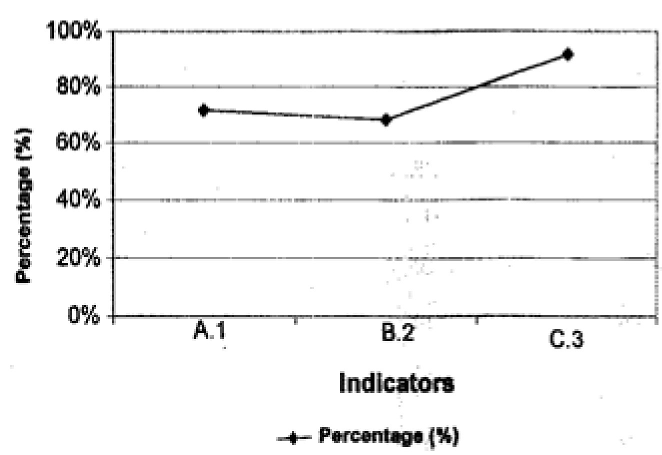


Figure 4. Plot of NPV Vs Rate of Return using breakdown maintenance Strategy

For breakdown maintainable option, Alternative 2A (If repairable parts are repaired and reused). It was observed that a cost of ₦52,218,376.80 would be incurred on each breakdown while alternative 2B present a cost of ₦58,909,092.00. Again the different represents ₦6,690,715.20 or 7.5%. From the above analysis, repairing parts and reusing same appears to be a better choice over discarding them to procure all new pans. Other advantages derivable from this alternative include:

1. If recycled, parts were used; the much preached sustainable environment management would be achieved. Disused pans was used and not discarded to constitute environmental hazard.
2. Associated activities involved in the handling and transportation will generate employment for Nigeria in that sector.
3. The Nigeria Government would benefit from customs and imports duties from the Re-importation of the recycled materials.
4. This practice if encouraged and quality control maintained could stimulate the manufacturers to open up repair workshops in Nigeria.



Rate of Return on Investment

(Preventive Maintenance versus Breakdown Maintenance)

The economic appraisals of the two different maintenance strategies, preventive and breakdown maintenance were carried out using the Discounted Cash Flow (DCF) method. The DCF was used because it took into account the time value of money. The internal rate of return (IRR) on investment was also determined for the two best alternatives, 1 A and 2A. Fig 4.1 is a plot of NPV versus Rate of Return on investment when alternative 1A was adopted on the x-axis, 1 represent 0%. 2 represents 5%, 3 represent 25% and 5 represents 30%.

