

**An improved maintenance management strategy  
for gas field equipment in Escravos gas-to-liquid  
plant, Nigeria.**

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## **ABSTRACT**

The safety record of most petrochemical industries in the world and Nigeria in particular, has not been able to come down to the maximum allowable range of 0 – 0.1 percent of tolerance on recordable injuries, due to increasing failure rates of equipment within the plant. Investigations on the maintenance audit carried out on the Nigerian Gas Company (NGC) revealed that 85 percent of such failures are directly linked to improper adaptability of an effective maintenance management strategy and plan within the petrochemical industries in Nigeria.

Equally, the growth and continuous operation of any plant depends to a large extent on the maintenance of the equipment that refines the Crude Oil and natural Gas. As such, various maintenance management systems have been used over the years for the actualisation of the above purpose but with minimal success. This is evident in the fact that the level of maintenance performance of most Nigerian Petroleum Companies is always on the corrective maintenance model, which indirectly implies that the plant normally breaks down before maintenance management is applied.

A critical look at the deficiency of improper adaptability of these maintenance management plans have conspicuously manifested in five major categories of maintenance failures which includes the following;

- Failure of safety critical equipment due to lack of maintenance
- Human error during maintenance
- Static or spark discharge during maintenance in an intrinsically unsafe zone
- Incompetence of maintenance staff, and
- Poor communication between maintenance and production staff.

These gaps as identified in this research must be corrected in the Nigerian Gas Industry if meaningful progress is to be made.

Gas - To - Liquid technology is a very complex technology and with natural gas as the basic raw material, the technology not only looks intimidating but also is full of potential

hazards. People are naturally afraid of the complex nature of gas in a confined environment (because of its highly combustible nature), its gaseous state makes it more complex for it to be kept under control and at the same time be moved from one form to another at different temperatures and pressures.

The maintenance audit carried out on the Nigerian Gas Company (NGC) revealed some major loopholes in the maintenance management strategies adopted in the country. The audit reveals that the degree of adherence to conditions attached towards the maintenance management strategy of this equipment (in this case Gas field equipment) was too poor. Based on the above, this research is meant to improve the existing maintenance management strategy, by developing a Maintenance Management Strategy (MMS) that will be suitable for gas field equipment in the Escravos Gas-To- Liquid (EGTL) plant, planned to be commissioned in Nigeria early 2011.

The need to research the above mentioned Maintenance Strategy became imperative due to the fact that the rate at which most of the petrochemical plants in the world are being gutted by fire, mainly due to poor maintenance management systems is alarming.

This research work proffered solutions that will reduce or completely eliminate the highlighted problems above. This was based on investigations and analysis carried out in the chosen research area.

Models were developed for the actualization of this Improved Maintenance Management Strategy (IMMS), so that the desired safe operability of the gas field equipment in the Escravos Gas-To- Liquid (EGTL) plant will be achieved without maintenance failure of any kind.

**KEY WORDS:**

- Approach
- Asset
- Company
- Computerized
- Deliverable
- Develop
- Device
- Engineering
- Equipment
- Explosion
- Failure
- Function
- Gas
- Gas field equipment
- Gas-to-Liquid
- Growth
- Implementation
- Industrial
- Maintenance
- Management
- Monitor
- Objectives
- Oil
- Operator
- Performance
- Petrochemical
- Policy
- Preventive Maintenance

- Primary
- Productivity
- Project
- Reliability
- Research
- Standard
- Strategy
- Technical

| <b>TABLE OF CONTENTS</b>                                                         | <b>PAGES</b> |
|----------------------------------------------------------------------------------|--------------|
| TITLE PAGE.....                                                                  | i            |
| ACKNOWLEDGEMENT.....                                                             | ii           |
| ABSTRACT.....                                                                    | iii          |
| KEY WORDS.....                                                                   | v            |
| TABLE OF CONTENTS.....                                                           | vii          |
| LIST OF TABLES.....                                                              | xi           |
| LIST OF FIGURES.....                                                             | xii          |
| LIST OF ACRONYMS.....                                                            | xiii         |
| <br><b>CHAPTER ONE</b> .....                                                     | <br>15       |
| 1.0 INTRODUCTION.....                                                            | 15           |
| 1.0.1 PROBLEM STATEMENT.....                                                     | 16           |
| 1.0.2 SCOPE OF THE RESEARCH.....                                                 | 17           |
| 1.0.3 EXPECTED DELIVERABLE OF THE RESEARCH.....                                  | 18           |
| <br><b>CHAPTER TWO</b> .....                                                     | <br>19       |
| 2.0 BACKGROUND THEORY AND LITERATURE SURVEY.....                                 | 19           |
| 2.0.1 HOW EQUIPMENT FAILS.....                                                   | 19           |
| 2.0.2 WHY EQUIPMENT FAILS.....                                                   | 19           |
| 2.0.2.1 OVER-STRESSED COMPONENTS.....                                            | 19           |
| 2.0.2.2 PHYSICAL ATTACK.....                                                     | 20           |
| 2.0.2.3 ERRORS OR MISTAKES.....                                                  | 20           |
| 2.0.2.4 POOR DESIGN CHOICES AND/OR POOR MANUFACTURING /<br>ASSEMBLY QUALITY..... | 20           |
| 2.0.2.5 LACK OF MAINTENANCE AND CARE.....                                        | 20           |
| 2.0.2.6 UNIMAGINED INCIDENTS AND KNOCK-ON EFFECTS.....                           | 21           |
| 2.0.3 WHEN EQUIPMENT FAILS.....                                                  | 21           |
| 2.1.0 THE MAINTENANCE CONCEPT.....                                               | 22           |
| 2.1.1 MAINTENANCE IN THE OIL & GAS INDUSTRY.....                                 | 22           |
| 2.1.2 MAINTENANCE MANAGEMENT.....                                                | 24           |

|                                                                                   |           |
|-----------------------------------------------------------------------------------|-----------|
| 2.2 TYPES AND FORMS OF MAINTENANCE OBTAINED IN NIGERIA.....                       | 26        |
| 2.3 TODAY’S MAINTENANCE STRATEGIES AND THEIR CHALLENGES.....                      | 27        |
| 2.3.1 TOTAL PRODUCTIVE MAINTENANCE, TPM.....                                      | 29        |
| 2.3.2 BUSINESS CENTERED MAINTENANCE, BCM.....                                     | 31        |
| 2.3.3 TOTAL QUALITY MAINTENANCE, TQM.....                                         | 32        |
| 2.3.4 RELIABILITY CENTERED MAINTENANCE, RCM.....                                  | 33        |
| 2.3.5 PERFORMANCE BASED MAINTENANCE, PBM.....                                     | 35        |
| 2.3.6 RISK BASED MAINTENANCE, RBM.....                                            | 36        |
| 2.3.7 RUN-TO-FAILURE, RTF.....                                                    | 37        |
| 2.4 IDENTIFYING COMMON PROBLEMS EVIDENT IN TODAY’S<br>MAINTENANCE STRATEGIES..... | 39        |
| <b>CHAPTER THREE.....</b>                                                         | <b>41</b> |
| 3.0 METHODOLOGY.....                                                              | 41        |
| 3.1 EMPIRICAL INVESTIGATION.....                                                  | 41        |
| 3.1.1 BREAKDOWN OF THE DESIGN.....                                                | 42        |
| 3.1.2 METHOD FOR OBTAINING RESULTS.....                                           | 43        |
| 3.1.3 TEST PERSONS/RESEARCH GROUP.....                                            | 44        |
| 3.1.4 MEASURING INSTRUMENTS OR SOFTWARE.....                                      | 45        |
| 3.1.5 PILOT STUDIES, VALIDITY PROCEDURE AND QUALITY CONTROL....                   | 46        |
| 3.1.6 METHOD OF (STATISTICAL) DATA PROCESSING.....                                | 46        |
| 3.1.7 OUTCOMES OF THE RESEARCH INVESTIGATION.....                                 | 47        |
| <b>CHAPTER FOUR.....</b>                                                          | <b>48</b> |
| 4.0 EXPERIMENT AND RESULTS ANALYSIS.....                                          | 48        |
| 4.1 MAINTENANCE AUDIT ANALYSIS.....                                               | 49        |
| 4.2 CASE STUDY ANALYSIS.....                                                      | 51        |
| 4.2.1 THE QUESTIONNAIRE METHOD.....                                               | 51        |
| 4.2.2 THE INTERVIEW METHOD.....                                                   | 56        |
| 4.3 UTILIZATION OF AVAILABLE INFORMATION TO DEVELOP AN IMMS...65                  |           |
| 4.4 APPLICABILITY OF FMECA IN THE DEVELOPMENT OF THE IMMS.....                    | 65        |

|                                                                                          |    |
|------------------------------------------------------------------------------------------|----|
| 4.5 OVERALL EQUIPMENT EFFICIENCY (OEE).....                                              | 66 |
| <b>CHAPTER FIVE</b> .....                                                                | 68 |
| 5.0 DISCUSSION AND EVALUATION ON THE DEVELOPED IMMS.....                                 | 68 |
| 5.1 FACTORS CONSIDERED DURING THE DEVELOPMENT OF THE (IMMS)....                          | 69 |
| 5.1.1 PRE-EMPTIVE DETECTION AND ELIMINATION.....                                         | 69 |
| 5.1.2 QUALITY CONTROL AND ASSURANCE.....                                                 | 70 |
| 5.1.3 PREVENTATIVE MAINTENANCE.....                                                      | 70 |
| 5.1.4 SHUTDOWN OVERHAUL MAINTENANCE.....                                                 | 71 |
| 5.1.5 PREDICTIVE MAINTENANCE.....                                                        | 72 |
| 5.1.6 INTENTIONAL OVER-DESIGN SELECTION.....                                             | 72 |
| 5.1.7 IMPROVED TECHNOLOGIES.....                                                         | 73 |
| 5.1.8 ROOT CAUSE ELIMINATION AND DESIGN-OUT.....                                         | 73 |
| 5.1.9 PROACTIVE EDUCATION AND TRAINING.....                                              | 74 |
| 5.1.10 MAINTENANCE PLANNING AND SCHEDULING.....                                          | 75 |
| 5.1.11 THE RIGHT MIX OF STRATEGIC MAINTENANCE MANAGEMENT<br>STRATEGIES.....              | 75 |
| 5.2 EVALUATING THE IMPROVED MAINTENANCE STRATEGY.....                                    | 76 |
| 5.2.1 INSPECTION DECISION.....                                                           | 76 |
| 5.2.2 REPAIR POLICY.....                                                                 | 77 |
| 5.2.3 REPLACEMENT POLICY.....                                                            | 78 |
| 5.3 THE GENERAL RENEWAL PROCESS.....                                                     | 79 |
| 5.3.1 SIZE OF MAINTENANCE CREW.....                                                      | 79 |
| 5.3.2 SCHEDULING MAINTENANCE WORK.....                                                   | 80 |
| 5.4 MAINTENANCE CONTROL.....                                                             | 80 |
| 5.4.1 MAINTENANCE CONTROL LOOP.....                                                      | 80 |
| 5.4.2 CONTROL PROCEDURE.....                                                             | 81 |
| 5.4.3 STEPS TO DEVELOP EFFECTIVE ROUTES.....                                             | 82 |
| 5.5 THE IMMS: AN OPERATOR DRIVEN BASED PROACTIVE MAINTENANCE<br>MANAGEMENT STRATEGY..... | 82 |
| 5.5.1 THE OPERATOR DRIVEN CONCEPT.....                                                   | 83 |

|                                                          |            |
|----------------------------------------------------------|------------|
| 5.5.2 THE PARAMETRIC MONITORING AND CONTROL CONCEPT..... | 84         |
| <b>CHAPTER SIX.....</b>                                  | <b>89</b>  |
| 6.0 CONCLUSIONS AND RECOMMENDATIONS.....                 | 89         |
| 6.1 SUMMARY.....                                         | 89         |
| 6.2 CONCLUDING REMARKS.....                              | 90         |
| 6.3 RECOMMENDATIONS.....                                 | 92         |
| 6.4 SUPPORTIVE SYSTEMS.....                              | 93         |
| 6.4.1 OPERATOR DRIVEN OBJECTIVES.....                    | 93         |
| 6.4.2 ORGANIZATION.....                                  | 94         |
| 6.4.3 STAFF TRAINING.....                                | 94         |
| 6.4.4 PREVENTIVE MAINTENANCE (PM).....                   | 94         |
| 6.5 AREA FOR FURTHER RESEARCH.....                       | 95         |
| <b>APPENDICES.....</b>                                   | <b>96</b>  |
| MAINTENANCE AUDIT REPORT.....                            | 97         |
| QUESTIONNAIRE.....                                       | 105        |
| IMMS TEMPLATE.....                                       | 111        |
| <b>REFERENCES.....</b>                                   | <b>120</b> |

## **LIST OF TABLES**

|                                                                     |         |
|---------------------------------------------------------------------|---------|
| TABLE 4.1: Comparative Analysis for Questionnaire.....              | 52 - 55 |
| TABLE 4.2: Comparative Analysis of the Interview Documentation..... | 57 - 63 |
| TABLE 6.1- Effective Maintenance Vs Non-effective Maintenance.....  | 90      |

## LIST OF FIGURE

|                                                                                     |         |
|-------------------------------------------------------------------------------------|---------|
| <b>Fig 2a:</b> Maintenance Management Strategic Box.....                            | 25      |
| <b>Fig 2b:</b> Waiduncle picture of maintenance management process.....             | 26      |
| <b>Fig. 2c:</b> Overview of the different maintenance types.....                    | 28      |
| <b>Fig. 2d:</b> Graph of failure rate against change in maintenance philosophy..... | 28      |
| <b>Fig. 5a:</b> Maintenance control loop.....                                       | 81      |
| <b>Fig. 5b:</b> IMMS Template.....                                                  | 86 - 88 |

## **LIST OF ACRONYMS**

|          |                                                                                     |
|----------|-------------------------------------------------------------------------------------|
| BCM      | Business Cantered Maintenance                                                       |
| B/D      | Barrels per Day                                                                     |
| CBM      | Condition Based Maintenance                                                         |
| CNL      | Chevron Nigeria Limited                                                             |
| EGTL     | Escravos Gas-To- Liquid                                                             |
| ETA      | Event Tree Analysis                                                                 |
| FTA      | Fault Tree Analysis                                                                 |
| FMEA     | Failure Modes and Effects Analysis                                                  |
| FAF      | Fail and Fix                                                                        |
| FMECA    | Failure Modes, Effects and Criticality Analysis                                     |
| GTL      | Gas-To-Liquid                                                                       |
| IMMS     | Improved Maintenance Management Strategy                                            |
| ISO      | International Organization for Standardization                                      |
| JV       | Joint Venture                                                                       |
| LNG      | Liquefied Natural Gas                                                               |
| MMS      | Maintenance Management Strategy                                                     |
| MTTR     | Mean Time to Repair                                                                 |
| NGC      | Nigerian Gas Company                                                                |
| NNPC     | Nigerian National Petroleum Cooperation                                             |
| NNPC-EID | Nigerian National Petroleum Cooperation - Environmental<br>Investigative Department |
| OEE      | Overall Equipment Effectiveness                                                     |
| O&M      | Operations & Maintenance                                                            |
| PAP      | Proactive and Preventive                                                            |
| PBM      | Performance Based Maintenance                                                       |
| PdM      | Predictive Maintenance                                                              |
| PM       | Preventative Maintenance                                                            |

|        |                                                  |
|--------|--------------------------------------------------|
| PR     | Performance Rate                                 |
| RBI    | Risk Based Inspections                           |
| RBM    | Risk Based Maintenance                           |
| RCM    | Reliability Centered Maintenance                 |
| RE     | Rate Efficiency                                  |
| RTF    | Run-To-Failure                                   |
| SA     | South Africa                                     |
| SCADA  | System Control and Data Acquisition              |
| SNEPCO | Shell Nigeria Exploration and Production Company |
| SOP    | Standard Operating Procedures                    |
| SR     | Speed Rate                                       |
| TPM    | Total Productive Maintenance                     |
| TQM    | Total Quality Maintenance                        |

## **CHAPTER ONE**

### **1.0 INTRODUCTION**

The Oil and Gas Industry has become one of the world's largest economy contributors to the GDP of Oil Producing Nations. As the industry grows, more and more Plants are built to refine the Crude Oil and natural gas, hence new equipment with complex mechanism and function are developed for better processing and refining of these natural resources. In order to make these large Plants continue to function as designed week in week out, maintenance strategies need to be constantly improved upon.

The operators of oil and gas companies are constantly under pressure to attain both technical and commercial standards required in managing oil and gas assets. The criterion includes achieving and maintaining production targets, minimizing production costs and maintaining the highest safety and environmental standards. This can be seen from the quote, "managing oil and gas assets has become increasingly more complex". (Marcus Evans 2008)

"In order to achieve operational excellence and maximize asset performance over their lifetime, a range of activities need to be performed" quoted by Marcus Evans at an Advanced Maintenance and Asset Optimization Forum for the Oil and Gas Industry in 2008.

Nigeria, being one of the largest producers of Oil and Gas in Africa (according to Basil Omiyi, Shell's CEO/ Managing Director for Nigeria, 1995) is being faced with the challenge of achieving and maintaining production targets, minimizing production costs, whilst maintaining the highest safety and environmental standards.

Based on the report by National Petroleum Cooperation - Environmental Investigative Department (NNPC-EID) 2000, in Nigeria nine out of every ten explosions are pipeline explosions. These pipelines are the property of NGC (Nigerian Gas Company), a

subsidiary of NNPC (Nigerian National Petroleum Cooperation) which regulates the Oil and Gas exploration deals in the country.

NNPC and other subsidiary companies have over the years only implemented corrective and preventive maintenance management strategies in their respective plants (Prof. G. Nwokeji, 1994). The need for an Improved Maintenance Management Strategy is therefore evident in the bid to actualize the above mentioned operational excellence.

### **1.0.1 PROBLEM STATEMENT**

For years now, Nigeria has failed to resolve the problems of pipe line explosions as identified by the investigative report of NNPC-EID.

In seeking the research aims and objectives, effort was made to examine the Nigerian Gas Company's maintenance management strategy. This helped in noting the deficiencies that ought to be considered.

Deficiencies such as inadequate description of responsibilities with regards to maintenance matters, inadequate operating systems for detecting abnormal conditions, inadequate maintenance management follow-up action plans and systems that will ensure consistency in the implementation of the preventive / corrective actions, sufficient to resolve these conflicts were all identified (NGC's Maintenance Audit Report, January 2008).

