Optimizing rotating equipment maintenance management in Nigerian refineries

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Preface

This dissertation focuses on optimizing rotating equipment maintenance management in Nigerian refineries.

In analyzing the issue of low rotating equipment availability in the Nigerian refineries, the study employed the use of case studies, questionnaires, observation technique, interviews, internet resources, oil and gas journals and other relevant literatures.

I would like to express my sincere gratitude to my supervisor, Professor Harry Wichers, from the Faculty of Engineering Centre for Research and Continued Engineering Development (CRCED). His guidance and constructive approaches has brought me thus far.

I also gratefully acknowledge the support and resources made available to me by the staffs of the Nigerian refineries and Sasol Synfuels.

My gratitude has no bound to God almighty, because of Him, “I have become like a wonder to many, but He is my refuge and my fortress”.

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Oluwasesan Odeyinde

To my loving parents

Abstract

Nigeria ranks among notable global exporters of crude oil. However, the refineries positioned for providing finished petroleum products have not met this obligation. Plant reliability is a major crisis amidst rising demands for petroleum products. Rotating equipment availability, a critical constituent of a petrochemical plant, is vital to ensuring refinery reliability.

The aim of this research is to:

1. Investigate and identify the causes of rotating equipment failures in Nigerian refineries while also identifying shortcomings in the implementation of current maintenance procedures.
2. Propose a procedure to Manage Rotating Equipment Maintenance Strategy (MREMS) in the Nigerian refineries.
3. Develop a new Internal Job Card system for the rotating equipment maintenance departments of the Nigerian refineries.
4. Propose a model Framework and Approach for Training and People Development (FATPD) amongst other recommendations to optimize rotating equipment maintenance management in the Nigerian refineries.

The research evolved around a case study of four (4) petrochemical industries. This was embarked upon to present empirical data on rotating equipment maintenance management practices. Also, survey questionnaires and interviews were adopted to complement data gathering.

The research presents five (5) core empirical findings. Firstly, minimal maintenance activity takes place outside scheduled turn around maintenance leading to excessive corrective maintenance actions in Nigerian refineries.

Secondly, job card system in the rotating departments of the Nigerian refineries is not efficient.

Thirdly, core skill and competence of bottom level maintenance workforce was discovered to be inadequate.

Fourthly, computer maintenance management system or computer support structures to optimize rotating equipment maintenance in Nigerian refineries have little or zero presence.

Lastly, rotating equipment maintenance management practices in Sasol proves rewarding with the integration of condition monitoring into maintenance program. Computer supports have also been vital to achieving commendable equipment availability. Management commitment, driven by customer focus, ensures that plant reliability is restored on schedule.

A procedure to Manage Rotating Equipment Maintenance Strategy (MREMS) was developed for the Nigerian refineries. This is expected to tackle the issue of low availability of rotating equipment maintenance and also assist maintenance personnel to review or evolve a more specific equipment maintenance strategy based on reliability-centred maintenance principle of condition-based maintenance.

A new Internal Job card is also presented in this dissertation. It would also serve to support the MREMS procedure.

The proposed Framework and Approach for Training and People Development (FATDP) have a huge potential to address skills and competency deficiencies, particularly, for bottom level maintenance personnel at the Nigerian refineries.

Recommendations on the adoption and implementation of MREMS procedure, Internal Job card and FATDP were also presented in this dissertation.

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List of Acronyms

RE	*- Rotating Equipment*
DPR	*- Department of Petroleum Resources*
PM	*- Preventive Maintenance*
RtF	*- Run-to-Failure*
TaM	*- Turnaround Maintenance*
MMS	*- Maintenance Management System*
CMMS	*- Computerized Maintenance Management System*
TQM	*- Total Quality Management*
LPG	*- Liquefied Petroleum Gas*
PMS	*- Premium Motor Spirit*
CBM	*- Condition Based Monitoring*
MTTR	*- Mean Time To Repair*

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RCA	*- Root Cause Analysis*
CF	*- Causal Factor*
PPE	*- Personal Protective Equipment*
CM	*- Condition Monitoring*
UT	*- Ultrasonic Testing*
TM	*- Training Matrix*
CM & R	*- Centralized Maintenance & Reliability*
FL	*- Functional Location*
FMEA	*- Failure Mode, Effect and Analysis*
RCM	*- Reliability Centred Maintenance*
MSR	*- Maintenance Strategy Review*

1. Introduction

Chapter 1 introduces the dissertation research objective, stating the problem and stating the reasons it is being researched.