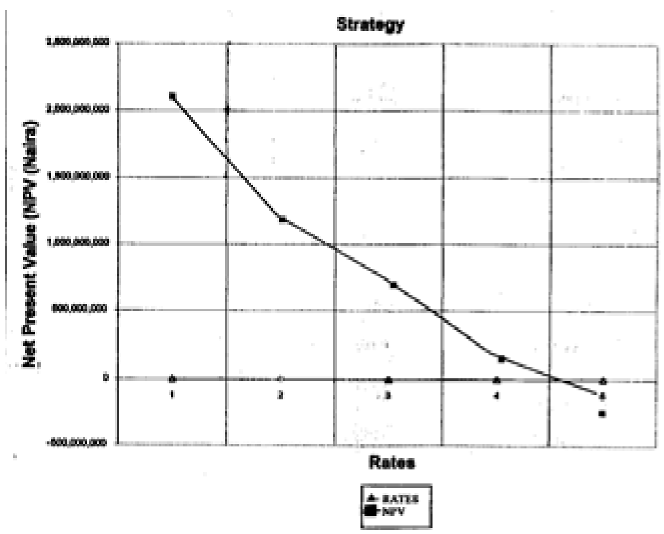


Figure 3: *NPV vs Rate of Return using Preventive Maintenance Strategy*

The point of intersection with the x-axis (i.e. at NPV=0) is at 26% and this is the rate of return on investment if preventive maintenance strategy is adopted. Figure 4.2 is a plot of NPV versus rate of return on investment if alternative 2A was adopted (for breakdown maintenance). On the x-axis, 1 represent 0%, 2 represent 5%, 3 represent 10%, while 4 represent 25%, the point of intersection with the x-axis(when NPV=0) is 24% and this is the rate of return on investment if breakdown maintenance strategy was adopted. The result shows that for the period of equipment life (18 years), adopting a breakdown maintenance strategy yielded an NPV of ₦1,952,268,119.00, while a preventive maintenance strategy resulted to an NPV of ₦2,101.896. A, significant different in NPV of ₦149,625,777.00 resulting in the two strategies. This repressed 7.11 %. A further comparison of Figure 4.3 and 4.4 show that a policy of dispose of equipment at a point of constant wear might be of more financial benefit Figure 4.5 shows that up to ten years breakdown maintenance strategy has an advantage over preventive maintenance for r = 5% and 10%.

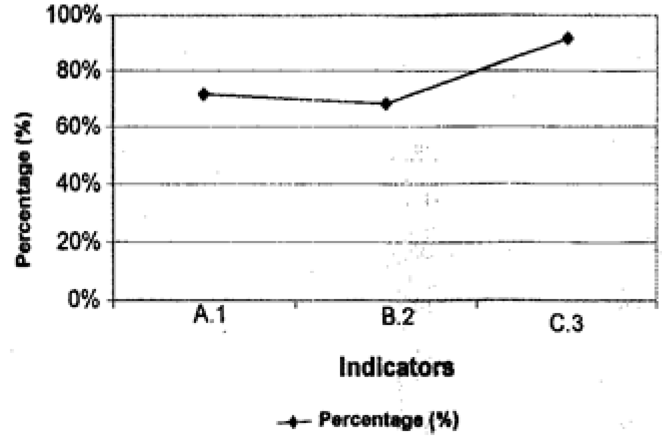


Figure 5 *Preventive Maintenance Awareness Level expressed in percentages.*

A: Indicates general level of staff participation in preventive maintenance.
B: Indicate the level of staff participation in preventive maintenance within the last two years.
C: Indicate the level of resources being devoted to preventive maintenance.

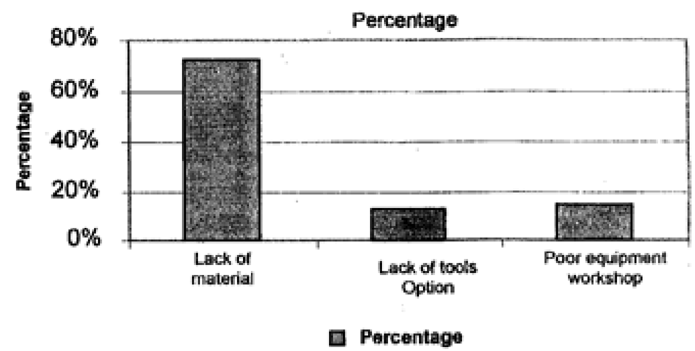


Figure 6: *Causes of Slow Breakdown Maintenance Response*

Breakdown maintenance does not eliminate abandoning preventive maintenance. Preventive maintenance Strategy however presents a better overall advantage. Hence, alternative 1A was considered better than alternative 2A.

Economics and its Effects on Maintenance

The research also revealed that the awareness level of preventive maintenance in the oil industry was high but also indicated that lack of material was the highest factors that affected slow response to breakdown maintenance. Lack of training tools and poorly equipped workshop enhance slow response to breakdown maintenance in the following percentages: 72%, 13% and 15% respectively. Poor recognition and remuneration of maintenance personnel were also found to be having negative impact on optimal maintenance system just as Jack, (1991) concluded that those with ability and intellectual incisiveness must be given due rewards and recognition. Companies need to adopt this strategy in their maintenance departments.

CASE 1: Preventive Maintenance of a Unit

Principle: Preventive maintenance of a unit requires planning. The overhaul of compressors was carried out after manufacturer's stipulated run hours. A high degree of planning skill was expected in the overhaul process and the scheduled shutdown involves a complete planning of each activity that would be done to accomplish the overhaul process. As pointed out earlier, planning for a major inspection is supposed to start between six to twelve prior to actual shutdown date. This was used to ensure that all materials, resources, personnel needed for the job were available (Anderson, 1980).

Instrument: Information obtained from company project files.