**The recurring nature of these problems indicates that maintenance management control has weakened (Barrett, 2001).**

The research is based on improving the existing maintenance management strategy to thereby improve the maintenance management control. It will also help to develop a Maintenance Management Strategy (MMS) that will be suitable for Gas field Equipment in the EGTL (Escravous Gas-To- Liquid) plant. The outputs from this research will improve the maintenance of the plant, due for commissioning in Nigeria by 2011.

## **1.0.2 SCOPE OF THE RESEARCH**

Efforts have been made to ensure that the primary deliverable of this research work will be developed based on a specific technique known as “systematically applied maintenance strategy” (Wireman, 1997). It will consist of a computerized maintenance management system, with a sophisticated feedback control mechanism to help monitor the complete system. This will ensure that the much needed improvement on the maintenance function performance on the gas field equipment is achieved.

This strategy will be combined and adapted to a certain extent with the maintenance strategy of SASOL and that of the newly built Oryx GTL Plant at Qatar. This combined and adapted strategy will be the proposed Improved Maintenance Management Strategy (IMMS) for gas field equipment in escravos gas-to-liquid plant in Nigeria.

Also to form part of the strategy is the maintenance approach of UK’s high-pressure National Grid Transmission System. This grid is considered because, for the past 35 years of operation, it hasn’t experienced any explosion (BBC News, 17 July 2006). This will give the basis for suggesting improvement measures required for the proposed IMMS.

The proposed IMMS will incorporate the maintenance of monitoring devices built-in on this gas field equipment. A good maintenance strategy incorporates a good feedback network. This helps in monitoring the applicability, workability, reliability and maintainability of the company’s MMS. This also ensures proper implementation through the proper maintenance of these monitoring devices (RELOGICA, Vol. 8).

Basically, the research implementation will be targeted towards the elimination of failures on gas field equipment. Failure of this equipment can be combated effectively with the introduction of a reliable and effective maintenance management Strategy.

Furthermore, the IMMS developed from this research will potentially provide the management of Oil and Gas industry globally with sufficient information for the development of an adequate maintenance support system for its Plants.

It will also help in achieving operational excellence as well as maximize asset performance. It will help in achieving and maintaining production targets; minimize production costs, whilst maintaining the highest safety and environmental standards.

### **1.0.3 EXPECTED DELIVERABLE OF THE RESEARCH**

The main objective of this research project is to develop an IMMS that has the potential to provide the EGTL (Escravos Gas-To-Liquid) Maintenance Management, as well as Maintenance Managements of other Nigerian petrochemical industries with sufficient maintenance management information necessary for the development of adequate maintenance support system for proper maintenance of gas field equipment.

Besides the IMMS, the research work would also deliver the following;

- i. The maintenance audit report review for Nigerian Gas Company (NGC) on gas field equipment maintenance management strategy.
- ii. Questionnaires on the need for an improved maintenance management strategy on gas field equipment based on functional perceptions of engineering performance.
- iii. Interview with the maintenance manager of NGC based on the audit report and the implementation of action plan.
- iv. Interview with the maintenance manager of SASOL, to showcase the company's view towards achieving a functional engineering performance using a good maintenance strategy.

This research therefore is geared towards contributing to the reduction of explosions from gas field equipment as has been identified in Nigeria by NNPC-EID. Overall, the deliverable would provide an all encompassing maintenance strategy that might be used as a model in oil and gas companies in Nigeria and the world at large.

## **CHAPTER TWO**

### **2.0 BACKGROUND THEORY AND LITERATURE SURVEY**

Basically, the research is targeted towards the elimination of failures on gas field equipment (see page 17 above). Failure of this equipment can be combated effectively with the introduction of a reliable and effective maintenance management Strategy.

Equipment failure investigation includes why equipment fails, how equipment fails and when equipment fails. With that, one can select the right mix of maintenance strategies to extend and maximize its service and performance.

#### **2.0.1 How Equipment Fails**

Today's equipment technologies can be broadly grouped as mechanical or electrical. Equipment in both groups has physical presence. You can touch them. Because they are made of solid matter, they can break or deteriorate.

Equipment fails because its physical substance and structure cannot support the 'duty' required for it to execute. In other words a final incident destroys it because it is not physically able to withstand that incident. In some cases the end of an equipment's life is instantaneous and without warning. Many times there is a gradual worsening of performance that can be detected.

#### **2.0.2 Why Equipment Fails**

Equipment fails because some part of it has broken or deteriorated. The question we need to ask is - "What can cause an equipment part to break or deteriorate?" There are usually hundreds of combinations of causes that can make a piece of equipment fail. Fortunately they can be categorised into a few simple explanations.

##### **2.0.2.1 Over-stressed Components**

Physical matter can only survive within a limited range of imposed stresses and environments. Once matter is stressed beyond its endurance it will suddenly fail.

Some common examples are overloading, becoming too hot and placing an item under fluctuating forces leading to fatigue situations.

#### **2.0.2.2 Physical Attack**

This is the case where the environment around the equipment actually damages the equipment. When environmental attack gets too severe the equipment is compromised and fails; as it no longer has the strength or capacity to handle its duty. Common examples are rusting, chemical corrosion, wear, erosion and cavitations.

#### **2.0.2.3 Errors or Mistakes**

Equipment can fail due to the wrong usage, or a wrong choice being made in ignorance. Failure by error can start on the drawing board at the design stage. It can be due to an operator or maintenance personnel making a mistake. It can be due to incompetent management decision.

Some examples include starting equipment when not fully coupled, forgetting to put oil in a gearbox, introducing incompatible chemicals and doing the wrong instruction sequence.

#### **2.0.2.4 Poor Design Choices and-or Poor Manufacturing / Assembly Quality**

As the heading implies there are times when a part is made incorrectly, built incorrectly or its design was unable to withstand the imposed service duty.

Design errors include selecting undersized equipment, wrongly specified components and introducing safety risks. Manufacturing errors like poor welding, poor casting, incorrectly positioned holes and out of tolerance machining are real possibilities. Similarly, assembly errors, such as under-torque on bolts, poorly fitted electrical connections and short-cut assembly quality practices will eventually lead to equipment failure.

#### **2.0.2.5 Lack of Maintenance and Care**

When equipment is designed, the designer makes the assumption that it will be treated with reasonable care and it will undergo a minimum amount of required maintenance. When care and maintenance is withheld from equipment for an extended period of time, accumulated problems develop which eventually cause failure.

This can include not changing lubricating oil, leaving electrical equipment open to dust and dirt ingress, starting machines under full load, not checking remaining service life and not cleaning equipment down.

#### **2.0.2.6 Unimagined Incidents and Knock-on Effects**

Occasionally, an unexpected disastrous event occurs that destroys the equipment. These include sabotage, natural occurrences, such as lightning and terrorism.

Included in this category are unforeseen preventable events that are a consequence of planned events. An example is where a bolt falls into a machine during a repair and is not noticed. On start-up the bolt is jammed into the working parts and causes a breakdown. Another example is negligent behaviour, such as backing forklifts into operating plant or out-of-control vehicles running into machinery.

#### **2.0.3 When Equipment Fails**

Equipment failure is defined as the point when the equipment no longer delivers the minimum duty required of it. It may not yet be broken, but it is not able to deliver the needed service.

The actual time of failure depends on when the cause of the failure coincides with the item's ability to accommodate the failure mechanism. This means that the failure happens at the time the item can no longer operate as required. This point in time can be controlled by the selection of the right maintenance strategies!

Equipment failure can even be totally prevented with appropriate maintenance strategy. The importance of effective maintenance thus as shown in table below will have a great impact on the overall accountability of a company. By reducing the direct and indirect cost of equipment failure, the concept of productive, effective and profitable can be achieved from the maintenance program.

Return of Assets = Revenue Asset Value -----(1)

Revenue = Price X Volume -----(2)

Volume = Max. Capacity X Overall Equipment Effectiveness -----(3)

Effective maintenance has a positive effect on equation (1), (2) and (3). Improved maintenance helps to boost plant availability by reducing the need for expensive capital upgrades to increase output.

### **2.1.0 THE MAINTENANCE CONCEPT**

Maintenance is the act of preserving a particular asset in its original condition, to prolong its useful life (Isermann, 1997). It is also the physical act of preventing, determining, and correcting equipment or software faults. It includes all actions taken to retain the system/equipment/product in a useful serviceable condition (<http://www.threesl.com>). Maintenance aims at ensuring plant availability, increasing production flow and outputs while decreasing failure of production equipment (Jarrell, 2001).

The maintenance function is concerned with the aspect of decision-making that relates to effective maintenance, replacement and reliability of industrial equipment (Levis, 2003). These decisions relating to the maintenance of equipment often serves as guide towards ensuring proper maintenance implementation.

Just as it is done in product manufacturing, work maintenance should have scheduled inventories of spare parts maintained and prescribed level of maintenance quality (Isermann, 1997). Therefore to meet these aforementioned demands, a maintenance concept should be drawn.

The maintenance concept can tentatively be put forward as an idea or outline of the way maintenance will be conducted with supplemented information within the environment (Levis, 2003). This concept becomes the Maintenance Plan when the outline has finally been filled.

### **2.1.1 MAINTENANCE IN THE OIL AND GAS INDUSTRY**

It is not enough to purchase sophisticated equipment because of the advancement in technology, without a proper plan on how these equipment will be maintained. Basically, the effectiveness of any operational system is based largely upon the maintenance of the entire parts of the system, most especially in oil and gas industries (Apelgren, 2000).

Most industrial equipment whether simple, cheap or expensive degenerates as a result of wear, tear and ageing, except when prompt action is taken to maintain them (David, 1985). This in turn decreases the performance and reliability of the equipment and eventually increases the potential for failures. This slowly but steady regression during the operational life of equipment leads to high cost of operation, technical ageing, leading to low level and poor quality production.

Maintenance is aimed at the improvement and the revival of various activities which results in increased productivity at a reduced cost (Jarrell, 2001). In other words, it increases equipment efficiency over a long period and sustains productivity. It also makes equipment conditioning normal.

Maintenance is thus required in oil and gas industry to:

- Place plants in serviceable condition to enable appropriate quality of work in order to boost production.
- Preserve the fixed assets in a satisfactory condition.
- Bring down the cost of lost production as a result of plant breakdowns.

To ensure high rate of plant availability and reliability, constant maintenance must be done (Jarrell 2001). This maintenance must be planned in accordance with production requirements and planned so that it causes a very minimal downtime and production loss. Inadequate maintenance can result in damage, which is highly expensive not only in repairs but also in production loss (Jarrell 2001).

Maintenance within the Oil and Gas industries need specialized skills in order to meet up with the challenges of extracting the “difficult oil” (Prof. G. Nwokeji, 1994). It requires customized technology and project management expertise. The geology of formation for Oil and Gas reservoirs is complex. The different complex formation (e.g. deep water formation) requires different technological applications.

### **2.1.2 MAINTENANCE MANAGEMENT**

Maintenance management can be defined as the structural process designed to ensure the implementation of strategies developed towards the actualization of the effective operation of equipment (Swedish Standards Institute, Def. 2001). It was born out of the dire need to combat failure within the production main stream (Narayan, 2004). This resulted in the various forms of maintenance processes which are aimed at improving equipment reliability thereby resulting in increased productivity at a reduced cost (Smith, 1997).

In the bid to develop maintenance management strategy that can combat these equipment failures effectively, we must first x-ray the various efforts made by previous studies towards eliminating these equipment failures. This will help in identifying areas of weakness in the bid to actualizing effective maintenance and completely eliminating equipment failure.

The major reason for the existence of the maintenance department is to ensure that the existing plant equipment function well as expected by the production department (Kaith, 1987). This situation is tenable in SASOL and NNPC (Nigeria National Petroleum Cooperation) which are examples of enterprises that incorporate some of the maintenance principles mentioned in the course of this research.

In relation to plant operation, the following are applicable;

- ❖ Availability of start-up for plant
- ❖ Non-breakdown of plant in the course of operation
- ❖ Efficient level of operation
- ❖ Lack of interference between down time maintenance and production
- ❖ Minimization of the down time breakdown
- ❖ Mutual understanding between maintenance and production department
- ❖ Effective maintenance policy should be ensured in directing and controlling all maintenance activities.

The major aim of the maintenance management is designing an operation to actualize and thus feature a maintenance policy that should be adopted including its objectives (Jarrell, 2001). Thus for maintenance policy to be operational, the maintenance work is organized and planned in decision making.

Five strategic aspects of maintenance management have been identified, namely: maintenance methodology, support processes, organization and work structuring, comparable culture and general management policy (Barrett, 2001). Three factors that permeate these dimensions are wise leadership, excellent communication and an understanding of the human factors involved.

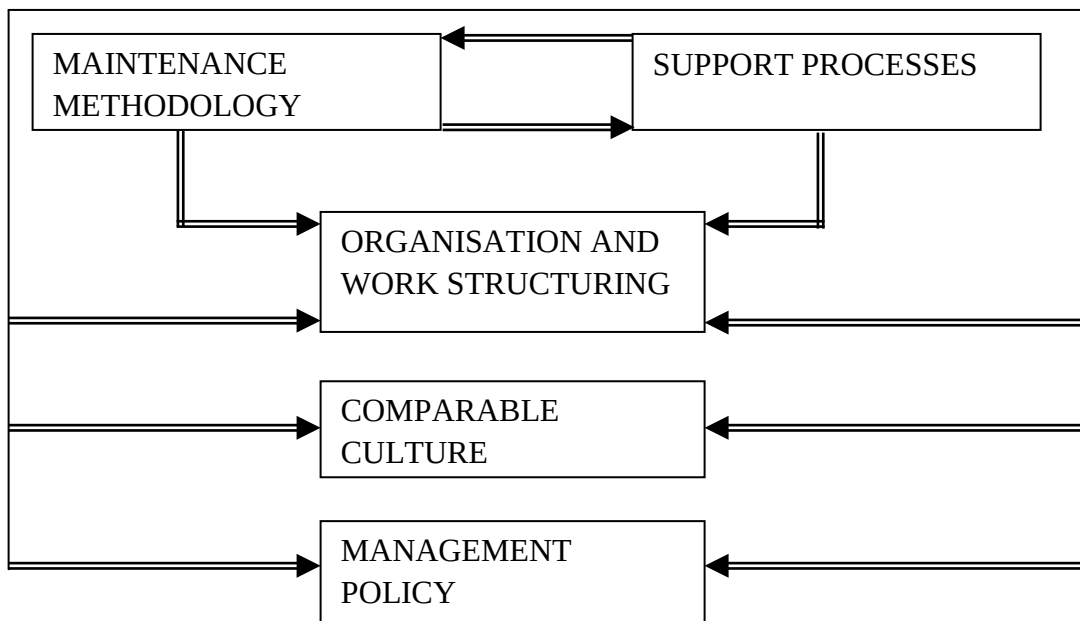


**Fig 2a:** Maintenance Management Strategic Box

The Waiduncle picture of maintenance and its management process is shown in the figure below.

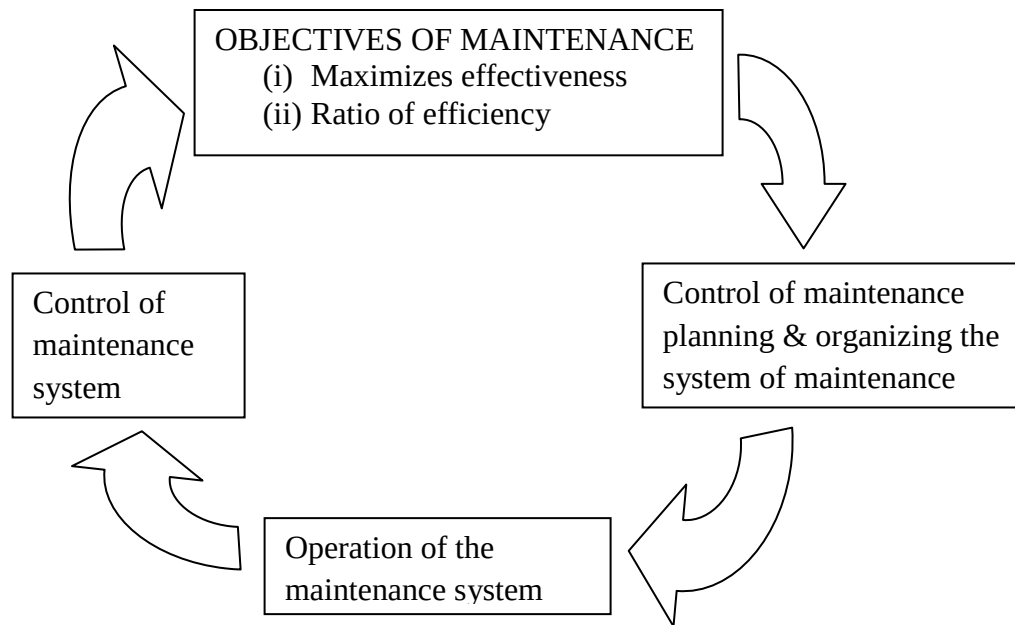


**Fig 2b:** Waiduncle picture of maintenance management process

## 2.2 TYPES AND FORMS OF MAINTENANCE OBTAINED IN NIGERIA

Different types and forms of maintenance are practiced in various industries of the world. But focusing on Nigeria as the area of interest, the following forms of maintenance are practised; corrective maintenance, preventive maintenance, condition based maintenance and performance based maintenance (Prof. G. Nwokeji, 1994). These maintenance forms will be discussed under today's maintenance strategies and their challenges.

These various forms of maintenance were adopted by various companies in Nigeria based on their own maintenance plan; created to suit their maintenance activities. These maintenance activities may be based on periodic intervals. These intervals could mean a facility that is functional, then it stops functioning, and it finally breaks down (Levis, 2003). It can be planned or done based on necessity. We have:

- ✓ Corrective,
- ✓ Preventive,
- ✓ Conditional, and

- ✓ Performance based maintenance.

All these were not able to address the maintenance management deficiencies discovered by the maintenance audit carried out on the Nigeria Gas Company, where potential issues which are high risk to the operation of gas field equipment were identified.

Based on the audit, there was no good corrosion management plan to militate against equipment and pipelines exposed to atmospheric wear and tear. There was no inspection and rehabilitation program on ground to monitor and respond respectively to failing equipment and corroding pipelines.

Also there was no functional incident investigation program and damage prevention program to manage gas field equipment failure from re-occurrence as revealed by the audit. The system control and data acquisition platform that was in place were obsolete thereby making it impossible to get vendor support on such outdated software. Upgrading was procrastinated leaving the existing maintenance management strategy in a mess.