Method: Repair level analysis provides determination of the most efficient and optimum maintenance strategy for the repair of failed parts. On a cost basis, the economic decision to be made is the best alternative whether to repair some of the repairable parts and reuse them or to discard all disused parts and replace with new ones, as way of reducing maintenance cost and identifying an optimal strategy. Input data considered include the number of repairs anticipated. The time to complete the overhaul repairs, cost of personnel labour, spares inventory, shipment of failed and repaired items (mostly at manufacturer's facility overseas).This analysis provided the minimum cost of the overhaul activity when the optimal strategy was adopted.

Repair Level Analysis

Overhaul of Dresser - Rand Compressor, Unit at Agbada Compressor Plant of SPDC

In the overhaul of DRESSER RAND Gas compressor at Agbada, the anticipated parts are as detailed in Table 4, while support materials required are shown in Table 4 and Table 5 shows manpower costs for preventive maintenance. Table 3 consists of spares for the overhaul of Agbada compressor, parts are provided by the original equipment manufacturer (OEM). The spares are required to keep the Agbada compressor up and running.

***Table 3**: Materials used for standard 20,000 run hours overhaul (preventive maintenance)*

S/No	Description of Spare	Quality	Unit Price ($)	Total Price ($)
1	Axial compressor inboard and out-board bearings	2	6922.43	13.844.86
2	2nd stage filter element (2nd stage)	20	88.89	1777.8
3	Piston and packing (1st stage seal ring)	8	160.94	1287.75
4	Exhaust Gasket	4	70.06	280.24
5	Bearing (Half)	1	20,846.39	20,846.39
6	Journal Bearing	1	2,343.86	2,343.86
7	Combustion Liners	1	94,374.48	94,374.48
8	Oil filter	6	212.11	1,272.66
9	Fuel filter	6	436.87	2,621.22
10	Spark plugs	12	12.56	150.72
11	O' Ring	2	15.20	30.4
12	Pins	16	7.60	121.60
13	1st stage shim kit	1	180.35	180.35
14	Seal oil filter	2	3.34	6.68
15	Compressor Seals	10	169.87	1,698.70
16	Main Lube oil pump coupling assembly	1	100.00	100.00
17	Strainers	1	14.60	14.60
18	First Stage Nozzle	1	52,214.10	52,214.10
TOTAL				$193,166.18

Table 3 and 4 consist of consumables/ parts for the repair of Agbada compressor, they are very essential for the repair purpose and are provided to aid the workers on site. Table 5 consist of operational cost. The cost of workers salary engaged in the repair of the Agbada compressor is tabulated, this involves all associated manpower cost.

***Table 4**: Support materials used for preventive maintenance*

Summary of ABC Analysis and Classification of Material Inventory in the three Equipment Manufacturing Firms.

Table 4

S/N	Equipment Manufacturing Firms	Total Number of Inventory items	Total Value of Inventory Item ($)	Number of units accounting for 70% of the total value.
1	Siemens Nig. Ltd	543	10,546,692.83	137 (25.23% of total)
2	Dresser-Rand Nig Ltd	551	13,304,404.55	154 (27.95% of total)
3	Nigerian Engineering Works Ltd	551	6,093,825.00	162 (29.40 of total)

***Table 5** Manpower costs used for preventive maintenance*

Summary of paired Sample Pearson Product Moment Correlation Analysis results with four IMS in the three EMFs

Table 5

		Paired Sample of EMF					
		SIE/DRR	DRR/NEW	SIE/NEW	Mean value	Rank	Remark
IMS 1	Pearson correlation (R)	0.204	0.255	0.242	0.234	4th	Not Significant
	Sig (2-tailed) P –value	0.219	0.146	0.068	0.144		
IMS 2	Pearson correlation (R)	0.902	0.916	0.728	0.849	1st	Significant
	Sig (2-tailed) P –value	0.000	0.000	0.002	0.001		
IMS 3	Pearson correlation (R)	0.075	0.612	0.028	0.238	3rd	Not significant
	Sig (2-tailed) P –value	0.655	0.000	0.880	0.512		
IMS 4	Pearson correlation (R)	0.596	0.688	0.524	0.603	2nd	Significant
	Sig (2-tailed) P –value	0.016	0.006	0.020	0.014		

Source: Field Work 2017

The alternatives considered here were whether to discard damaged parts and replace with new ones or to replace all the parts with new ones as a way of reducing maintenance costs and hence optimise maintenance strategy.

Alternative 1A: Repair Some Parts and Reuse

Experience showed that materials often repaired among the needed items were:

a) 1st stage Nozzles C'
b) Combustion liners
c) Half bearing

All other parts were replaced with new ones. Since they were not repairable, the parts repaired are typically recovered in the 'as new' condition and the cost was between 30% and 65% of the cost of new parts. For this research work, 47.5% of the cost of the new part was assumed.

Cost of repairing some materials	= $79.531.61
Cost of new materials	= $25,731.21
Cost of support materials	= $ 3,443.62
	$108,706.44
Total Costs of Materials	**₦13, 044,772.80**

<u>Shipment of parts to Dresser - Rand Yard South Moor Road Wythenshawe UK</u>

Air freight	₦ 825.000.00
Handling charges	₦ 80,000.00
Custom Re-importation Certification	₦ 20,000.00
Agency Fee @ W 250/kg	₦ 400,000.00
	₦ 1,325,600.00

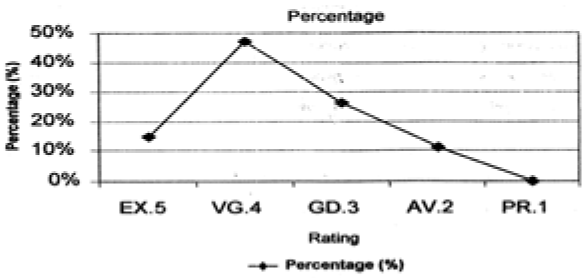


Figure 7 Equipment Performance Level

where: EX: Excellent, V. G.: Very Good, GO: Good, AV: Average, PR:Poor

Shipment of parts from Dresser - Rand Yard, UK to Nigeria

Airfreight to Nigeria ₦ 825,000.00
Handling charges ₦ 80,000.00
Agency Fee @ N 250/kgl ₦ 400,000.00
₦ 1,305,600.00

Total shipment cost=
₦ 1,325,600.00 + ₦ 1,305.600.00**= ₦ 2,631,200.00**

Cost incurred while the crew members were on standby, (see App. A): **= ₦ 1,498,500.00**

Labour Cost (see Table 4.3)

Field Engineers: = ₦ 5,418,000.00
Technicians: = ₦ 546,000.00
Labourer: = ₦ 30,000.00
Community Public Relations: = ₦ 50,000.00
Total = ₦ 6,0044,00.00

Labour cost (cost of labour + stand by charges):
= ₦ 1,498,500.00 + ₦ 6,044,000.00
= ₦ 7,542,500.00
Allow for Logistics: = ₦ 500,000.00

S/N	Description of Spare	Quantity	Unit Price ($)	Total Price ($)
1	Cylinder and liner of cylinder 2	1	56,765.65	56,765.65
2	Connecting rod bushing in 1st, 2nd and 3rd stages	3	4207.35	12,622.05
3	Main lube oil pump	1	4312.98	4312.98
4	New valves	26	5586.02	145,236.52
	TOTAL			218,937.20

Total cost to be incurred if alternative A is chosen:
Shipment cost: = ₦ 2,631,200.00
Labour cost (cost of labour + stand by charges): = ₦ 7,542,500.00
Cost of materials (including refurbished materials) = ₦13,044,772.80
Logistic = ₦ 500,000.00
Total = ₦ 23,718,472.80

Alternative 1B: Discard all Disused Parts and Replacement with New Ones

1. Cost of materials to be replaced: $193,166.20
= ₦ 23,179,944.00
2. Cost of support materials/tools: $3,445.65
= ₦ 413,478.00
3. Total cost materials: $196,611.85
= ₦ 23,593,422.00

Labour Cost

1. Field Engineers: $63,000.00 = ₦ 5,418,000.00
2. Technicians: = 6,000.00 + ₦30,000.00
₦720,000 + ₦30,000 = ₦ 750,000.00
3. Labourer: = ₦ 30,000.00
4. Community Public Relations: = ₦ 50,000.00
Total: = ₦5,418,000.00
₦ 546,000.00
₦ 30,000.00
₦ 50,000.00
₦6,248,000.00

Allow for logistics = ₦ 500,000.00
Total cost of overhaul for alternative B is:
Cost of materials = ₦23,593,422.00
Labour costs = ₦ 6,248,000.00
Logistics = ₦ 500,000.00
₦ 30,341,442.00

The other detailed calculation procedure is showed in App. B.