(Basil Omiyi, 1995) the Managing Director of Shell Nigeria stated that, “all machines require regular and effective maintenance to operate correctly and meet their design specifications. The consequences of ineffective maintenance can be huge in terms of profitability, personnel morale and management time” (<http://www.smpltd.co.uk>).

### **2.3 TODAY’S MAINTENANCE STRATEGIES AND THEIR CHALLENGES**

In the Oil and Gas Industry today, many maintenance strategies have been formulated and applied. However, all these maintenance strategies are developed to optimize the uptime of a system by choosing a suitable maintainability plan ‘believed’ to enhance the availability of such system.

These maintenance strategies include; Total Productive Maintenance (TPM), Business Centered Maintenance (BCM), Total Quality Maintenance (TQM), Reliability Centered

Maintenance (RCM), Performance Based Maintenance (PBM), Risk Based Maintenance (RBM), Run-To-Failure (RTF) etc.

The different forms of maintenance strategies and the graph of failure rate against change in maintenance philosophy are represented below.

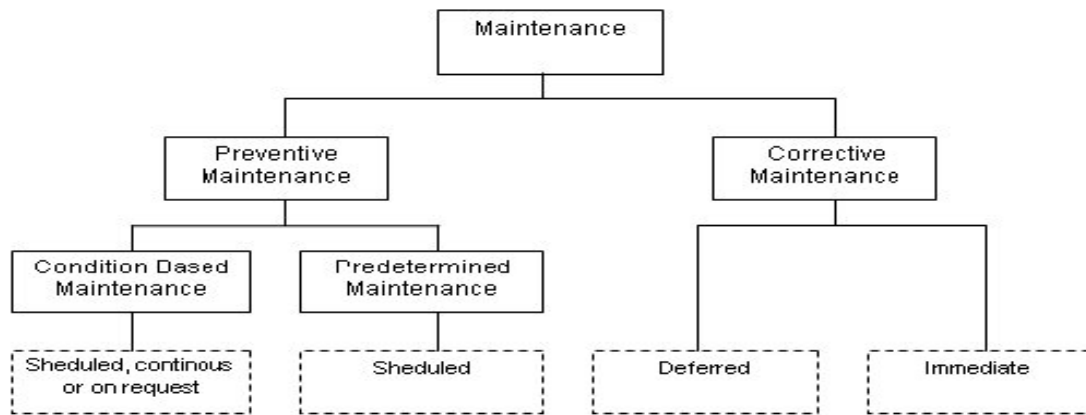


**Fig. 2c:** Overview of the different maintenance types

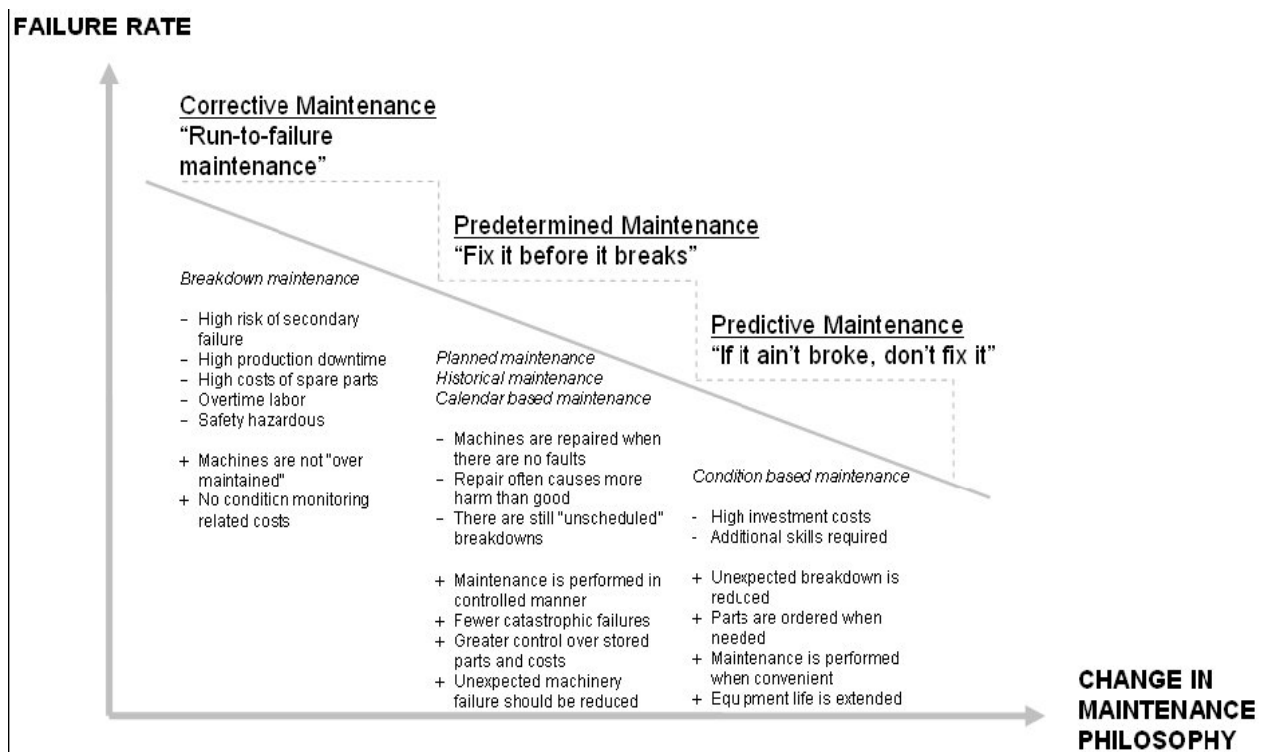


**Fig. 2d:** Graph of failure rate against change in maintenance philosophy

There is no maintenance strategy that has been globally accepted as the best strategy. This confirms the words of Bill Hughes that, *“Like the ultimate machine, the perfect maintenance program does not exist, failures will occur and an organization must be prepared to embrace a disciplined approach to root cause analysis if a standard of zero failures and zero defects is to be attained”*, (<http://www.maintenanceresources.com>).

It is a fact that there is no perfect maintenance program (Hughes, 2000). Since no machine is perfect there is the need to reduce failure to minimal levels. This does not just achieve the system optimization, but it ensures the safety of the equipment, the operators and the entire system.

### **2.3.1 Total Productive Maintenance, TPM**

This is one approach that tries to eliminate failure as a way of improving the performance of maintenance activities within the main stream of production. Total productive maintenance (TPM) is a methodology that aims to increase the availability of the existing equipment (Chan, et al., 2003).

Hence it reduces the need for further capital investment. Investment in human resources can further result in better hardware utilization, higher product quality and reduced labour cost (<http://www.maintenanceworld.com>).

TPM program is closely related to the Total Quality Management (TQM) program. Tools such as employee empowerment, benchmarking, documentation, etc, that are used in TQM, are also used to implement and optimize TPM. TPM is the equipment and process improvement strategy that links many of the elements of a good maintenance program to achieving higher levels of equipment effectiveness (<http://www.maintenanceworld.com>).

According to Environment Protection Agency (2006), TPM engages all levels of organizations to maximize the overall effectiveness of their equipment. This method further tunes up existing processes and equipment by reducing mistakes and accidents (<http://www.maintenanceworld.com>).

The ultimate goal of TPM is to achieve zero equipment breakdowns and zero product defects (Roberts, 1997). The other important goal is the total elimination of all equipment failures, breakdowns, equipment setup/adjustment losses, idling/minor stoppages, reduced speed, defects/rework, spills/process upset conditions, start-up and yield losses (<http://www.epa.gov>).

Hermann (2000) stated that “the introduction of a TPM system is by no means an easy task, because there are several barriers that encumber the implementation process”. The driving forces to success have to be identified and well understood, and a process of organizational change has to be managed successfully ([www.maintenanceworld.com](http://www.maintenanceworld.com)).

TPM is difficult to implement because of failure to develop a good installation strategy. According to Hermann (2000), every second attempt of installation of Total Productive Maintenance (TPM) results in failure.

The reasons for this include:

- Lack of management support, and inadequate TPM staff,
- Union resistance, insufficient training carried out,
- Change of priorities,
- Lack of determination,
- Lack of good installation strategy, and
- Adaptation of the wrong approach.

TPM is not a “quick fix” approach, it involves cultural change to the way things are done. For this reason, ChoyDS (2003) concluded that implementing TPM is a dramatic organizational change that can affect organizational structure, work-force management system, employee responsibilities, performance measurement, incentive systems, skill development and the use of information technology. Little wonder the success rate of such large-scale change is less than 30% for most organizations. That also explains why TPM is difficult to implement (<http://www.maintenanceworld.com>).

### **2.3.2 Business Centered Maintenance, BCM.**

Business Centered Maintenance (BCM) was developed as a result of shortcomings in other maintenance strategies, although it is traceable to the enhancements of Total Productive Maintenance. Business Centered Maintenance's core principles are "to give the operator greater authority to take charge of the plant or equipment" (Eti, et al., 2000). This principle in the Business Centered Maintenance is known as autonomous responsibility.

The research carried out at SASOL revealed that the success of Business Centered Maintenance is dependent on its many principles, and the most outstanding of them is the continuous improvement involving all individuals and departments. This enhances their ability to monitor the condition of equipment and to predict and prevent failures.

Business Centered Maintenance (BCM) was developed from Total Productive Maintenance. It is known that the fundamental goal of TPM is to increase productivity by minimizing input and maximizing output as it relates to cost. A profit improvement programme is the basis of this strategy, hence the nomenclature – Business Centered Maintenance.

The Business Centered Maintenance Strategy main driving force is the improvement of system's turnover (Eti, et al. 2000). However, certain elements have to come into play for this objective to excel. The elements include Early Equipment Management and Maintenance prevention, and training of all personnel involved in the system to improve on their maintenance skills.

The elements of the Business Centered Maintenance include profit improvement strategy (closing the gap between actual costs and running cost); quality output target and waste elimination oriented approach. This is simply an addendum to some suitable maintenance philosophy. It is basically profit oriented, and not cost oriented.

Business Centered Maintenance may not be suitably classified as a maintenance strategy as such, but it acts as the watchdog for the other maintenance techniques. This is because,

BCM depends on other maintenance, like total productive maintenance (TPM), Cost BM, Reliability Centered Maintenance (RCM) etc.

The difficulty is with its implementation and execution. The challenges of BCM are very close to those of TPM. These challenges include; lack of management support and, inadequate staff. Others include insufficient training, change of priorities, lack of determination, and lack of good installation strategy (<http://www.mt-online.com>).

### **2.3.3 Total Quality Maintenance, TQM**

TQM is a maintenance approach that is centered on quality developed for an organization. It is based on the involvement of all the members within the organization. It aims at long-term successes through customer satisfaction.

TQM ensures that the company maintains QUALITY STANDARDS in all aspects of its business (<http://www.answers.com>). In other words, total quality maintenance is a maintenance approach that aims at evaluating the culture, attitude and organization of a company.

TQM is all about “doing the right thing, right at the first time, and at every other time”. (Venkatesh, 2005). TQM was originally designed and formulated for the manufacturing industry. For a while now, it has found application as a generic management tool. It has been shown that TQM cannot just be used in only industries but also in corporate organizations. TQM is practiced by all departments, which includes manufacturing, marketing, engineering, Sales, Purchasing, Human Resources, research and development (R&D) etc.

Another boost to TQM is the support it enjoys from The International Organization for Standardization (ISO). The ISO promotes worldwide standards for the improvement of quality, productivity and operating efficiency through series of standards and guidelines. Two of the most well known of these are ISO 9000 and ISO 14000. These standards provide a sound base for TQM. They define and expect the manufacturers “to establish

and maintain a documented quality system”. It does this as a means of ensuring that products conform to specified requirements (<http://www.cl.uh.edu>).

ISO 9000 pertains to quality management. It defines what an organization does to ensure that its products or services conform to its customers’ requirement.

On the other hand, ISO 14000 was developed to control the impact of an organization’s activities and impact on the environment. This standard can lead to reduced cost of waste management, energy and materials conservation, lower distribution costs, and improved corporate image (Benchmarking: An International Journal, Volume 10, Issue 2 - 2006-09-19).

Like other strategies, TQM has one major shortcoming, i.e. it limits an organization’s flexibility (Jurow Barnard, 1993).

The four barriers to the adoption of TQM in the maintenance sector include:

**Vocabulary:** Objections to terms like "total," "quality," and "management" which implies that high standards are not met.

**Commitment:** TQM requires a long-term commitment by maintenance managers because it takes several years to implement.

**Process:** Because of impatience, the companies try to solve problems quickly. This is contrary to TQM’s process analysis; which is systematically structured.

**Professionalization:** Professional staff can be hesitant to turning over their services to what they perceive as excessive demands of the customers. “It is not possible to satisfy everyone’s demands; choices will need to be made” (Sirkin, 1993).

### **2.3.4 Reliability Centered Maintenance, RCM**

Reliability Centered Maintenance (RCM) is the concept of developing a maintenance scheme based on the reliability of the various components of the system or product (<http://www.reliability-centered-maintenance.com>).

“To develop an effective RCM program, knowledge of reliability and maintainability of the system and its components are required” (Moubray, 1991). The essential factors include; the MTTR (Mean Time to Repair) and failure rate (total number of failures within a given time period) of the product or system.

In practice, RCM brings together principal maintenance strategies (reactive, time or interval-based, condition-based and proactive maintenance practices), rather than being applied independently. They are integrated to take advantage of their respective strengths in order to maximize facility and minimize equipment life-cycle costs (<http://www.wbdg.org>).

RCM is a maintenance strategy that is based on consequence and cost of failure. Consequence as used here is in terms of mission (quality and quantity), safety, environment and security.

There is also software that enables user to calculate the reliability information necessary to develop an effective RCM program (<http://www.reliability-centered-maintenance.com>). It also enables machinery stakeholders to monitor, assess, predict and generally understand the working of their physical assets (<http://www.ebme.co.uk>). This software analyzes the system or product. They include the following:

**Failure Modes and Effects Analysis (FMEA):** which determines the different ways a system can fail (<http://www.reliability-centered-maintenance.com>).

**Fault Tree Analysis (FTA):** This shows the specific steps involved in a system failure; mechanical problem or human error (<http://www.cyberlink.ch>).

**Event Tree Analysis (ETA):** This illustrates the different consequences of component or system failure (<http://www.cyberlink.ch>).

Even with all the software mentioned above, the RCM still has its challenges. These challenges include: the high cost of implementation because of its huge start-up cost, training and equipment.

Also, reliance on historical records and personnel knowledge can introduce errors into the process. This may lead to missing hidden failures, where a low probability of occurrence exists (<http://www.wbdg.org>; Kennedy, 2005).

In addition, the intuitive process requires that at least one individual has a thorough understanding of the various condition monitoring these technologies. Rigorous RCM analysis is extremely labour intensive and often postpones the implementation of obvious condition monitoring tasks.

### **2.3.5 Performance Based Maintenance, PBM**

Performance Based Maintenance is a modern maintenance approach that ensures performance reliability. It is carried out by assessing and predicting the process or equipment performance based on data gotten from the process or equipment (Piotrowski, 2001).

It involves the use of data and sensors which transcends into collation and transmitting medium to extract performance related information. From this, inference and predictions can be drawn on the system failure.

Performance Based Maintenance in line, with the proactive and preventive maintenance paradigm is centred on quantifying and predicting performance degradation of a process, machine or service. Since performance degradation is a shadow of the entire system failure, it can be used to predict unacceptable system performance before it occurs.

Performance Based Maintenance operates in such a way that proactive actions are taken to address the performance degradation which will eventually lead to system failure. This is done instead of taking reactive actions after the system fails because of performance degradation. This reactive action usually comes with a longer MTTR.

The performance of a plant/equipment degenerates as a result of wear, tear and aging. These factors also decrease the performance reliability and increase the potential for failures and faults. This in turn will impact on the quality of products as well as

productivity (Refer 1.2; paragraph 2). However, it is imperative for a plant to maintain highest quality in terms of products. This is in order to attain and retain ones' business.

Hence, in order to realize best possible quality and zero or minimal downtime, it is imperative to predict and prevent process or equipment failure. This follows the **Proactive and Preventive (PAP)** maintenance paradigm instead of the **Fail and Fix (FAF)** maintenance paradigm (which involves reactively addressing and fixing the failures).

Performance Based Maintenance would have been classical, but for the following shortcomings; insufficient inventory data, insufficient bearing capacity measurement and inexperienced personnel (Piotrowski, 2001).

### **2.3.6 Risk Based Maintenance, RBM**

Risk Based Maintenance (RBM) approach is a maintenance approach that considers risk factors associated with a system and designs an optimal maintenance schedule that allocates economic resources to minimize risk factors that could lead to the system failure (Narayan, 2004).

RBM methodology recognizes that equipment design differs from operations. It also recognizes the fact that different equipment will have a higher probability to undergo failures from different degradation mechanisms than others (<http://www.spintelligentlabs.com>).

The RBM prioritizes and categorizes maintenance activities by assigning risk numbers to each activity. In risk based maintenance (RBM), the risk of failure is determined by summing the probability of failure with a measure of the consequences of that failure.

The probability of failure is the mean frequency or rate with which the specified failure event would be expected to occur in a given period of time (<http://www.atsc.army.mil>).

The consequence of failure is the effect that the failure would have on the equipment, the process operation, and the environment.

Risk can be expressed mathematically as thus:

$$\text{Risk} = \text{Probability of Failure} \times \text{Consequence of Failure}$$

This independent assessment of the probability or frequency and the consequence of failure provide a ranking system for a risk based maintenance, RBM program. Computing risk as an explicit numeric value, failure modes can be ranked individually from high to low risk. This ordering list will provide a priority ranking for choosing maintenance strategies. This will mitigate the occurrence of failures through the adoption of “risk based inspections”, RBI.

Finally, like the other maintenance strategies, the challenges of RBM weighs heavily on probability, which in some cases is not certain. It has a high level of subjectivity, such as the weight-age of the risk factors. This is based on the experience and the availability of data. It creates increased investment in diagnostic equipment, and increased investment in staff training. This makes the savings potential invisible to the management.

### **2.3.7 Run-To-Failure, RTF**

Kezunovic et al, 2001, defined Run-To-Failure (RTF), as, “the repair and restoration of equipment or components that have failed or are malfunctioning, and are not performing their intended function” (<http://www.pserc.org>).

Within the context of first generation maintenance management, RTF is viewed as a corrective maintenance process. This process comprises of unscheduled actions, which are accomplished as a result of failure (<http://www.atsc.army.mil>). This helps to restore a system to a specified level of performance.