S/N	Description of Personnel	Qty	Days	Unit Rate ($)	Unit Rate (₦)	Total Rate ($)	Total Rate (₦)	total (All in Naira)
1	Field Engineers	3	40	700	-	84,000	-	7,224,000
2	Technicians	2	40	100	500	8,000	40,000	688,000
3	Artisan	1	40	-	1,000	-	40,000	40,000
4	Community Public Relations	-	-	Lump sum	-	-	-	50,000
TOTAL								8,002,000

Case 2: Breakdown Maintenance of a Unit

Principle

According to Okah-Ake (1995) the primary objective of a breakdown maintenance system is to keep equipment running without maintenance until they breakdown. The essential parameters for measurement are the cost of lost machine-hours in terms of production units and the effect upon profits and the breakeven point. When the combined costs of breakdown repairs and reassemble costs exceed the cost of a preventive maintenance program, the breakeven point was reached.

Instrument: Information was obtained from company project files.

S/N	DESCRIPTION OF SPARE	QUANTITY	UNIT PRICE ($)	TOTAL PRICE ($)
1	Axial compressor inboard and outboard bearings	2	6922.43	13,844.86
2	2nd stage filter element (2nd stage)	20	88.89	1,777.80
3	Piston and packing (1st stage seal ring)	8	160.94	1287.52
4	Exhaust Gaskets	4	70.06	280.24
5	Bearing (Half)	1	20,846.86	20,846.39
6	Journal Bearings	1	2, 343.86	2,343.86
7	Combustion Liners	1	94,374.48	94,374.48
8	Oil Filters	6	212.11	1,272.66
9	Fuel Filters	6	436.87	2,621.22
10	Spark plugs	12	12.56	150.72
11	O'rings	2	15.20	30.4
12	Pins	16	7.60	121.60
13	1st Stage Shim Kit	1	180.35	180.35
14	Seal Oil Filter	2	3.34	6.68
15	Compressor Seals	10	169.87	1,698.70
16	Main Lube oil pump coupling assembly	1	100.00	100.00
17	Strainers	1	14.60	14.60
18	First Stage Nozzle	1	52,214.10	52,214.10
	TOTAL			$193,166.18

S/N	Description of Materials	Quantity	Unit price ($)	Total Price ($)
1	Combustor Puller	1	1,536.83	1,536.83
2	Silicone Gasket Sealant	14	16.58	232.12
3	Anti – Seize Compounds	1	12.52	12.52
4	Alignment tool	1	1,378.95	1,378.95
5	Dye - Penetrant	8	21.17	169.39
6	Anti Rust Liquid (Drums)	3	40.04	120.13
7	Valve Extractor	1	1,845.76	1,845.76
8	Shellsol (Liquid Detergent)	1	60.00	60.00
	TOTAL			$5,355.70

Method:
Determination of the cost associated in breakdown maintenance was compared with that in scheduled preventive maintenance. Usable materials to sustain breakdown maintenances are shown in table 6 while those actually to be used for a standard breakdown after 20,000 hrs inspection is shown in table 6
Table 6: Materials used due to damages sustained during breakdown.
Table 6: Materials used for standard 20,000 hrs inspection (breakdown maintenance)
Table7 Materials for repairs: 7

Tables 6, 7, 8 and 9 show support materials and manpower costs respectively for the breakdown maintenance. These are the spares required to carry out repairs for breakdown maintenance.
Table 8 Support materials used for breakdown maintenance
Table 9: Manpower costs used for breakdown maintenance
**Prices in dollars were based on tile conversion/exchange rate of $ 1.00 = ₦ 120.00*

Due to the extra required to achieve the breakdown maintenance, extra ten (10) days were allocated for the duration for the maintenance.
Alternative 2A: Repair Some Parts and Reuse
The calculation for this alternative is as shown

Experience showed that materials often repaired among the needed items are:
a) 1st stage Nozzles
b) Combustion liners
c) Half bearing

All other parts were replaced with new ones, since they were not repairable. The parts to be repaired were typically recovered in the 'as new' condition and the cost was between 30% and 65% of the cost of new parts. For this research work, 47.5% of the cost of the new part was assumed.