RTF is basically a reactive/corrective maintenance mode (Rausand, 2004). Traditionally, there is no routine task to perform and no action is taken to maintain the equipment. This action is to prevent failure or to ensure that the designed life of equipment or its component is reached.

Equipment is repaired or replaced only when obvious failures occur, with little or no loss of production. This is considered to be a sound business decision since the failure is of no significant consequence. This is a first generation maintenance strategy (Smith, 1997). It places greater emphasis on cost considerations, and should be avoided for production critical equipment (Wilson, 2002).

The modern truth is that, a purely RTF program would ignore many of the opportunities to influence equipment 'survivability'. In reality, RTF, also called reactive maintenance (Al Rose, 2002), often incurs some major high maintenance cost when utilized in the first generation or in its pure form. Despite these overwhelming shortfalls and in the face of extensive PM programs, more than 50% of maintenance works in some organization are reactive.

Over the years, companies that have invested millions of US dollars to develop, implement and sustain Preventive Maintenance still find that 50 – 60% of their maintenance work is reactive. This happens because there is no headway in reducing the number of breakdowns. Without a strategic mix of preventive maintenance and predictive maintenance, which is sandwiched between RCM and CBM, Run-to-failure shortens the Mean Time Between Failure (MTBF) of production equipment (Leonard, 2005).

Consequently, there would be more frequent replacement and higher capital costs. Significantly, repair cost would be higher because downtime events would often be unplanned, more frequent and longer in duration.

In conclusion, RTF increases cost due to unplanned downtime, overtime requirement of labour and inefficient use of staff resources. Maintenance stakeholders would have to operate "crisis management" maintenance activities with unexpected production interruptions, coupled with a high inventory of spare parts to react quickly.

## **2.4 IDENTIFYING COMMON PROBLEMS EVIDENT IN TODAY'S MAINTENANCE STRATEGIES**

Having x-rayed most of the existing maintenance management strategies and their challenges, the need for an improved maintenance management strategy becomes inevitable. This is because of the fact that some major limitations have been identified, which is common to all the existing maintenance strategies.

These limitations depend largely on the gap between the following;

- Maintenance strategy and its implementation,
- Cost of implementation,
- Difficulty in accepting changes within the system, and
- Little or no technical knowledge.

All the above mentioned limitations are the basis of this dissertation.

A second look at the objective of maintenance within any given system shows that these strategies have not lived up its expectations. This is most especially in the developing countries of the world like Nigeria.

In spite of this situation, Nigeria is looking forward to building one of the biggest gas plants in Africa, which will surely be faced with the maintenance of gas equipment. The question that stares all in the face is, “how prepared is Nigeria to maintain a gas field within its borders? How prepared is it to minimize equipment breakdowns, avoid possible future occurrence of gas explosions and still maintain optimal production?”

The main objectives of the maintenance department include:

- To guarantee trouble free machine operation
- Securing of minimum downtime during breakdowns, so as to maximize machine availability for production.

Despite the efforts made so far, problems still arise and this leads to challenges facing the present maintenance management strategies.

These problems include:

- Frequent breakdown, due to inadequate maintenance follow up programme.
- Scarcity of original and standard parts. This is caused by low level of spare parts and high cost of standard parts.
- Inadequate tool stock.
- Insufficient staff strength
- Insufficient technical study staff
- Lack of technical staff training facilities
- Maintenance and production staff conflict

## **CHAPTER THREE**

### **3.0 METHODOLOGY**

The methodology that was used in developing this improved maintenance management strategy involved a detailed design of a maintenance practice which integrates all current maintenance practices and operations together with current industry best practice. This will provide a strategic and coherent 'road map' for engineering to follow in order to achieve the desired goal (Wireman, 1997).

Designing and operating the maintenance system is a major task in managing the operational work of production. The main objective here involves the balance of cost and the repair of maintenance compared to that of a breakdown.

Managerial policies to improving maintenance systems include the following:

1. Determination of the right level of preventive maintenance.
2. Determination of the size of repair facilities.
3. Determination of the appropriate slack level of the system.

### **3.1 EMPIRICAL INVESTIGATION**

The empirical investigation comprised of the following:

- Breakdown of the design
- Method for obtaining result.
- Test persons/research group.
- Measuring instruments or software.
- Pilot studies, validity procedure and quality control.
- Method of (statistical) data processing.
- Outcome of the research investigation.

### **3.1.1 Breakdown of the design.**

Maintenance system design is a process of maintenance management which empowers the organization with a continuous philosophy of enabling all manpower resources to work together in order to accomplish the mutual goal of manufacturing efficiency.

Based on the definition above, this research work aimed at developing a new maintenance strategy using the following processes:-

1. Extract of a maintenance audit conducted on NGC.
2. Findings on the maintenance audit report review formed bases for interviews.
3. Completion of questionnaire exercise and analysis
4. Utilize all available information to develop a relevant and effective maintenance Strategy.

The Maintenance Audit was used to examine the current engineering function. This examination unraveled the current situation in the existing maintenance strategy of Nigeria Gas Company (NGC). The Maintenance Audit helped in identifying areas of functional weakness upon which improvement strategies will be planned and executed. In addition, the Maintenance Manager of NGC was interviewed based on the audit report and the company's present action plan.

An accurate assessment of other company's functional perceptions of engineering performance was performed. This was achieved using questionnaires and possibly interviews with the maintenance technicians of NGC. The developed questionnaires were distributed to the maintenance technicians of SASOL LTD for comparative analysis. This provided an information frame work for the development of an improved maintenance strategy. The Maintenance Manager of SASOL LTD was also interviewed, to ascertain the company's view towards achieving a functional engineering performance using a good maintenance strategy.

### **3.1.2 Method for obtaining results.**

Based on design breakdown, results were obtained from the following:

1. The maintenance audit report review.
2. Questionnaires completed based on functional perceptions of engineering performance.
3. Interview granted the maintenance manager of NGC based on the audit report and the implementation of action plan.
4. Interview granted the maintenance manager of SASOL, to see the company's view towards achieving a functional engineering performance using a good maintenance strategy.

The interview questions were formed around equipment maintenance management strategy. It included maintenance management strategy review, development of maintenance management strategy, and the method of measuring the effectiveness of a maintenance management strategy.

Some of the model questions that were featured during the interview sessions include the following:

- a. What is the present maintenance management strategy that is adopted in your company for equipment maintenance?
- b. What procedural steps do your company take in managing their equipment maintenance strategy?
- c. What is the role of equipment in the functional block breakdown of your plant?
- d. How can one locate equipment stipulated for maintenance in your plant?
- e. In ensuring the reliability of your equipment, what are the possible maintainable items?
- f. How does your company obtain inputs for their maintenance management strategy?
- g. Briefly explain the terms function, failure mode, and root cause as regards your equipment.
- h. What is the direct cause of a failure mode?

- i. What are the steps involved in developing maintenance management strategy for your equipment?
- j. What are the possible things to specify before undertaking a maintenance task?
- k. What is the importance of Risk Based Inspection (RBI) in the cause of developing a maintenance management strategy?
- l. What is the possible question that comes to mind when one wants to review a maintenance strategy?
- m. What are the possible steps that are required in order to approve a maintenance strategy?
- n. What is FMEA and what is the process for approving FMEA in your company?
- o. What is meant by the word, “Job grouping”?
- p. What are the requirements for grouping tasks together?
- q. What is the process for registering task list and maintenance plan in your company?
- r. What is the process step for work management in your company?
- s. How does your company measure the effectiveness of their maintenance strategy?
- t. What will work flow look like when corrective work originates from a maintenance strategy schedule?
- u. What will work flow look like when corrective work originates from a plant inspection?

The answers to these questions above provided a fair lead towards developing a Maintenance Management Strategy that will be appropriate for Gas field equipment.

Having gathered these data, the next task was to tabulate their responses and analyze them critically. These analyses formed part of the overall engineering judgment by the time the results were collated.

### **3.1.3 Test Persons/ Research Group.**

The Improved Maintenance Management Strategy was developed for the Nigeria Gas Company; this research was based upon their recent maintenance audit report. The report

was reviewed while the questionnaire was developed based on the shortfalls identified in the audit.

The questionnaires were handed out to SASOL LTD technicians (because of SASOL's excellent Maintenance Strategy), where the functional perception of engineering performance is the focus. The questionnaires were also handed out to the Nigerian Gas Company, who is the central focus of this research.

The questionnaires were completed by the maintenance personnel who are always the first line of maintenance in the company. They provided a ground work of information for the development of the Improved Maintenance Strategy.

In determining the sample size, the total number of all the maintenance personnel at SASOL and NGC were considered. Also considered was the confidence/significance level, which showed the amount of uncertainty that was tolerated. Equally considered was the margin of error, which captured the amount of error that could be tolerated.

Using Raosoft sample size calculator;

With a population of 85 maintenance technicians, 5% of marginal error, 95% of confidence level and 50% as the response distribution, a sample size of 70 was used. (<http://www.raosoft.com/samplesize.html>).

#### **3.1.4 Measuring Instruments or Software.**

The measuring instrument that was used is the Comparative Table analysis. It compared the outcome of the questionnaires of both companies (NGC and SASOL). The NGC's response was compared with SASOL's responses on the premise that SASOL has a better maintenance strategy with focus on engineering performance. The comparative table provided a good platform for comparison.

A workshop was organized, where the NGC's maintenance managers and their maintenance personnel were in attendance. Engineering scholars who were interested in this study were also given the opportunity to participate in the workshop. During the workshop exercise, the vision & mission statements were declared, the developed

strategy and its implementation were analysed. The trade off analysis of the alternative solution was done using FMEA.

#### **3.1.5 Pilot Studies, Validity Procedure and Quality Control.**

Initial release and validation by comparison was applied where a glance at the maintenance approach being used in SASOL was of great help. Besides having a good maintenance strategy, they are also going to offer technical training support required for the operation of the EGTL plant. Finally, the responses to the interview of both maintenance managers enhanced the Validation and Quality Control Process.

Copies of the newly developed Maintenance Management Strategy were made, and were made available to the maintenance managers interviewed earlier. The reason for this was to get their input and feedback after reviewing the Strategy. This formed part of the validation process.

After the workshop, the attendees had the opportunity to criticize or adopt the new Improved Maintenance Strategy. This also served as quality assurance for the work.

#### **3.1.6 Method of (Statistical) Data Processing.**

Having gathered all the data from the questionnaires and interviews, they were analysed, based on the comparative table. It clearly showed the difference in the Maintenance Strategies of both company and areas where there will be need for improvement. I also plotted their response graph, to output a pictorial analysis of both strategies.

Similarities were also drawn on the weaknesses identified from maintenance audit report carried out on NGC and the differences identified on the comparative table analysis from the survey. The analysis gathered from both of them formed part of the overall engineering judgment by the time the overall result was interpreted.

Finally an Improved Maintenance Management Strategy was developed based on the identified differences on the comparative table. The developed strategy will compensate for the differences, such that the comparison difference will cancel out.

#### **3.1.7 Outcome of the research investigation.**

The research identified, corrected and upgraded the existing Maintenance Strategy for the gas field equipment of Nigerian Gas Company (NGC). The upgrade was based on the critical evaluation of the maintenance audit report, and questionnaire response on the existing maintenance management approaches and its deficiency.

The research delivered an improved maintenance management strategy based on the investigation.

## **CHAPTER FOUR**

### **4.0 EXPERIMENT AND RESULT ANALYSIS**

This experiment involves reviewing the maintenance audit report of NGC (with regards to its current maintenance management strategy), in order to identify areas of functional weakness that needs improvement. Questionnaires were distributed to NGC technicians to buttress the merits and demerits of their existing maintenance strategy. An interview with the maintenance manager of NGC was also conducted on the subject matter. These activities were carried out in the previous chapter and their analyses were presented in this chapter.

For proper analysis using the comparative technique, an accurate assessment of another company's functional perceptions of maintenance engineering performance was carried out using the same questionnaire. These questionnaires were distributed to the maintenance technicians of SASOL, to provide a ground work of information for the development of an improved maintenance strategy. The maintenance manager of SASOL was equally interviewed to see the company's view towards achieving a functional engineering performance using a good maintenance strategy.

The outcome of the questionnaires and the interviews granted were also examined in this chapter.

The experimental results obtained were broken down thus:

- i. The maintenance audit report review.
- ii. Questionnaires that were completed based on functional perceptions of engineering performance.
- iii. Interview granted the maintenance manager of NGC based on the audit report and the implementation of action plan.
- iv. Interview granted the maintenance manager of SASOL, to showcase the company's view towards achieving a functional engineering performance using a good maintenance strategy.

#### **4.1 MAINTENANCE AUDIT ANALYSIS**

The maintenance audit carried out on NGC with regards to its maintenance management strategy on Gas field equipment, captured the need for an improved maintenance management strategy.

A total of 12 measuring parametric indices for an effective maintenance management strategy in Nigeria, were used based on the NNPC's allowable operability level. These parametric indices are corrosion management plan, inspection and rehabilitation program, system control and data acquisition, damage prevention program, encroachment procedure, incident investigation program, management of change, depth of cover program, fatigue analysis and monitoring, scenario based risk mitigation, incorrect operations mitigation, and system integrity plan score carding. There is an allowable operability level as classified under a risk assessment table (see page 4 of appendix 1) and its outcome which were grouped into 4 categories.

The 4 categories include:

- Potential issues identified,
- No issues identified,
- Issues not applicable
- Issues not reviewed.

Out of the 12 parametric indices, there were 8 parameters with Potential issues identified bearing almost 66.7% of the total risk chart in percent, 3 parameters had No issues identified accounting for about 25% of the total risk chart, and 1 parameter with issues not applicable representing 8.3% of the total risk chart.

On close examination, the 8 parameters with Potential issues identified reveals that most of the proactive programs that would have prevented accidents and incidents from occurring are not fully implemented. Programs like corrosion management plan (CMP), inspection and rehabilitation program, damage prevention program (DPP), incident investigation program, fatigue analysis and monitoring, scenario based risk mitigation, system control and data acquisition etc.

The risk analysis reveals that these programs that has to do with the regular inspection of these gas field equipment and implementation of appropriate maintenance management program to mitigate failure were not applied or are impossible to apply because the maintenance strategy used in the company.

The absence of a standard monitoring network with enhanced surveillance and patrol frequency intervals was obvious. The presence could have helped to monitor the activities that could lead to adverse effect on these equipment.

Besides the external surveillance, the System Control and Data Acquisition (SCADA) process has its shortcoming towards fault detection process for line balancing and transient condition monitoring.

The SCADA systems assessed includes SCADA coverage, platform, architecture, control rooms, applications, displays, operations and training. The current SCADA system was installed in 1985. Although the original computer hardware has been replaced, the SCADA monitoring and control software is of the original vintage and no vendor-provided support is available for the installed SCADA platform.

There are very few companies who are still using this particular SCADA software. In addition, the current hardware platforms are approaching the end of their expected service lifecycle, while the processor loads during peak times has reached the 90% utilization range.

So based on the Maintenance audit analysis, it was clear that the maintenance management strategy of NGC, for the maintenance of those gas field equipment is not properly implemented or is less than adequate. (Detailed report on the outcome of the audit is attached as an appendix 1 for further clarification).

## **4.2 CASE STUDY ANALYSIS**

The case study analysis comprises of two different data collation technique, the questionnaire method and the Interview method. These two methods were analyzed using the comparative table analysis.

### **4.2.1 The Questionnaire method**

The questionnaire method was used to determine the extent upon which the functional perceptions of engineering performance was perceived at the different engineering institutions comprising; the NGC, which was the focal point and SASOL which was the base comparator.

The questionnaires were basically meant for the technicians who undertake the maintenance responsibilities of the gas field equipment in question. They are the ones who perform the day-to-day task of ensuring the integrity of those equipment. In the process, they employ the company's maintenance management strategy stipulated by the equipment owners.

Within the ranks of these maintenance technicians, their ages and sex categories were documented due to the required effective maintenance implementation levels. Also documented were their work levels, division or unit of operation and years of experience on the job.

Below are responses that were captured and tabulated for easy analytical deductions.