Cost of repairing some materials	= $ 9,531.61
Cost of new materials	= $ 25,731.21
Cost of replacing damaged materials	$ 218,937.20
Cost of support materials	= $ 5,355.70
Total costs of materials;	= $ 329,555.64
	= ₦ 39,546,676.80

<u>**Shipment of parts to Dresser - Rand Yard South Moor Road Wythenshawe UK**</u>

Air freight = ₦ 825,000.00
Handling charges = ₦ 80,000.00
Custom Re-importation Certification ₦ 20,000.00
Agency Fee @ ₦250/kg = ₦ 400,000.00
= ₦ 1,325,600.00

<u>**Shipment of parts to Dresser - Rand Yard UK to Nigeria**</u>

Air freight to Nigeria = ₦ 825,000.00
Handling charges = ₦ 80,000.00
Agency Fee @ ₦25/kg = ₦ 400,000.00
= ₦ 1,305,600.00
Total shipment cost =
₦ 1,325,600.00 + W 1,305,600.00 = ₦ 2,631,200.00

Cost incurred while the crew members were on stand by, (see App. A):
= ₦ 1,498,500.00

Labour Cost (see Table 4.3)
Field Engineers = ₦ 7,224,000.00
Technicians = ₦ 728,000.00
Labourer/Artisan = ₦ 40,000.00
Community Public Relations: = ₦ 50,000.00
TOTAL = ₦ 8,0042,00.00

Labour cost (cost of labour + stand by charges):
₦ 1,498,500.00 + ₦ 8,042,000.00 = ₦ 9,540,500.00
Allow for Logistics = ₦ 500,000.00
Total cost to be incurred if alterative A is chosen.
Shipment cost: = ₦ 2,631,200.00
Labour cost (cost of labour + stand by charges):
= ₦ 9,540,500.00
Cost of materials (including refurbished materials) = ₦39,546,676.80
Logistics = ₦ 500,000.00
= ₦ 52,218,376.80

Alternative 2B: Discard All Disused Parts and Replacement with New Ones
The detailed calculation to optimize this alternative is further shown in App. D.
1. Cost of materials damaged materials
damaged materials: $218,937.20 =₦ 26,272,464.00

2. Cost of materials to be replaced: $193,166.20
=₦ 23,179,944.00
3. Cost of support materials/tools: $5,355.70
=₦ 642,684.00
Total cost of materials: $417,459.10 = ₦ 50,095,092.00

Labour Cost

1. Field Engineers: $84,000.00 = ₦7,224,000.00
2. Technicians: = $8,000.00 + ₦40,000.00 ₦960,000 + ₦40,000 = ₦1,000,000.00
3. Labourer: = ₦ 40,000.00
4. Community Public Relations: = ₦ 50,000.00

Total: **₦7,224,000.00**
₦ 728,000.00
₦ 40,000.00
₦ 50,000.00
₦8,314,000.00

Allow for logistics = ₦ 500,000.00
Total cost of overhaul for alternative B is:
Cost of materials =₦50,095,092.00
Labour costs =₦ 8,314,000.00
Logistics =₦ 500,000.00
₦58,909,092.00

Calculation of Return on Investment and Net Present Value

From the cost analysis made, the cost to be incurred if Preventive maintenance is adopted and repairable parts are repaired and reused (i.e. Alternative 1A) is lower than the cost if alternative 1B is adopted. Hence Alternative 1B is eliminated in favour of alternative 1A. Again, in the breakdown maintenance option, alternative 2A presents lower cost when compared with alternative 2B, hence the calculation on the return on investment will only be carried out on only alternatives 1A and 2A.

Data

a) Cost of equipment is $5,000,'000.00 at an exchange rate of ₦120.00 = $1.00 55,000,000.00 x ₦ 120.00
= ₦ 660,000,000.00
b) Production yield of the compressor = 300 barrels of crude oil per day
c) Equipment life: 18 years

Alternative '1A' is Adopted

Maintenance cost = ₦ 23,718,472.80
Income for the period under consideration:
300 barrels x 365 days x 2 years= 219,000 barrels in 2 years @ $ 50/barrel = 219,000 x $50 = $10,950,000.00 @ ₦ 120 = $1 = ₦ 1,314,000,000.00

Actual cash flow (AFC) = ₦ 1,314,000,000 - ₦23,718,472.80
= ₦ 1,290,281,527.00

$$\text{Net present value NPV} = \sum_{i=1}^{n} \frac{Ai - C}{(1+r)^i}$$

Where NPV = Net Present Value
r = rate of ratio on capital
c = capital outlay (cost of equipment)
A_i = Actual cash flow

If i = 5%

Then NPV =

$$\frac{281,321,544}{(1+0.05)^2} = \frac{281,321,544}{1.1025} = 255,166,933$$

The detailed calculations adopted are shown in App. E and results tabulated in the table 10

Table 10: Return on investment using preventive maintenance

Year	Actual	5%	10%	25%	30%
0	-660,000,000.0	-660,000,000.0	-660,000,000.0	-660,000,000.0	-660,000,000.0
2	1,290,281,527.0	1,176,323,380.0	1,066,348,369.0	825,780,177.3	763,480,193.5
4	1,290,281,527.0	1,061,517,805.0	881,279,644.1	528,499,313.5	451,763,428.1
6	1,290,281,527.0	962,827,941.4	728,330,284.4	338,239,560.6	267,315,637.9
8	1,290,281,527.0	873,313,325.6	601,925,854.9	216,473,318.8	158,174,933.7
10	1,290,281,527.0	792,120,930.2	497,459,384.2	138,542,924.0	93,594,635.3
12	1,290,281,527.0	718,477,034.2	41,112,345.8	88,667,471.4	55,381,441.0
14	1,290,281,527.0	651,679,849.6	339,771,452.9	56,747,181.7	32,770,083.4
16	1,290,281,527.0	591,092,834.1	280,802,853.6	3,631,896.3	19,390,581.9
18	1,290,281,527.0	536,138,625.1	232,068,474.1	23,243,645.6	11,473,717.1
NPV	**10,952,533,743.0**	**6,703,491,725.2**	**4,009,098,663.0**	**1,559,825,489.2**	**1,193,344,652.0**

If Alternative '2A' is Adopted

Maintenance Cost for alternative: 2A = ₦ 52,218,376.80
In breakdown maintenance, the cost of maintenance involved was dependent upon the probability of failure to occur.

Assumptions:

Probability of the equipment breaking down without any preventive maintenance being carried out from the date of purchase/installation/commissioning is assumed as follows: The "first" failure was assumed to occur after four (4) years of commissioning, without carrying out any preventive maintenance. After the first breakdown maintenance was carried out, the reliability of the equipment decreased without any preventive maintenance. It would have continued in that trend if left unattended to.

Table 11 shows failure trend and the years the equipment is likely to breakdown.

Table 11: Return on investment using breakdown maintenance

Year	Actual(₦)	5%	10%	25%
0	-660,000,000	-660,000,000	-660,000,000	-660,000,000
4	2,575,781,623	2,118,241,466.2	1,759,413,676.9	1,055,215,740.6
7.5	2,247,281,623	1,558,447,727.5	1,099,543,364	421,533,799.3
10.5	1,918,781,623	114,966,221.1	705,346,241	184,276,694.7
13	1,590,281,623	843,203,405.6	460,647,939.9	87,426,656.8
15	1,261,781,623	606,938,534.7	302,060,488.6	44,394,994.12
16.5	933,281,643.2	417,243,220.7	193,657,097.6	31,401,949.6
17.5	604,781,643.2	257,505,119	114,084,491.3	12,180,731.58
18	276,281,643.2	114,800,729.3	49,691,682.02	4,977,047.6
NPV	**10,748,253,045**	**5,371,346,424**	**4,024,444,981**	**1,181,407,614.3**

It shows that the equipment would likely breakdown after the first 4 years. It shows the reliability of the equipment decreasing without any preventive maintenance. @ 5% NPV becomes

$$\frac{2,575,786.23}{(1+0.05)^4} = \frac{2,575,786.23}{1.216} = ₦2,119,105,706.00$$