## QUESTIONNAIRE INTERPRETATION

| NIGERIA (30 Technicians)                                        |                                                                               |          |   |           | SOUTH AFRICA (40 Technicians)                                   |          |   |           |    |
|-----------------------------------------------------------------|-------------------------------------------------------------------------------|----------|---|-----------|-----------------------------------------------------------------|----------|---|-----------|----|
| PART A: RESPONDENTS INFORMATION                                 |                                                                               |          |   |           |                                                                 |          |   |           |    |
| GENDER                                                          |                                                                               | 24 Males |   | 6 Females |                                                                 | 31 Males |   | 9 Females |    |
| AGE                                                             | 0 – 20                                                                        | 2        | - | =         | 2                                                               | 4        | 2 | =         | 6  |
|                                                                 | 21 – 30                                                                       | 4        | 2 | =         | 6                                                               | 8        | 4 | =         | 12 |
|                                                                 | 31 – 40                                                                       | 5        | 3 | =         | 8                                                               | 8        | 2 | =         | 10 |
|                                                                 | 41 – 50                                                                       | 6        | 1 | =         | 7                                                               | 6        | 1 | =         | 7  |
|                                                                 | 51 – 60                                                                       | 4        | - | =         | 4                                                               | 3        | - | =         | 3  |
|                                                                 | 60 & above                                                                    | 3        | - | =         | 3                                                               | 2        | - | =         | 2  |
| Date                                                            | Fluctuates between 26 <sup>th</sup> of Sept. and 4 <sup>th</sup> of Oct. 2008 |          |   |           |                                                                 |          |   |           |    |
| Specialist Technicians                                          | 5                                                                             |          |   |           | 7                                                               | = 12     |   |           |    |
| Senior Technicians                                              | 7                                                                             |          |   |           | 10                                                              | = 17     |   |           |    |
| Technicians                                                     | 18                                                                            |          |   |           | 23                                                              | = 41     |   |           |    |
| Division/unit                                                   | Electrical                                                                    | 7        |   | 10        | = 17                                                            |          |   |           |    |
|                                                                 | Mechanical                                                                    | 20       |   | 25        | = 45                                                            |          |   |           |    |
|                                                                 | Instrument                                                                    | 3        |   | 5         | = 8                                                             |          |   |           |    |
| Work period                                                     | 0 – 6 months                                                                  | 2        | - | =         | 2                                                               | 4        | 2 | =         | 6  |
|                                                                 | 6 – 12 months                                                                 | 4        | 2 | =         | 6                                                               | 8        | 4 | =         | 12 |
|                                                                 | 1 – 3 years                                                                   | 5        | 3 | =         | 8                                                               | 8        | 2 | =         | 10 |
|                                                                 | 3 – 8 years                                                                   | 6        | 1 | =         | 7                                                               | 6        | 1 | =         | 7  |
|                                                                 | 8 – 15 years                                                                  | 4        | - | =         | 4                                                               | 3        | - | =         | 3  |
|                                                                 | 15 years & above                                                              | 3        | - | =         | 3                                                               | 2        | - | =         | 2  |
| In the past 12 months,<br>10 out of 30 Participated in Training |                                                                               |          |   |           | In the past 12 months,<br>35 out of 40 Participated in Training |          |   |           |    |

| <b>PART B: MAINTENANCE BACKGROUND</b>                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                              |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NIGERIA                                                                                                                                                                                                                                     | SOUTH AFRICA                                                                                                                                                                                                                                                                                                 |
| <p>Question 9 to 12 tested their knowledge of equipment maintenance in their various unit.</p> <p>-----</p> <p>-----</p> <p>20% had the Preventive maintenance mindset</p> <p>80% had the corrective maintenance mindset</p>                | <p>Question 9 to 12 tested their knowledge of equipment maintenance in their various units</p> <p>30% had the Predictive maintenance mindset</p> <p>35% had the condition based maintenance mindset.</p> <p>25% had the Preventive maintenance mindset</p> <p>10% had the corrective maintenance mindset</p> |
| <p>Frequency of maintenance operations on the equipment in their units.</p> <p>15% of frequent maintenance operation</p> <p>85% of occasional maintenance operation</p>                                                                     | <p>Frequency of maintenance operations on the equipment in their units.</p> <p>80% of frequent maintenance operation</p> <p>20% of occasional maintenance operation</p>                                                                                                                                      |
| <p>Affirmation of the fact that maintenance is critical to gas field equipment.</p> <p>85% Agreed</p> <p>5% Disagreed</p> <p>10% Wasn't sure</p>                                                                                            | <p>Affirmation of the fact that maintenance is critical to gas field equipment.</p> <p>100% Agreed</p> <p>----</p> <p>----</p>                                                                                                                                                                               |
| <b>PART C: MAINTENANCE EFFICIENCY/PERFORMANCE</b>                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                              |
| <p>Questions 15 and 16 tested their knowledge on critical operations required for safe maintenance of gas field equipment</p> <p>45% had a good knowledge</p> <p>15% had fairly good knowledge</p> <p>40% had very poor or no knowledge</p> | <p>Questions 15 and 16 tested their knowledge on critical operations required for safe maintenance of gas field equipment</p> <p>85% had a good knowledge</p> <p>10% had fairly good knowledge</p> <p>5% had very poor or no knowledge</p>                                                                   |

|                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Question 17 sampled view on monitoring and proactive maintenance action as an enhancement tool towards effective operability of gas field equipment.</p> <p>50% confirmed</p> <p>50% Disagreed</p>                                                                          | <p>Question 17 sampled view on monitoring and proactive maintenance action as an enhancement tool towards effective operability of gas field equipment.</p> <p>100% confirmed</p> <p>----</p>                                                                                 |
| <p>Question 18 and 19 tested their knowledge on conditions negating the effective maintenance operations on equipment</p> <p>45% had a good knowledge</p> <p>15% had fairly good knowledge</p> <p>40% had very poor or no knowledge</p>                                        | <p>Question 18 and 19 tested their knowledge on conditions negating the effective maintenance operations on equipment</p> <p>85% had a good knowledge</p> <p>10% had fairly good knowledge</p> <p>5% had very poor or no knowledge</p>                                        |
| <p>Questions 20 to 28 was added to further clarify the extent their technicians were grounded on the understanding of maintenance efficiency and performances.</p> <p>40% had good understanding</p> <p>20% had fair understanding</p> <p>40% had poor or no understanding</p> | <p>Questions 20 to 28 was added to further clarify the extent their technicians were grounded on the understanding of maintenance efficiency and performances.</p> <p>80% had good understanding</p> <p>15% had fair understanding</p> <p>5% had poor or no understanding</p> |
| <p>Questions 29 and 30 acted as verification on questions 20 to 28 above. It really brought out the understanding of factors that affects and or enhances equipment efficiency and performances. It equally buttressed the percentages above.</p>                              |                                                                                                                                                                                                                                                                               |
| <p>Question 31, based on understanding of questions 29 and 30 sampled views on the possibilities of combating those factors that affects maintenance efficiency negatively.</p> <p>40% believes it can be combated</p> <p>60% believes it cannot be combated.</p>              | <p>Question 31, based on understanding of questions 29 and 30 sampled views on the possibilities of combating those factors that affects maintenance efficiency negatively.</p> <p>85% believes it can be combated</p> <p>15% believes it cannot be combated</p>              |

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|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Question 32 to 34 dealt on the technicians ability to coordinate equipment maintenance before failure and repair after failure.</p> <p>35% gave impressive responses</p> <p>30% Talked about normal Fix it when broken</p> <p>35% Cannot say</p> | <p>Question 32 to 34 dealt on the technicians ability to coordinate equipment maintenance before failure and repair after failure.</p> <p>75% gave impressive responses</p> <p>20% Talked about normal Fix it when broken</p> <p>5% Cannot say</p> |
| <p>The survey was concluded with the fact that given a good equipment maintenance strategy, equipment will always be in service with optimum efficiency.</p> <p>70% concurred.</p> <p>30% disagreed</p>                                             | <p>The survey was concluded with the fact that given a good equipment maintenance strategy, equipment will always be in service with optimum efficiency.</p> <p>95% concurred.</p> <p>5% disagreed</p>                                             |

**TABLE 4.1:** Comparative Analysis for Questionnaire

Based on the survey above, it became evident that there was a clear comparative analysis between the technicians of NGC in Nigeria and those of SASOL in South Africa towards their various levels of exposure to the knowledge of maintenance of gas field equipment.

It was obvious that the awareness level of preventive maintenance is less than adequate in the existing gas field equipment of NGC. This would pose a huge challenge with the expected commissioning of the EGTL plant (an extension of NGC). It was equally clear that the functional perception of engineering performance in the industry was below the normal level unlike their counterpart in SASOL. That was why it manifested in the maintenance audit carried out in the company.

**From the comparative table analysis, one can deduce that: For NGC;**

- 55% of the technicians of NGC had a good knowledge of maintenance background, efficiency and performance
- 20% had fairly good knowledge
- 25% had very poor or no knowledge of good maintenance background, efficiency and performance.

**On the other hand, for SASOL LTD:**

- 90% of the technicians of SASOL had a good knowledge of maintenance background, efficiency and performance,
- 8% had fairly good knowledge
- 2% had very poor or no knowledge of good maintenance background, efficiency and performance.

Based on the above deduction, we can reiterate the fact that there is need for an improved maintenance management strategy on gas field equipment of Nigerian Gas Company (NGC).

#### **4.2.2 The Interview method**

The Interview method was used to determine the extent upon which the functional perceptions of engineering performance was perceived at the management level of the different engineering institutions comprising; the NGC, which was the focal point and SASOL which was used as the base comparator.

The interview was basically meant for the maintenance manager who is saddled with the responsibility of ensuring proper maintenance and optimal performance of equipment within the various engineering domain. He must also ensure that his company has a good/working maintenance management strategy in place for the maintenance of these equipment.

As an insight for complete interview analysis, a brief narration of previous work experience before ascending the position of the maintenance manager was demanded by the interviewer.

Below are responses that were captured and tabulated for easy analytical deductions.

### **INTERVIEW DOCUMENTATION**

| <b>INTERVIEW SESSION</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Questions and Answers session with the Maintenance Manager of NGC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Questions and Answers session with the Maintenance Manager of SASOL                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <p><b>Question:</b> <i>Sir, may we know you?</i></p> <p><b>Answer:</b> I am Engr. Kenneth Orieh. I hail from Owerri in Imo state, Nigeria. Presently, I am the Maintenance Manager of the Nigerian Gas Company (NGC). I am married with four kids.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <p><b>Question:</b> <i>Sir, may we know you?</i></p> <p><b>Answer:</b> I am Engr. André Joubert. I hail from Cape Province, South Africa. Presently, I am The Maintenance Manager of SASOL Technology. I am married with two kids.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <p><b>Question:</b> <i>How long have you been in your Present position as the Maintenance Boss?</i></p> <p><b>Answer:</b> I have been in my present position for the past five years</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <p><b>Question:</b> <i>How long have you been in your Present position as the Maintenance Boss?</i></p> <p><b>Answer:</b> I have been in my present position for the past three years now.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <p><b>Question:</b> <i>Just for records, before the assumption of office as the maintenance manager, what was your experiences like in the engineering or maintenance profession?</i></p> <p><b>Answer:</b> Before the assumption of office, I have been in the engineering profession for more than two decades now. I have worked at different engineering firms as maintenance Technician and as a supervisor. In fact, I came to NGC as a maintenance coordinator and after two years, was promoted to the position of a maintenance superintendent. I was in that position for a period of about a year and half when our former maintenance manager retired. Then I was considered by the management of the company as the suited to act in my capacity as the maintenance manager until after six months before I was finally confirmed as the company's new</p> | <p><b>Question:</b> <i>Just for records, before the assumption of office as the maintenance manager, what was your experiences like in the Engineering or Maintenance Profession?</i></p> <p><b>Answer:</b> Before the assumption of my new office, I have been in the maintenance field for the past sixteen years now. I started work at the coal mines as maintenance artisan, later got promoted to senior artisan and special Artisan respectively. Because of Interest I have developed in maintenance, I enrolled into the University to read Maintenance and Reliability Engineering. After graduation, was promoted to the position of section leader and later area Leader position. I left the mines and went for my masters programme on Engineering Management and development. I later got job a new job with R &amp; D department of SASOL from where I switched over to management</p> |

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|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Maintenance Manager. So you can see that I have wealth of knowledge on maintenance matters.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <p>positions. Just three years ago, the vacancy for the maintenance manager's position came up and after due consideration, I was offered the position.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <p><b>Question:</b> <i>On the assumption of office, what were the existing maintenance operations like in your firm? Were equipment regularly and properly maintained? Were there plans for occasional shutdowns and turnaround maintenance? How can you describe your company maintenance performance towards the actualization of the company's production targets?</i></p> <p><b>Answer:</b> Well, I met a maintenance operation that has to do with Fix it when broken. A maintenance philosophy that is only directed towards addressing failure. Although it was working, it kept costing the company so much when major failure occurs because of the time spent in getting the plant back on line. So equipment were maintained but not properly. Then as for shutdowns, we normally observe it, although it basically depends on the economic situation of the country at that time to avoid scarcity. In all, I can say that we are trying to keep our production up, in order to control problems that may arise from scarcity bearing in mind that we are developing nation.</p> | <p><b>Question:</b> <i>On the assumption of office, what were the existing maintenance operations like in your firm? Were equipment regularly and properly maintained? Were there plans for occasional shutdowns and turnaround maintenance? How can you describe your company maintenance performance towards the actualization of the company's production targets?</i></p> <p><b>Answer:</b> Actually, SASOL has a good that has maintenance programme that borders on managing the operational reliability of the system where part of it has to do with managing the equipment maintenance using reliability philosophies. We have not met our Target yet but we are on course. Equipment are regularly maintained so also shutdowns and turnaround maintenances. In fact we have a running maintenance plan for the next ten years and we execute each as at when due. So to me the company's maintenance performance towards actualizing production target has been attained although there is still room for improvement.</p> |
| <p><b>Question:</b> <i>How does your company manage their equipment maintenance strategy?</i></p> <p><b>Answer:</b> we manage our equipment maintenance strategy by reviewing the equipment maintenance process with our value chain. The process review has to do with aligning the maintenance strategy to the company's goal of having a cost effective maintenance task and at the same time ensure that equipment delivers its intended process function over its expected life. Unfortunately proper consideration is not given as stipulated based on the fact that the company is still battling on the corrective maintenance process. As such there are few parameters to consider as the procedural step in managing</p>                                                                                                                                                                                                                                                                                                                                                          | <p><b>Question:</b> <i>How does your company manage their equipment maintenance strategy?</i></p> <p><b>Answer:</b> we have a standardized process for managing our equipment maintenance strategy. This includes reviewing the maintenance policy, reviewing our value chain, develop functional location structure, input assessment, determine maintenance strategy, implement strategy, work order types and failure catalogues. Actually, our company's equipment maintenance strategy is reliability driven since we operate Reliability Centred Maintenance (RCM). We use reliability to checkmate failures while we also use asset performance tools (APT) comprising of ATP maintenance and ATP inspection for</p>                                                                                                                                                                                                                                                                                                           |

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| the equipment maintenance strategy.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Optimizing task frequencies.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <p><b>Question:</b> <i>What is the role of equipment in the functional block breakdown of your plant?</i></p> <p><b>Answer:</b> Equipment plays a very crucial role in the plants breakdown diagram. It is the tool with which the plant operates, so as to deliver product successfully. It is the most fundamental in any Plant design. For a plant to deliver optimally, its component equipment must be in top shape performance. In order words it is our equipment that drive our plant to deliver.</p>                                      | <p><b>Question:</b> <i>What is the role of equipment in the functional block breakdown of your plant?</i></p> <p><b>Answer:</b> Equipment is at the base of our Company's functional block diagram. It can be seen as the livewire of the company where merges to form assembly, assembly merges to form sub-system. Sub-system merges to form Systems. Systems merge to form section of the Plant and sections merges to form plant. So the plant existence depends on the Equipment capability to perform.</p>                           |
| <p><b>Question:</b> <i>How can one locate equipment stipulated for maintenance in your plant?</i></p> <p><b>Answer:</b> Equipment are equipped with an alphanumeric numbering system developed by the company using a functional location structure numbering system. This numbering system ensures that equipment in the plant at different structural location and function are well identified. Each piece of equipment has a unique identification number. These numbers is used to locate equipment in the Plant.</p>                         | <p><b>Question:</b> <i>How can one locate equipment stipulated for maintenance in your plant?</i></p> <p><b>Answer:</b> We have an alphanumeric numbering system that is developed which captures all the equipment in the plant. The numbering system accommodates the equipment, its unit function, location, structure etc. The numbering system ensures that all equipment are well accounted for with a unique number. It is this unique numbers that makes the identification of equipment very easy in our Company.</p>             |
| <p><b>Question:</b> <i>In ensuring the reliability of your Plant? What are the possible maintainable Items?</i></p> <p><b>Answer:</b> The reliability of our Plant depends on the maintenance of the equipment that makes up the plant. These equipment can be maintained by the normal repair which takes care of its functionality. It can also be extended to the failure mode which can be calculated, digging deep into the root cause of a failure and developing task that can address the root cause so that it will not repeat again.</p> | <p><b>Question:</b> <i>In ensuring the reliability of your Plan? What are the possible maintainable Items?</i></p> <p><b>Answer:</b> To ensure the reliability of our plant equipment maintenance becomes paramount. These equipment are maintained based on the reliability report. The reliability report is generated from the history of equipment, its primary/secondary function, its failure mode, its manufacturing process/procedure, its re-engineering/redesigning, its root cause analysis and the task that addresses it.</p> |
| <p><b>Question:</b> <i>How does your company obtain inputs for their maintenance management Strategy?</i></p> <p><b>Answer:</b> The inputs for our maintenance strategy are obtained from measurements comprising work order spread, frequent</p>                                                                                                                                                                                                                                                                                                  | <p><b>Question:</b> <i>How does your company obtain inputs for their maintenance management Strategy?</i></p> <p><b>Answer:</b> The inputs for our maintenance management strategy are obtained through a defined part on the company's value chain</p>                                                                                                                                                                                                                                                                                    |

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|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>schedule, daily plant inspection, maintenance strategy not working, then shutdown reviews, new equipment/ replacement and Stakeholder management.</p>                                                                                                                                                                                                                                                                                                                                                                                                                        | <p>process. The part is design to manage the operational reliability performance by monitoring the operational reliability Performance through work order types and Failure catalogues. Inputs can also be obtained from root cause analysis request so also from an executed corrective action.</p>                                                                                                                                                                                                                                                                                                                                 |
| <p><b>Question:</b> Briefly explain the terms function, failure mode, and root cause as regards your equipment.</p> <p><b>Answer:</b> Basically since we are talking about equipment, function simply means the basic duty the equipment is designed to achieve. Once there is deviation, then there is need to revisit the equipment and possibly recalibrate it back to its original function. Failure mode can be describe as condition that arises when an equipment or its component is malfunctioning. Root Cause helps to unravel the cause of an equipment failure.</p> | <p><b>Question:</b> Briefly explain the terms function, failure mode, and root cause as regards your equipment.</p> <p><b>Answer:</b> The term function as it relates to equipment can be viewed as the primary purpose upon which the equipment is needed. Other function may include accessibility of the equipment, safety/structural integrity of the equipment, protection of the equipment etc. Failure mode is the condition that creates failure/ malfunctioning of an equipment, While Root cause is the underlying reason <i>that leads to equipment failure.</i></p>                                                      |
| <p><b>Question:</b> What are the steps involved in developing maintenance management Strategy for your equipment?</p> <p><b>Answer:</b> The steps involved in developing maintenance management strategy for equipment includes knowing the basic function of the equipment in question. Scheduling maintenance task for the equipment based on maintenance technique, frequency of maintenance and cost implication. Ensure that the maintenance task is technically feasible Finally develop its failure mode based on the equipment Trouble shooting Manual.</p>             | <p><b>Question:</b> What are the steps involved in developing maintenance management Strategy for your equipment?</p> <p><b>Answer:</b> To develop a maintenance strategy for equipment, the following steps can be followed. Firstly the basic function of the equipment must be known. The maintenance task for the equipment must be specified in the form of the preventive, predictive, and proactive or run to failure. Ensure that the maintenance task is technically feasible. Consider the frequency and resources for executing the task. Finally develop its failure mode based on the manufacturer's Specification.</p> |
| <p><b>Question:</b> What is the importance of risk based inspection (RBI) in the cause of developing a maintenance management strategy?</p> <p><b>Answer:</b> In the cause of developing Maintenance management strategy, the risk base inspection becomes necessary in that it is a tool with which one can generate</p>                                                                                                                                                                                                                                                       | <p><b>Question:</b> What is the importance of risk based inspection (RBI) in the cause of developing a maintenance management strategy?</p> <p><b>Answer:</b> The risk base inspection is a failure mode generating tool. It estimates a risk-value associated with specific fixed equipment based on consistent methodology. It prioritizes the</p>                                                                                                                                                                                                                                                                                 |