Another assumption was that the average cost that would have been spent on any breakdown maintenance, could have been equal to that incurred during the first breakdown maintenance, i.e. ₦ 52,218,376.80. The failure trend shown below was assumed. The equipment would have likely broken down after:

4 years in operation without maintenance. Subsequently the trend followed:
Another 3.5 (i.e. 7.5 years) in operation without maintenance
Another 3.0 (i.e. 10.5 years) in operation without maintenance
Another 2.5 (i.e. 13 years) in operation without maintenance
Another 2.0 (i.e. 15 years) in operation without maintenance
Another 1.5 (i.e. 16.5 years) in operation without maintenance
Another 1.0 (i.e. 17.5 years) in operation without maintenance
Another 0.5 (i.e. 18 years) in operation without maintenance

Calculating the actual cash flow
For 4 years operations, the plant will generate.
300 barrels/day x 365 x 4 years
= 438,000 barrels @ $50 per barrel, 438,000 barrels x $50
= $21,900,000,000 @ ₦ 120 = ₦ 2,628,000,000.00
ACF = ₦ 2,628,000,000.00 - ₦ 52,218,376.80
= ₦ 2,575,781,623.20

(i.e. income - maintenance cost)
3.5 years in operation (i.e. 7½ years commissioning)
300 x 365 x 3.5 = ₦383,250 barrel
383,250 x $50 x ₦ 120 = ₦2,299,500,000.00
₦2,299,500,000.00 - 52,218,376.80 (i.e.: income – maintenance cost)
ACF = 2,247,281,623.00.

3.0 years in operation (10½ years after commissioning)
300 x 365 x 3 = 328,500.00
328,500 x 50 x 120 = 1,971,000,000.00
1,971,000,000.00 - 52,218,376.80 = 1,918,781,623.00
ACF = ₦1,918,781,623.00

2.5 years in operation (13th year after operation)
300 x 365 x 2.5 = 273,750.00
273,750 x 50 x 120 = 1,642,500,000.00
1,642,500,000.00 - 52,218,376.80 = 1,590,281,623.00
ACF = ₦ 1,590,281,623.00

2.0 year in operation (the 15th year of operation)
300 x 365 x 2.0 = 219,000.00
219,000 x 50 x 120 = 1,314,000,000.00
1,314,000,000 - 52,218,376.80 = 1,261,781,623.00
ACF = ₦ 1,261,781,623.00

1.5 years in operation the plant will generate (16½ years in operation)
300 x 365 x 1.5 = 164,250.00
164,250 x 50 x 120 = 985,500,000.00
985,500,000 - 52,218,376.80 = 933,281,643.20
ACF = ₦933,281,643.20

1 year in operation (17½ years in operation)
300 x 365 x 1.0 = 109,500.00
109,500 x 50 x 120 = 657,000,000.00
657,000,000 - 52,218,376.80 = 604781623.20
ACF = ₦ 604781623.20

For the 0.5 year (i.e. the 18th year in operation)
328,500,000.00 – 52,218,376.80
ACF = ₦276,281,643.20.

Table 11 shows failure trend and the years the equipment is likely to breakdown.

FINDINGS
Repairing and reusing repairable parts of a gas compressor is less expensive as compared with discarding all parts and replacement with new ones. This option will give the same service, provided the repair is carried out by the original equipment manufacturers, (OEM). A saving of 14.63% was achieved if the company operated a preventive maintenance strategy while using repairable spare parts.

CONCLUSION
The Internal rate of return on investment of a gas compressor while using preventive maintenance system was higher as compared to interest rate of return in investment while using breakdown maintenance strategy while using repairable spare parts. This implies that operating a preventive maintenance system will therefore ensure a higher NPV. The study revealed that maintenance personnel were not well treated, equipped and appreciated and they were aware of this fact. Lack of tools, equipment and adequate training were negatively impacting on the output and hence on productivity.

Recommendations
The recommendations as a result of this study are as follows:
i. The advantages of terotechnology should be exploited as a veritable maintenance approach.
ii. Maintenance personnel should be well-treated.
iii. Adequate training, retraining, discipline and welfare should be integrated into the optimal planning and maintenance system.
iv. There should be a dual system of communication between management and workers.
v. Team-work should be encouraged in maintenance and planning systems.

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