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| equipment's failure mode. It takes into account all the possible failure conditions for equipment using the worst case scenarios as its probability. This helps to structure the best maintenance for such equipment.                                                                                                                                                                                                                                           | equipment based on the measured risk. It expresses the risk of equipment taking the worst case consequences into account with the probability that a specific degradation mechanism will happen. This is used to determine the NDE type and task frequency.                                                                                                                                                                                                                                                                                                               |
| <p><b>Question:</b> <i>what are the possible questions that are likely to come to mind when one wants to review a maintenance strategy?</i></p> <p><b>Answer:</b> When the need to review a maintenance strategy arises, the following questions may come to mind. Is the equipment still performing its function?, Are we still observing its maintenance schedule as at when due?, Is there anything we are doing to the equipment which we are not doing</p> | <p><b>Question:</b> <i>what are the possible questions that are likely to come to mind when one wants to review a maintenance strategy?</i></p> <p><b>Answer:</b> The questions that are likely to come to mind are closely related to those required when developing a new strategy. Questions like; Did the equipment function change? Was the equipment operated outside the critical process parameters? What did we find on the failure mode? Is the maintenance task still technically feasible and worthwhile doing? Should we change the frequency and so on?</p> |
| <p><b>Question:</b> <i>What are the possible steps that are required in order to approve a maintenance strategy?</i></p> <p><b>Answer:</b> The steps required includes; approving the Failure Mode and Effect Analysis (FMEA) and approving job groups (schedules).</p>                                                                                                                                                                                         | <p><b>Question:</b> <i>What are the possible steps that are required in order to approve a maintenance strategy?</i></p> <p><b>Answer:</b> To approve a maintenance strategy, its FMEA needs to be approved, So also the job Grouping (scheduling) requires approval.</p>                                                                                                                                                                                                                                                                                                 |
| <p><b>Question:</b> <i>What is FMEA and what is the process for approving FMEA in your company?</i></p> <p><b>Answer:</b> Like I said earlier, FMEA means Failure Mode and Effect Analysis. Then for the process of approving FMEA; the strategy document is first compiled, afterwards various meetings are held with all relevant authorities (stakeholders). It is at these meetings that they discuss and approve the FMEA of specific equipment.</p>       | <p><b>Question:</b> <i>What is FMEA and what is the Process for approving FMEA in your company?</i></p> <p><b>Answer:</b> FMEA means Failure Mode and Effect Analysis. It is a tool used to identify all potential failure modes and determine their possible effect. As for approving of FMEA, a committee is entrusted with the responsibility to develop the strategy document. Once it is developed, the committee with the maintenance management team and people from reliability team will have to discuss it. It gets approved if the merit</p>                   |
| <p><b>Question:</b> <i>What is meant by the word, "Job Grouping"?</i></p> <p><b>Answer:</b> Job grouping means to group the entire maintenance task that can be carried out at the same time together thereby making The actualization of the entire task a bit easy.</p>                                                                                                                                                                                       | <p><b>Question:</b> <i>What is meant by the word, "Job Grouping"?</i></p> <p><b>Answer:</b> Job grouping can be described as the ability to group all maintenance tasks that can be performed at the same time together. The content of a job group is called a task sheet.</p>                                                                                                                                                                                                                                                                                           |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Each job group forms a maintenance plan for Maintenance Strategy actualization.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <p><b>Question:</b> <i>What are the requirements for grouping tasks together?</i></p> <p><b>Answer:</b> The requirement varies from company to company. From our own stand point, jobs can be grouped together if they belong to the same job card, perform similar function, operate at the same frequency, belong to the Same maintenance strategy etc.</p>                                                                                                                                                                                 | <p><b>Question:</b> <i>What are the requirements for grouping tasks together?</i></p> <p><b>Answer:</b> The requirements for grouping task together are as follows; task must be in the same maintenance strategy category, task must have the same availability/access, task must have the same frequency, task must have the same initiated date. Plant condition must be the same.</p>                                                                                                                                                                                                                                   |
| <p><b>Question:</b> <i>What is the process for registering task list and maintenance plan in your Company?</i></p> <p><b>Answer:</b> The process for registering task list and maintenance plan in our company includes getting the task list completed by the line Managers. They will also complete the maintenance plan sheet. The Planners are responsible for creating and capturing the entire task list in the system. They will do same to the maintenance plan sheet also and finally Distribute these tasks for implementation.</p> | <p><b>Question:</b> <i>What is the process for registering task list and maintenance plan in your Company?</i></p> <p><b>Answer:</b> The process for registering task list and maintenance plan is as follows; The Line/strategy coordinator will complete task list table. The same line/strategy coordinator will complete maintenance plan table. Schedulers will create one linear task list in the system. The same schedulers will create one linear maintenance plan in the system. Then finally, a planner will expand task list in the system. The system will be generating each Task for possible execution.</p> |
| <p><b>Question:</b> <i>What is the process step for work Management in your company?</i></p> <p><b>Answer:</b> Since we basically operate corrective maintenance, we identify work, prioritize them, plan and schedule the maintenance for implementation. Then after execution, do documentation and Work order feedback.</p>                                                                                                                                                                                                                | <p><b>Question:</b> <i>What is the process step for work Management in your company?</i></p> <p><b>Answer:</b> The process step for work management in our company includes; work identification, work prioritization, job planning, scheduling, work execution, work Order feedback, work status control.</p>                                                                                                                                                                                                                                                                                                              |
| <p><b>Question:</b> <i>Briefly explain the work executable step for a corrective work that originated from a maintenance strategy schedule in your Company?</i></p> <p><b>Answer:</b> Based on our company's perspective, when a corrective work originates from maintenance strategy schedule, it can be executed as follows: From the corrective maintenance, create work order, schedule order, determine cost, release order, perform</p>                                                                                                 | <p><b>Question:</b> <i>Briefly explain the work executable step for a corrective work that originated from a maintenance strategy schedule in your Company?</i></p> <p><b>Answer:</b> When a corrective work emanates from our maintenance strategy schedule, such work can be executed as follows: from the reliability centred maintenance, create work order, plan order, schedule order, determine cost, release order, perform work, analyse job</p>                                                                                                                                                                   |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Work, analyse job card and complete order.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | card feedback, create PM notification specifying work order number, complete order and complete notification history.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <p><b>Question:</b> Briefly explain the work executable step for a corrective work that originated from a plant inspection in your company?</p> <p><b>Answer:</b> Based on our company's perspective, We operate correction maintenance so we do not pay much attention to plant inspection until when there is a failure, we correct them. But as for your question, I guess it should follow the same principle as in the case of corrective work generated from the Maintenance schedule.</p>                                                                                                                                                                    | <p><b>Question:</b> Briefly explain the work executable step for a corrective work that originated from</p> <p><b>Answer:</b> When a corrective work emanates from a plant inspection, such work can be executed as follows: From the plant inspection, create work order, plan order, schedule order, determine cost, release order, perform work, analyse job card feedback, create PM notification if it is on process equipment, complete order and complete Notification history.</p>                                                                                                                                                                                                                                              |
| <p><b>Question:</b> How does your company measure the effectiveness of their maintenance strategy?</p> <p><b>Answer:</b> Well, the effectiveness of our maintenance strategy can be measured by calculating the following; production efficiency of the plant which is actual production/actual production plus downtime losses, lost profit opportunity (LPO) which is total losses related to equipment failures before repair, equipment mean time before failure (MTBF). If the downtime loss is increasing, the production efficiency will be decreasing which invariably means that the maintenance strategy is not effective so improvement is required.</p> | <p><b>Question:</b> How does your company measure the effectiveness of their maintenance strategy?</p> <p><b>Answer:</b> The effectiveness of our maintenance strategy can be measured by analysing the failure history of each maintainable item. Compare the failure mode and the frequency of failure obtained from the failure catalogue with the failure mode specified in the maintenance strategy for deviations. Also analyse the mean time before failure and the state of the protective device, if applicable. If the probability of failure is greater or equal to one, then the maintenance strategy is not effective, as such needs improvement but where it is less than one, the maintenance Strategy is effective.</p> |
| Engr. Kenneth Orieh, it has been a pleasure having you on this interview. Thank you for sparing your time and experience. You may not know how much you have contributed to my research work. Hope to see you again by the time the research work is successfully completed. Best of Luck in all your endeavours.                                                                                                                                                                                                                                                                                                                                                   | Engr. André Joubert, it has been a pleasure having you on this interview. Thank you for sparing your time and experience. You may not know how much you have contributed to my research work. Hope to see you again by the time the research work is successfully completed. Best of Luck in all your endeavours.                                                                                                                                                                                                                                                                                                                                                                                                                       |

**TABLE 4.2:** Comparative Analysis of the Interview Documentation

The above interview was a demonstration of facts that were already gathered from the survey carried out to determine the functional perception of engineering performance in the two engineering institutions. The interview, confirmed the level of exposure existing in the two engineering institution with regards to the maintenance management strategy for the gas field equipment.

The best part of the interview was that it was directed to the maintenance managers of both engineering firms, which helped us understand their maintenance management strategies.

The interview session covered the major points in maintenance management strategy. These include:

- How to develop a functional location,
- How to obtain inputs,
- How to develop a new maintenance strategy,
- How to get it approved, its implementation, its review, measurement of its effectiveness etc.

The NGC representative was a bit handicapped based on their choice of maintenance strategy (corrective maintenance). As a result of this, the maintenance manager's contribution was based on his personal knowledge rather than what was obtained from the company. His contributions were a bit closer to SASOL's maintenance strategy, which was based on Reliability Centered Maintenance (RCM).

For SASOL representative, besides his personal knowledge on the subject matter, his company's commitment to a comprehensive maintenance management strategy boosted his confidence on the topic.

Based on the above, conclusion was drawn on the ground that the survey and the interview points to the need for an improvement on the maintenance management strategy of (NGC). With the knowledge of the requirements to developing a new maintenance management strategy, the next topic below will be dedicated to the development of an improved maintenance management strategy for NGC.

#### 4.3 UTILIZATION OF AVAILABLE INFORMATION TO DEVELOP AN IMMS

The Improved maintenance management strategy was operator driven based. It comprised of monitoring, preventive and corrective maintenances all encompassing.

##### METRICS DEFINITION

The gas field equipment tracked for the EGTL plant Escravos are as follows:

| <b><u>Equipment</u></b>             | <b><u>Count</u></b> |
|-------------------------------------|---------------------|
| <b>Gas compressors</b>              | <b>11</b>           |
| <b>Reciprocating Engines</b>        | <b>66</b>           |
| <b>Turbine Generators</b>           | <b>13</b>           |
| <b>Reciprocating pipeline Pumps</b> | <b>7</b>            |
| <b>Turbine Pipeline Pumps</b>       | <b>7</b>            |
| <b>TOTAL</b>                        | <b>= 104</b>        |

##### GLOBAL METRICS REQUIREMENTS

104 PIECES OF EQUIPMENT TRACKED.

The Operator Driven Based Maintenance was developed based on the information gathered from the comparative output analysis on the questionnaire, interview sessions and intelligent engineering assumptions.

#### 4.4 APPLICABILITY OF FMECA IN THE DEVELOPMENT OF THE IMMS.

In this aspect of the maintenance strategy, the performance study done was used to determine the system operating parameters (see appendix 3).

The performance indicators were critically adjusted to optimize the systems reliability. Also for the improvement of equipment efficiency, other analysis and studies were carried out, such as Failure modes, Effects and Criticality Analysis (FMECA), Failure Mode and Criticality Analysis (FMCA) and Fault Tree Analysis (FTA).

The goal was geared towards running of the system at full capacity with minimum running cost, maximum output and trying as much as possible to avoid failure of the system.

#### 4.5 OVERALL EQUIPMENT EFFICIENCY (OEE)

Overall Equipment Effectiveness (OEE) incorporates not just availability but also performance rate and quality rate. Stated alternatively, OEE addresses the following:

All losses caused by the equipment:

- not being available when needed due to breakdowns or set-up and adjustment losses
- not running at the optimum rate due to reduced speed or idling and minor stoppage losses
- not producing first pass quality output due to defects and rework or start-up losses.

**Stating this mathematically, the Overall Equipment Effectiveness is expressed as:**

$$(OEE) = A \times PR \times Q;$$

Where

**A-** Availability of the machine.

*[Availability is proportion of time machine is actually available out of time it should be available].*

**PR-** Performance Rate (**PR=RE x SR**)

*[Rate efficiency (RE): Actual average cycle time is slower than design cycle time because of jams, etc. Output is reduced because of jams*

*Speed Rate (SR): Actual cycle time is slower than design cycle time machine output is reduced because it is running at reduced speed].*

**Q-** Is the quality rate.

*[Which is percentage of good parts out of total produced sometimes called yield].*

All these figures are usually expressed in percentage. Higher OEE translates into higher equipment efficiency from the equipment. Surprisingly, the OEE of most equipment range from 40% - 60% when measured initially, even though the benchmark is 85%.

This has made OEE the accepted indicator to assess how plants manage their most expensive asset (the equipment), to produce marketable goods, with minimal losses and wastes.

The research work developed an improved maintenance management strategy (IMMS), which will enable the gas field equipment in Nigeria to reach the optimal efficiency of 85% or above.

***(The operator driven maintenance was structured as can be seen in full on the IMMS template attached as appendix 3).***

## **CHAPTER FIVE**

### **5.0 DISCUSSION AND EVALUATION ON THE DEVELOPED IMMS**

The whole idea behind having an Improved Maintenance Management Strategy (IMMS) is based on improving the existing maintenance management strategy to thereby improve the maintenance management control. Its application will foster proper maintenance of the plant equipment which will in turn significantly reduce the overall operating cost, while boosting the productivity of the plant.

The Nigerian Gas Company's (NGC) maintenance operation deteriorated due to lack of proper maintenance management strategy (see maintenance audit). This research was developed to eliminate such re-occurrences on the Gas field equipment that are going to be used in the newly built EGTL plant in Nigeria.

It was a known fact that management personnel often view plant maintenance as part of expenses; and as such frown at efforts that proactively help in boosting maintenance because of cost implication. Nevertheless, this research identified, integrated and developed an Improved Maintenance Management Strategy that views maintenance works as a profit centre. The key to this approach lies in a new perspective of proactive maintenance approach that is operator driven.

Strategic Maintenance decision making were used in selecting the right care and repair methodologies that maximize equipment life and performance for the least cost to the user. But to be able to make successful Maintenance Management Strategy choices you must understand how equipment fails. Being aware of equipment's strengths and weaknesses means that it can be take care of properly and maximum maintenance service delivered at the least cost.

The newly developed IMMS (see appendix 3) has the potential to restore the glorious past of the NGC's maintenance philosophy, if fully implemented. It aims at ensuring plant availability, increasing production flow and outputs while decreasing failure of gas field equipment. It provides the management of other Oil and Gas industries with

sufficient information necessary for the development of an adequate maintenance support system for proper maintenance of gas field equipment.

## **5.1 FACTORS CONSIDERED DURING THE DEVELOPMENT OF THE (IMMS)**

There were several factors that were considered during the development of this Improved Maintenance Management Strategy (IMMS). They ranged from pre-emptive methods that could replace the need for maintenance where applicable, implementation of a good maintainability plan and the use of failure analysis methods to removing existing failures.

### **5.1.1 Pre-emptive Detection and Elimination**

The IMMS planning should be holistic and all encompassing. Once an item on the plant is built you are stuck with it. A piece of equipment requires whatever maintenance it needs to maintain its performance. There is no escaping the fact that the design specifies the maintenance requirements. Unless the necessary maintenance is done, the system will fail.

The pre-emptive detection and elimination method helped to uncover that if one wants less maintenance, then the appropriate design choices must be made initially to reduce the amount and time on maintenance. The methods used to highlight opportunities to reduce maintenance are based on Failure Mode and Effects Analysis (FMEA). A simple way to understand the approach is to consider it as a series of answers to ‘what-if’ questions used on each part of the equipment.

For example, ‘what-if’ the shaft bearing lost lubrication? The bearing would run dry, heat up and start wearing out. To prevent such a failure we need to provide maintenance that ensures the bearing is regularly lubricated. A further example might be ‘what-if’ there was loss of power? If this happens, what would be the effects? Depending on the consequence of the effects, one would put suitable design features in place to reduce the impact of the failure.

Pre-emptive Maintenance Strategies are the best because they are the least expensive way to reduce maintenance. It becomes very important because they are an equipment

lifetime strategy that brings continual and better operation for the equipment's entire operating life.

The involvement of Pre-emptive detection and elimination maintenance strategy in the development of the IMMS is visible. It provided a boost to the maintenance of gas field equipment as can be seen from the IMMS deliverable.

### **5.1.2 Quality Control and Assurance**

This is another very important factor. It was considered as priority during the development of the IMMS. This became necessary after seeing the result of the maintenance audit that was done on NGC. Quality Control and Assurance strategy originated in the manufacturing industry, and applies equally to maintenance work.

It is simply the proper and correct control of equipment maintenance and repair so that equipment performance will be in conformity to its designed operability level, with correct and accurate functionality. It also involves substantiating and proving that each equipment item meets its design requirements and that it is assembled into the equipment correctly. Typically this involves following specified, written procedures on how the work is done. It includes tests and check steps to confirm compliance and documented proof that the procedure was followed.

When equipment is accurately and properly maintained using the right strategy, it lasts longer between repairs and so has a longer Mean Time Between Failures (MTBF). It also runs optimally and produces more consistent output.

Adopting a 'Quality Control and Assurance' Maintenance Strategy improves the quality and accuracy of parts and personnel. This translates into better running equipment with longer mean times between failures. This strategic maintenance move will produce results immediately, while reducing errors. Its benefits become obvious within six to twelve months time.

### **5.1.3 Preventative Maintenance**

Preventative Maintenance (PM) Strategy was one of the very first and it is still very effective.

The IMMS application viewed preventive maintenance in two forms;

- ◆ Inspection and observation and
- ◆ Intervention and replacement.

This is where the first line users of the equipment, “The operators” are deeply involved for the first time in maintenance strategy management.

The first Preventative Maintenance form is the usual response used for equipment and parts that show signs of age and wear-out. It involves inspecting and noting the condition of equipment and its parts and servicing it on a regular basis, such as changing old lubricant.

During servicing is an ideal time to look for evidence of impending failures in critical and working parts. If evidence of failure is found, the part is immediately changed for a new one or at the earliest convenient time before breakage.

A Preventative Maintenance Strategy stops failures with the very first use. A well-run and an on-time PM Strategy are expected to stop failures by about 90%. Its benefits are usually obvious in the first month or two.

#### **5.1.4 Shutdown Overhaul Maintenance**

The second PM form is to automatically replace the parts known to experience aging and use related degradation on a set frequency shorter than the mean time between failures. Doing this should prevent an unexpected failure and give maximum production time.

Such work is typically done as an overhaul where the whole of the equipment is removed from operation during a shutdown and taken to the workshop to be stripped down to its component parts and rebuilt as new.

Use of Shutdown Overhaul Maintenance Strategy is aimed at ensuring uninterrupted production for a specific period of time. By renewing equipment regularly, the wear-out related stoppages are removed. Once equipment is overhauled to manufacturer's

standards, a new performance is expected. However one is exposed to ‘infant equipment mortality’ risks due to poor quality control, mistakes during assembly, incorrect material selection and introduced damage.

A ‘Quality Control and Assurance Strategy’ is required for a successful application of the Shutdown Maintenance Strategy, so as to achieve very good rebuild and checking procedures.

#### **5.1.5 Predictive Maintenance**

Predictive Maintenance (PdM) was also considered in the development of the IMMS. Since PdM is a very powerful maintenance strategy, it involves monitoring for evidence of changed conditions within the equipment. The amount of change and the rate of change are tracked and used to predict the time of failure.

PdM is based on the recognition that many failures take time to happen. Typically there is a start point, a gradual worsening, and eventually a point where the item cannot perform its duty. Finally there is a point in time when it breaks and totally fails. If it is possible to detect early onset of the failure then there is often time to manage the equipment carefully and continue operation until a replacement is actually needed.

PdM techniques include thermograph, oil debris analysis, vibration monitoring and ultrasonic thickness testing. They are all methods that detect a change, and allow measurement of the rate of change, so that predictions can be made on the equipment’s continuing performance.

When the predictive maintenance management strategy is used, problems are spotted immediately and can be acted on before a failure occurs that shuts the operation down.

#### **5.1.6 Intentional Over-Design Selection**

There was an accommodation on the IMMS to allow for intentional over-design where necessary. This is because there are times when it is useful to select more robust equipment than superficially appears necessary. This is a strategic maintenance choice that is intended to produce longer periods of equipment operation between failures.

It involves specifying equipment with stronger, harder, more resistant parts, using longer lasting components, applying improved protection against ingress of the external environment, etc.

There may be a higher purchase cost but it is offset with more production output over the equipment life. Immediate benefits through fewer stoppages are visible in the first year or two.

#### **5.1.7 Improved Technologies**

New inventions and innovative designs usually occur in response to existing problems. That was actually what led to the development of IMMS since the collapse of NGC's maintenance strategy. It is a wise and valid maintenance strategy to be constantly looking for new technologies that reduce equipment operating problems.

When a potentially useful technology is found, it is imperative to test it in a controlled and monitored experiment to prove its worth in your situation.

From experience, it is only wise that the only long-term solution to the need for maintenance is to invent equipment that does not need it. This means discovering new technologies that do not fail, or that vastly increase the mean time between failures.

When one changes to a new technology that solves a maintenance problem he immediately gains the benefit of improved production output. This benefit continues throughout the equipment's life.

#### **5.1.8 Root Cause Elimination and Design-Out**

In the developed IMMS, root cause elimination has a very important part to play in the actualization of gas field equipment maintainability for optimum performance and elimination of further equipment failure. This is a strategic maintenance step that if not done, results in long-term deterioration in production plant performance. If operating problems are not removed by designing them out, then the problems will accumulate to the point where production falls because equipment continually fails.

A problem can only be prevented from reoccurring if it is eliminated. There are methodologies available that use a systematic approach to trace the real cause of problems to their root cause. By removing the root cause, the problem can then not reoccur, meaning that the operating performance of that equipment or plant has been improved.

The benefits of root cause elimination are immediate with the permanent removal of a failure cause. The problem disappears for the rest of the equipment's life.

#### **5.1.9 Proactive Education and Training**

Factors considered in the development of the IMMS will not be complete if proactive education and training of people were not captured. People can only change their behaviour and thoughts when they find better ways to behave and think. Once a person knows what is right to do, they will most likely do it.

Ignorance is hugely expensive! One of the best maintenance strategies is to teach the engineering design requirements of the equipment to the operators and maintainers who will run and care for it. This is a sound strategic step because it means key knowledge is transferred to the users of the machinery.

Knowledgeable users will make wise choices and take corrective actions. A proactive and knowledgeable operation; plant and equipment care translates into longer periods of trouble-free operation and increased throughput.

A proactive training program involves 10 working days a year per employee (technical, safety and engineering training) on the design and operation of the equipment and systems used in operations. Included in the training is regular introduction to new information and constant revision and reinforcement of the key factors that produce long and reliable operation of your equipment.

Training and education benefits the company in future. Continuous improvement requires continual learning. When people are trained well, they bring the benefits to the

operation within six months. Most importantly they will think of new ideas and bring innovations into the business which produces competitive advantages.

#### **5.1.10 Maintenance Planning and Scheduling**

The last but not the least in the development of the IMMS is the maintenance planning and scheduling. This is a key strategic maintenance planning move. It is based on the principle that prior planning and preparation will improve the actual performance and execution. It is why elite athletes do not compete unless they have trained for the event.

They know that unless they have prepared thoroughly before hand they will not succeed. It is exactly the same with operations and maintenance – each must be thoroughly planned and organized before being actualized.

By doing maintenance planning and scheduling alone, maintenance crew manning can be reduced by at least 25% over the next two years. The manpower efficiency improvement will be visible in less than six months. Another certainty is that one can use a planning and scheduling system to insure the preventative maintenance is done on time, and this will invariably lead to reduction in breakdowns within three months.

#### **5.1.11 The Right Mix of Strategic Maintenance Management Strategies**

It has been observed that there is no maintenance strategy that is perfect enough for all situations and all companies. For this reason, the IMMS came with the blend of different maintenance management strategies, intelligently mixed to get the right strategy for the maintenance operation of gas field equipment. The essence is to maximize production and reduce equipment failure to minimal levels.

The IMMS requires an amount of preventative maintenance, as well as an amount of predictive maintenance when equipment ages, along with root cause analysis to eliminate non-random failures. Added to this is appropriate training, occasional overhaul shutdowns, replacement of old technologies with new technologies etc

The choice of the appropriate maintenance strategies is what strategic maintenance planning is all about. Strategic maintenance planning should also recognize when it is necessary to change the maintenance strategy mix.

## **5.2 EVALUATING THE IMPROVED MAINTENANCE STRATEGY.**

Critical analysis revealed that the IMMS was developed, to accommodate all other related maintenance function inform of maintenance policies for proper management and functionality (see chapter 4). This maintenance will be driven from the ‘operator’ perspective since the operator is the owner and as well the closest to the equipment for easy monitoring. The maintenance policies involved are as follows:

### **5.2.1 INSPECTION DECISION**

Inspection of equipment determines whether further maintenance attention is needed. Based on the philosophy of IMMS, the operators will also be responsible for the equipment inspection. They will know when the equipment functionality/performance is at its peak. This is beside the operator’s responsibility of carrying out routine checks, executing basic preventive maintenance programs developed for the equipment

Besides using equipment or logging down equipment output records, one might also log down information’s on the efficiency of the equipment. There are also situations where one can notice equipment malfunction from visual inspection, sound changes, response and delivery rate etc. So an operator is likely to be the first to observe deviations from expected logged values or behaviour. This way, the maintenance team is alerted for further test analysis on equipment status clarification.

The best frequency of maintenance must be known once the type of inspection has been decided upon. This will prevent loss of production or in some cases failure when equipment runs continuously. Inspection also causes the above dictation if it assumed that downtime due to inspection is proportional to the inspection frequency and downtime due to breakdown is inversely proportional to inspection frequency the total down time in unit time  $\Delta T$  is given by;

$$\Delta T = \Delta I N + \Delta D B K / N$$

Where:  $\Delta I$  is the downtime per inspection,  $N$  is the  $N_0$  of inspection per unit time,  $DB$  is the downtime per breakdown and  $K$  is a constant for a particular piece of equipment based on the operating experience.

Optimal frequency is got by the process of differentiation.

$$\text{i.e. } d\Delta T/dN = \Delta I - DBK/N^2$$

Assuming  $DB$  and  $DI$  are constants

$$\text{Hence } N_{0t} = \sqrt{(DB \times K/DI)}$$

Where  $N_{0t}$  is the frequency of inspection that minis raises downtime.

### 5.2.2 REPAIR POLICY

Failure will occur despite the amount of preventive maintenance that is in place. This can either be as a result of use of bad/substandard parts or incompetent maintenance personnel. Therefore, the IMMS recognizes the breakdown maintenance aspect of maintenance strategy in order to return the equipment to its original form when such equipment finally fails. This is covered under the repair policy.

Repair policy invariably involves sub-contractors. Equipment is repaired immediately or later once it breaks down, and this can be in bits or a whole. Temporary replacement can also be done. For the purpose of specialized skills, the service can be outsourced to outside specialists. Sub-contracted maintenance is highly advantageous.

In a situation where a system cannot be repaired, maintenance is by outright replacement only. This policy is useful where equipment is to be operated in a harsh environment and also in a situation where replacement cost is low.

It should also be noted that user maintenance formula calls for reduced training and cost of Maintenance Management. The user maintenance is limited only to replacement of spares and repair of defective unit of a central service facility. This service facility

provides service for many user installations. This minimizes the number of crew at installations, including cost.

The presence of standby machines most times in covering breakdowns is not practicable. It is more economical when the machines availability is assured and they are portable. What matters most is the best number of standby machines. The cost of production can be estimated, if the pattern of machine breakdown is known when compared to that of the standby machines.

### **5.2.3 REPLACEMENT POLICY**

The IMMS equally recognizes the need to accommodate replacement policy so that equipment can be replaced whenever the need arises. Replacement problems can be grouped as either deterministic or probabilistic. The former are those where the timing and pattern of replacement action are assumed to be known for sure. For example, equipment not prone to failure but incurs high cost as it operates. For this, greater output can be got at reduced cost if replacement is done.

On the other hand, the later problems are those where the timing and outcome of the replacement action depend on chance. Stated simply, the equipment may be described as good or failed. It is usually impossible to predict with assurance when a failure will occur or more generally when the transition from one state of equipment to another will occur. Another uncertainty is that except a definite maintenance action is performed, it is impossible to determine the state of the equipment.

To determine when replacement should be done, the emphasis is always on the time sequence in which the replacement action is to be carried out. It should be noted that the sequence of times can be considered a replaceable policy. The best policy is that which optimizes total cost.

In periodic policy, there is an unlimited lifetime trend which undergoes a constant or regular pattern. Also preventive replacement actions are done before equipment reaches a failed state.

Two necessary conditions for the above include:

- ◆ Greater cost of replacement after failure than before
- ◆ Increase in the failure rate of the equipment.

### **5.3 THE GENERAL RENEWAL PROCESS**

Preventive and Breakdown Maintenance are two major maintenance actions that constitute the general renewal process for plant equipment. They are inter-dependent. They are complementing and necessary for activities in the management of all types of maintenance operating system in which physical equipment is used. In determining the effectiveness of the renewal process, care must be taken in the management of the following factors.

#### **5.3.1 SIZE OF MAINTENANCE CREW**

In an organization some maintenance facilities or capacities available include; workshops, stores and manpower. There is also contract between the organization and its contractors in terms of some maintenance function. Also increase in the range of maintenance equipment increases the capital.

The major problem observed from the above includes:

- I) Increase in crew size which invariably results to increase in cost.
- II) Increase in crew size which in turn reduces the idle time of machines.
- III) Reduction in down time as a result of the use of a larger crew for the repair of equipment.

When determining the economic crew size, the following should be noted:

- IV) The type of the maintenance work needed.
- V) Availability of maintenance facility within the company.
- VI) The workload in these facilities.
- VII) Cost associated with the various alternatives.

Thus the size of maintenance crew is dependent on the training cost to the personnel against the cost of equipment downtime.

Some of the terms can include:

- ◆ Maintenance department staff should not be increased on the basis of supply
- ◆ Contract services should always be employed where specialized skills and equipment are needed to be cost effective.

### **5.3.2 SCHEDULING MAINTENANCE WORK**

Inspection and scheduled maintenance of an equipment and control equipment are required at established interval. A check of servicing needs, under operating conditions will establish the most practical inspection and maintenance scheduled.

There categories of maintenance include:

- (i) Intermediate Maintenance: This has to do with work around inspection to ensure the proper functioning of equipment and also to detect problems on time.
- (ii) Minor Maintenance: This requires the equipment shut down for most of the inspection. It is recommended that maintenance is performed after 6 months of operation.
- (iii) Major Maintenance: This involves disassembly of selected sub-system components for inspection. This is normally done for say 500<sup>o</sup> – 800 hours depending on the equipment operating condition.

Good maintenance schedule reduces downtime of equipment and makes it available for more production.

## **5.4 MAINTENANCE CONTROL**

The term ‘control’ has to do with the control over the time taken on jobs and to guarantee that jobs are performed more effectively. Therefore the control of a planned maintenance system depends on monitoring of the results and taking corrective actions.

### **5.4.1 MAINTENANCE CONTROL LOOP**

The control system must be capable of one commodity and responds speedily to changing situations.

The corresponding instruments of control are:

- (i) Sampling the effect of maintenance
- (ii) Analyzing the effect of maintenance
- (iii) Applying the corrective action. See fig 5a.

#### 5.4.2 CONTROL PROCEDURE

Improving control is attained by getting a record of equipment to be repaired.

A plant inventory shows the following:

- (i) Type of equipment, its design and use
- (ii) Equipment capacity
- (iii) Current and Potential utilization
- (iv) Age
- (v) Spares required
- (vi) A record of post breakdown
- (vii) A record of maintenance breakdown.

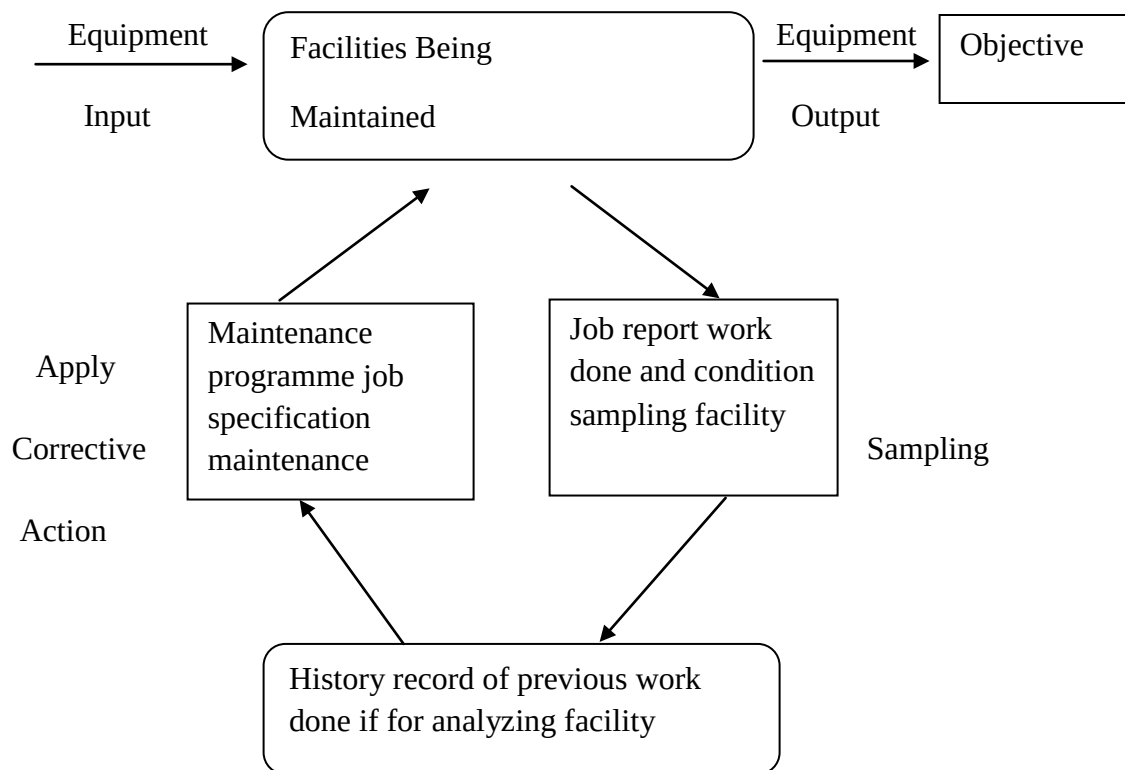


**Fig. 5a:** Maintenance control loop

The control procedure should quote the following: Type of machine or equipment involved, maintenance carried out, time taken to carry out the maintenance and a record of maintenance personnel.

How maintenance is requested and carried out.

-Who requests maintenance?

-What documentation is used?

-Is the cost of maintenance calculated and on what basis?

#### **5.4.3 STEPS TO DEVELOP EFFECTIVE ROUTES**

- (i) Equipment to be covered and their locations are listed.
- (ii) Determine crafts required
- (iii) Schedule for preventive route development is prepared
- (iv) Provide cooling system for all preventive maintenance data
- (v) List preventive maintenance activities to be performed
- (vi) Provide cooling system
- (vii) Time standard for all preventive maintenance activities are determined
- (viii) Preparation of maintenance check – list
- (ix) Preparation of preventive maintenance route
- (x) Review each route with production
- (xi) Install preventive maintenance system and follow up.

#### **5.5 THE IMMS: AN OPERATOR DRIVEN BASED PROACTIVE MAINTENANCE MANAGEMENT STRATEGY.**

Several theories have been postulated and all with the sole objective of optimizing maintenance function in the industrial sector. But, not all these theories, maintenance approaches, are equally effective and / or applicable to every plant.

The IMMS was developed based on the fact that, having studied several maintenance approaches, an operator-driven proactive maintenance strategy could be synergized and merged into an applicable approach.

The operator driven based proactive maintenance was carefully developed to satisfy the maintenance urge of the next generation maintenance. This is in accordance to the manufacturing enterprise demands, in which the fundamental factors in the next generation manufacturing are the manufacturing process and equipment.

The operator driven based proactive maintenance approach, specifically designed for Nigerian industry, covers two important concepts;

- ◆ the operator lead maintenance and
- ◆ the parametric monitoring and control of monitoring devices.

It is a known fact that maintenance management approach can affect company's fundamental premises, including production cost, product quality, on-time delivery, safety and general customer satisfaction.

That is why the operator driven proactive maintenance will be considered a good idea for the realization of the above mentioned company's fundamental at a reduced maintenance cost. The IMMS is set to deliver teamwork, empowerment, skills training of the operating personnel, monitoring and controlling of the production process and equipment parameters etc. It is actually designed to be the basic building blocks of all modern maintenance system.

#### **5.5.1 The Operator driven concept.**

The Operator driven concept of IMMS is an organizational support system for maintenance management which includes all employee empowerment, teamwork and training. It reflects a "*self-directed work team*" concept in a process oriented organization in which each unit operates as a self-directed work team to accomplish certain production operating tasks.

It clearly involves the working together of machine operators and maintenance technicians in order to achieve maintenance goals. It makes both parties multi-skilled. They must have received proper training and take responsibility for the operation of the production process, including the equipment in order to produce the desired product.

The IMMS made it possible that the operators and technicians should be the owner of the outcomes of a process and make decisions about day-to-day operations of the process.

This empowerment can be at different levels:

1. Doing things correctly the first time by sticking to rules, procedures (standard operating procedures-SOP).
2. Reflecting on their experience and make deductions from it, thereby creating their own understanding.

Empowerment is influenced by several factors of which one is reward system, teamwork can basically support the empowerment of operators and technicians to take responsibility to make the right decision in their day-today operations.

The IMMS ensures that operators and technicians acquire skills from each other. This gives rise to better understanding of the process and equipment in operations and maintenance (OM). They share their valued experience and skills so as to make the right decision at the right time.

Another advantage of the process is that it creates group learning, which is a vital to transfer of knowledge. The operator driven based proactive maintenance can further be divided into operational level & support level. The former includes the operators, technicians and supervisors; while the latter involves the production engineers, maintenance engineers, process engineers etc.

#### **5.5.2 The Parametric Monitoring and Control concept.**

The Parametric Monitoring and Control concept was introduced to monitor or control processes and equipment parameters in order to;

- ◆ gather useful data and information about the equipment conditions,
- ◆ ascertain the conditions of the monitoring devices.

The data gathered can then be used to design and adjust the maintenance management system, which is one of the basic challenges in the maintenance process.

This may include performance measurement, equipment parameter monitoring, risk assessment, economic analysis and on-condition monitoring. This is with consideration for technical and economic factors. The collected data and information can be the basis for predicting equipment failure and to meet the requirements of the maintenance process.

The IMMS emphasizes the controlling and monitoring of both the process parameters and equipment parameters together. This is to ensure that the manufacturing process is robust and scalable. If the changes of these parameters deviate from the norm, it means that an urgent maintenance attention is required (from a statistical point of view)

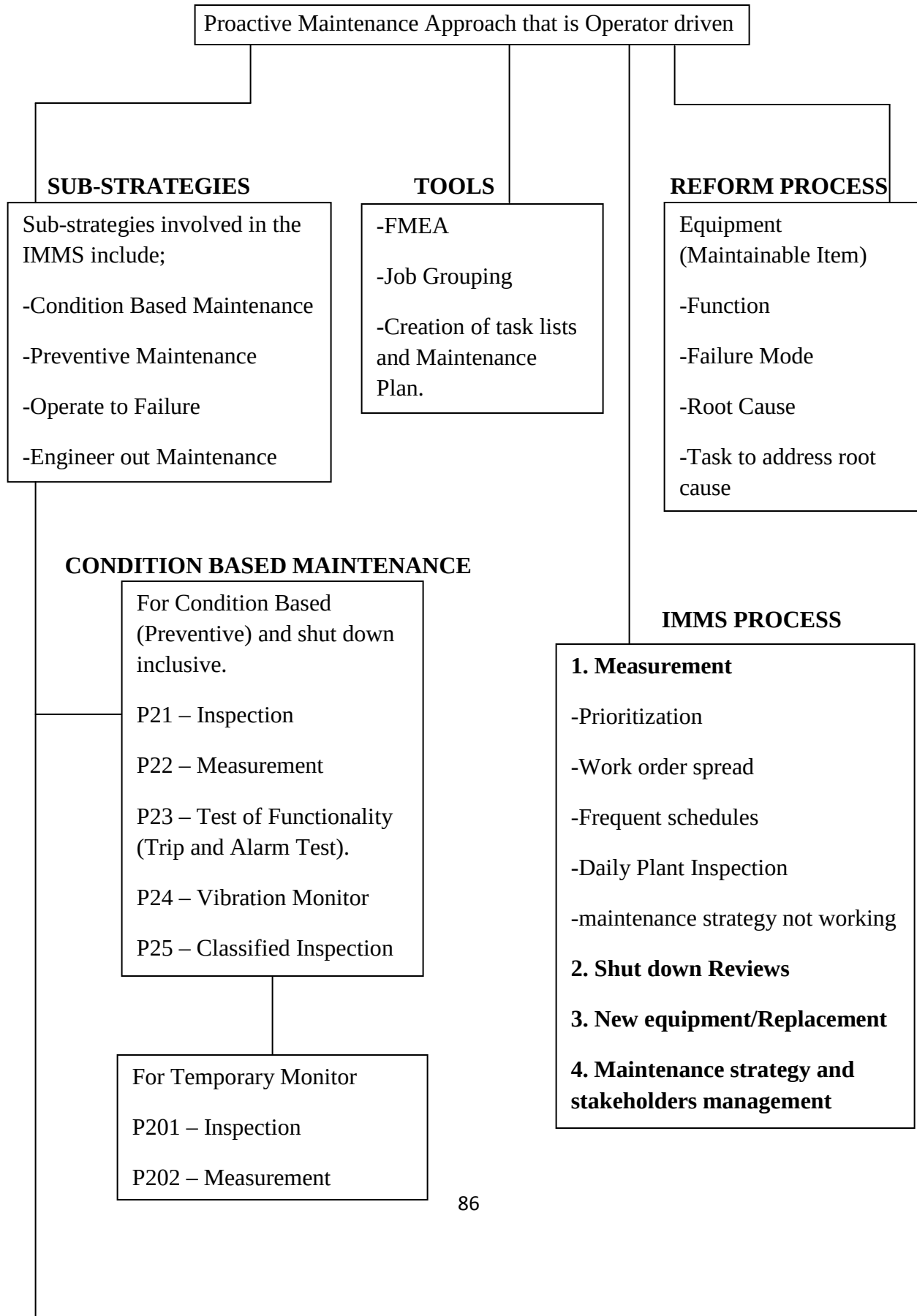
The parametric monitoring and control concept is regarded as an approach to maintenance decision-making, based on understanding of a production process. This is also based on determining the operating conditions of equipment using statistical methods. The essence of this is that not only problems regarding production losses can be solved; but also equipment functionality can be increased.

Finally, the parametric monitoring and control concept can be used quantitatively and qualitatively to analyze and control the production / maintenance process. In other words, it is vital for the operator driven based proactive maintenance approach for the Improved Maintenance Management Strategy (IMMS).

In conclusion, the importance of the Operator Driven based Proactive Maintenance cannot be over-emphasized. Its operator driven concept and the parametric monitoring and control concept will be very visible in achieving and maintaining high overall equipment effectiveness (OEE) in the newly built EGTL plant in Nigeria.

The Improved Maintenance Management Strategy (IMMS) in entity captured the need for creating knowledge, capturing knowledge and sharing knowledge among the maintenance and operator personnel. In addition to this, the parametric monitoring and controlling can be used in obtaining necessary information about operations and maintenance of process equipment conditions.

## IMMS TEMPLATE



## **PREVENTIVE MAINTENANCE**

For preventive maintenance including shutdown.

P11 – Restoration

P101 – Re-alignment

P12 – Replacement

P13 – Summarize

P14 – Calibration

P15 – Lubrication

P16 – Cleaning

## **OPERATE TO FAILURE**

For scheduled Origin, Operate to Failure and Breakdowns.

P31 – Restoration

P32 – Replacement

P33 – Modify

P34 – Re-alignment

P35 – Calibration

P36 – Lubrication

P37 – Repaired

P38 – Online leak sealing

P39 – Contingency

## **MAINTENANCE PROJECT**

P41 – Renewal

P42 – Modification

P43 – Capital

## **FABRICATION**

For Machine, Piping, and Re-tube jobs

P51 – Refurbishment

P52 – Manufacturing

P53 – Rework

P54 – Stores

P55 – External

P56 – Refurbishment affiliates

P57 – Manufacturing affiliates

P58 – Rework affiliates

## **GENERAL NON-PROCESS WORK**

P61 – General Workshop activities

P62 – Training

P63 – Task Team

P64 – Acting

P65 – Meeting

P66 – Administration

P67 – Hired Labor

P68 – Restoration

P69 – Re-alignment

P70 – Calibration

P71 – Lubrication

P72 – Modify

P73 – Replacement

P74 – Repaired

P75 – Cleaning

P76 – Vehicle Refuel

P77 – Process

**(Fig 5a).**

## **CHAPTER SIX**

### **6.0 CONCLUSIONS AND RECOMMENDATIONS**

The research work has explored maintenance strategies, plant availability and maintainability, existing maintenance management strategy in the Nigerian Gas Company (NGC) and finally developed an Improved Maintenance Management Strategy (IMMS). This is because the need to controlling failure of plant equipment has become inevitable.

It is a known fact that maintenance management strategy starts on the drawing board, from the plant conception, through design and construction. The application of maintenance management strategically can enable one to control failure effectively.

The growth of computerization, mechanization and automation has shown that reliability and availability of equipment should be held at high esteem. Increasingly, failures have serious safety or environmental consequences, at a time when standardization in the above mentioned areas are rising rapidly.

In some parts of the world, it has approached the point where organizations either conform to society's safety and environmental expectations, or they cease to operate. In view of this, maintenance has now been regarded as a support process in this Generation manufacturing, mining, and energy industrial framework.

### **6.1 SUMMARY**

The research work helped to develop an IMMS (see appendix 3) that has the potential to provide the EGTL (Escravos Gas-To-Liquid) Maintenance Management, as well as Maintenance Management of other Nigerian petrochemical industries with sufficient maintenance management information necessary for the development of adequate maintenance support system for proper maintenance of gas field equipment.

To appreciate a successful maintenance strategy, as the newly developed IMMS, one requires a good knowledge of equipment failure behaviour (as discussed in chapter 2).

The development of IMMS was borne out of the dire need for an effective maintenance delivery. This is because;

1. Only reduced amounts of breakdown occur in plant when regular checks and maintenances are applied.
2. Maintenance is carried out only when it is most convenient and will cause the minimum loss of production.
3. Excessive length of downtime is reduced, spares and equipment demands are known in advanced and are available when necessary.

| EFFECT OF MAINTENANCE                    |                                          |
|------------------------------------------|------------------------------------------|
| Effective Maintenance                    | Non-effective Maintenance                |
| † Restore system productivity            | † Increased maintenance cost             |
| † Avoid any unnecessary shutdown         | † Reduce the system/equipment life       |
| † Increase the efficiency of equipment   | † Reduce the efficiency of heat transfer |
| † Prolong the system life                | † Induced the unwanted waste             |
| † Improve the overall plant productivity | † Additional cost to clean the system    |
| † Essential to maintain product quality  | † Can affect product quality             |
| † Increases plant profit                 | † Reduced the plant productivity         |
|                                          | † Downgraded the system effectiveness.   |
|                                          | † Decreased plant profit.                |

**Table 6.1-** Effective Maintenance Vs Non-effective Maintenance

## 6.2 CONCLUDING REMARKS

Maintenance process has change drastically from the old concept of “fix-it-when-it-broke” to a more complex approach, which entailed adopting maintenance strategy of a more integrated approach and alignment. The goal of maintenance program is also changing and with the rapid technological development, improvement of equipment and

technology, it will be one of the key aspects of improved maintenance practiced for better productivity, effectiveness and profitability.

All machines require regular and effective maintenance to operate correctly and meet their design specifications. The consequences of ineffective maintenance can be huge in terms of profitability, personnel morale and management time.

Such consequences are often overlooked or miscalculated because machine breakdowns are not just a cause of lost time and potentially missed deadlines but have a direct effect on output, efficiency and thus profitability. Therefore, the importance of effective maintenance to reduce the occurrence of such incidents cannot be overstated.

Nowadays, management has become aware that maintenance will also be part of the investment decision-making, thus prompting managers to take into account the sources of funding. They also take into account the impact of the investment on credit lines and taxes, and not only to focus on upfront cost and depreciation rates.

The newly developed IMMS (see appendix 3) has the potential to provide the management of EGTL and other Oil and Gas industries with sufficient maintenance management information necessary for the development of an adequate maintenance support system for proper maintenance of gas field equipment.

It also has been realized that proactive maintenance, rather than reactive has always yielded a better result in the maintenance strategy adoption. This is in-line with the adage that “prevention is better than cure”. The IMMS is a little further than just proactive maintenance because this proactive maintenance is being driven by the operators of the equipment.

The approach aims to maintain not only machinery but all the elements constituting a manufacturing process, e.g. production/ operation, environmental condition, personnel, methods, material, quality control. Thus, this effective next generation maintenance approach should be adopted to provide and guarantee the required availability of plant machinery and product output quality.

As mentioned earlier, there is no one maintenance strategy for all situations and all companies. Rather the managers require a blend of maintenance management strategies that are right for their operation and for the age of the equipment. The IMMS was carefully blended for the rightful maintenance of gas field equipment for the Escravos Gas-To-Liquid plant in Nigeria.

The IMMS requires an amount of preventative maintenance, as well as an amount of predictive maintenance when equipment ages, along with root cause analysis to eliminate non-random failures. Added to this are added appropriate training, occasional overhaul shutdowns, and replacement of old technologies with new, and so on.

### **6.3 RECOMMENDATIONS**

1. Gas field equipment are suppose to be monitored. This monitoring becomes inevitable because these equipment are exposed to external attacks and atmospheric interferences. As such, these equipment poses risk to the environment and the people living in the neighbourhood.
2. In order to compliment the visual inspection effort of the operator, monitoring equipment will also be used to ensure that equipment are monitored closely and properly. It will be cost effective overall by investing on monitoring systems upgrade so that equipment maintenance will be condition based, other than relying on reliability or probability of failure before undertaking maintenance.
3. Besides external monitoring, there is need that the Operations Control Centre personnel monitors and provides equipment control commands that will communicate with field operations for prompt and appropriate response to alarms and other potential fault detection indication during equipment operation.
4. The System Control and Data Acquisition (SCADA) process need to be upgraded to suit today's technology, while the maintenance management strategy that is in place needs to be improved to accommodate for a proactive predictive maintenance as in the case of the newly developed IMMS.

5. Maintenance department should maintain careful records on the maintenance of important equipment. This is because, it is from these records that breakdown time distribution can be contracted. Varied maintenance policies on total annual maintenance related cost can be determined.

6. Equally, policies which tend to reduce frequency of failures like preventive maintenance, proper instruction of operator and early replacement among others can be determined. So also, the increase in the size of repair crew to help speed up the repairs service can equally be determined.

#### **6.4 SUPPORTIVE SYSTEMS**

Here are some outlines of IMMS cost effective concepts and techniques that promotes plant operation availability.

They include:

1. Operator Driven Objectives
2. Organization
3. Staffing Training
4. Preventive Maintenance (PM)

##### **6.4.1 Operator Driven Objectives**

Every Plant organization has a need to develop direction and establish priorities. This need can be realized through the development of objectives. The objective provides information that increases planning and execution of maintenance strategies.

The Operator driven objective is all about involving the operator in the maintenance of his equipment. It clearly involves the machine operators and maintenance technicians to work together in order to achieve maintenance goals. It makes both parties multi-skilled.

The IMMS ensures that operators and technicians acquire skills from each other giving rise to better understanding of the process and equipment in operations & maintenance (O&M). They shared their valued experience and skills so as to make the right decision at the right time. It reflects a “*self-directed work team*”. See chapter 5 for further elaboration.

### **6.4.2 Organization**

The IMMS organizations for a Plant operation are well structured to facilitate the attainment of set objectives. For an organization that lacks technical support, the maintenance department should be thoroughly staffed under the control of a Plant Manager. This ensures that maintenance do not affect production activities.

Maintenance organizations priorities should be co-ordinated with the plants objectives. Thus, maintenance and production staff should be aware of their immediate and long term needs. Communication channels should be set up to take care of the changing status of Plants direction.

### **6.4.3 Staff Training**

Complicated plant designs entail a wider range of maintenance, thus more training needed. Knowledge and skills helps in the execution of maintenance strategies. Direct teaching gives knowledge. Skills can also be obtained from experience got from simulated or real environment.

Training must thus include experience of practical fault finding on the actual development. Important skill should be well drawn out as well as the development of well structured programme skills. It should be described in objective terms such as knowledge, flexibility, dexterity, money, strength etc.

### **6.4.4 Preventive Maintenance (PM)**

It is a plan for avoiding costly shutdowns and repairs. It should therefore be handled like a project. The above should be cost effective, organized, scheduled, and audited. It also seems as instruction sheet. Preventive maintenance programme should have its own budget. Its progress should be determined by the audit. Modification of unsuccessful programmes should be carried out. The essence of the programme in some areas would be a reference point for future preventive maintenance activity.

## **6.5 AREA FOR FURTHER RESEARCH.**

The Improved Maintenance Management Strategy (IMMS) for gas field equipment has been developed and the awareness behind its applicability as an operator driven proactive maintenance approach has been created.

The need for further research on tools and test equipment most especially for the equipment monitoring devices and the maximum degree of standardization for the newly developed IMMS should be sought while personnel consideration are required for the definition of necessary skills to be acquired and appropriate development of suitable training programmes.

Besides, the need to also investigate the reliability of the monitoring equipment other than relying on the probability of failure before undertaking maintenance is advised. That will help develop a better system of determining monitoring device and equipment failure rate and the required quantity of spares to be allocated in other to prevent equipment failure. It is necessary that a sufficient number of spare are provided for replicable parts, units, module adder to maintain equipment in operational status.

Investigations are required when considering the following factors of the spare policy in order to enhance IMMS objective:

1. Reliability of the units to be spared.
2. The number of units used.
3. The probability of spare availability.
4. Criticality of application.
5. Physical and geographical locations of units.
6. Storage, shipping and handling considerations.
7. Cost considerations.

## **APPENDICES**

APPENDIX 1: Maintenance Audit Report for Nigerian Gas Company (NGC) on gas field equipment maintenance management strategy.

APPENDIX 2: Questionnaire document on the need for an improved maintenance management strategy on gas field equipment.

APPENDIX 3: Developed template on Improved Maintenance Management Strategy (IMMS) for gas field equipment, Escravos Gas-To-Liquid Plant, Nigeria.

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