1. INTRODUCTION

A sudden breakdown of rotating equipment (RE) in refineries can result in excessive facility downtime, immense production loss, missed contract deadlines, costly machinery replacement, as well as safety and environmental incidents resulting from oil or chemical spillage.

A well implemented rotating equipment maintenance management strategy is most needed for rotating equipment so as to achieve desired plant availability and efficiency. With this, problems can be identified and timely actions can be taken before a failure that could possibly result in operational shutdown occurs.

1.1 Problem Statement

Rotating equipment, which makes up the largest contingent of refinery hardware (numerically), is particularly susceptible to component wear, and, consequently, constitutes some of the more important maintenance issues in the refining sector *(http://www.citgo.com).*

Even though Nigeria ranks among top exporters of crude oil, it still depends on the importation of petroleum products. Nigeria imports more than half its daily demand of 30 million litres of fuel *(ACDF, http://www.acdf-assefad.org/whyrefineries.htm).*

"Nigeria's refining capacity is currently insufficient to meet domestic demand, forcing the country to import petroleum products. Nigeria's state-held refineries (Port Harcourt I and II, Warri, and Kaduna) have a combined nameplate capacity (Installed capacity) of 438,750 bbl/d, but problems including sabotage, fire, poor management and a lack of regular maintenance contribute to the current operating capacity of around 214,000 bbl/d" *(Energy Information Administration, Country Analysis Brief, http://www.eia.doe.gov/cabs/Nigeria/Full.html, March 2006:5).*

The maintenance problem in the refineries is quite similar to those faced by the power sector. E. E Okafor (*2007*) stated that these problems emanate primarily as a result of incompetence and poor accountability of the public sector in managing enterprise.

“While the up-stream sector appears to be working well (investments are managed by the foreigner technical partners), the down-stream sector is in a virtual state of collapse” (*E. E Okafor, 2007*).

Even with the huge investments on turn around maintenance, the refineries are still in a state of disrepair *(E. E Okafor, 2007).*

“The barrage of corruption, poor management, sabotage and lack of the mandatory turn around maintenance (TAM) every two years, has made all the four refineries inefficient, thereby operating at about 40 % of full capacity, at the best of times” *(Alexander’s Gas & Oil Connections).*

Many Nigerians worry that there is no accountability and transparency in the running of the refineries.

These maintenance issues in the Nigerian refineries have often resulted in the country having to depend heavily on importation of finished petroleum products, even though it has been well positioned as a major exporter of oil and gas.

“First of all, it is a shame that we are planning to refine our crude oil in Hungary and Romania that are supposed to be poorer than Nigeria and these two countries have no oil deposits beneath them, but are able to maintain and sustain refineries in their countries while Nigeria, the supposedly 5th largest producer of crude oil in the world has no functional refinery” *(Temple Chima Ubochi)*.

This consequently drove up the price of petroleum products in Nigeria. Government subsidies on petroleum product became the only means many Nigerians could afford these products.

Ineffective refineries and distributions systems have led to giant subsidies to keep gasoline prices at low levels in the local market (*afrol News - Refinery privitisation hastened in Nigeria, http://www.afrol.com/articles/10668*).

The petrochemical plants are problematic *(Afonja, 2003; Kupolokun, 2005).*

Aigbedion and Iyayi (2007) both agreed that the refining sector in Nigeria is "characterized by supply uncertainty, fuelled by the mismanagement of the nation's refineries, endemic corruption, lack of transparency, direct government interference and bureaucratic processes".

1.2 Scope

The Nigerian refineries work below designed capacity for most of the time, and have even been shut down on several occasions because of it not being properly maintained *(ACDF, http://www.acdf-assefad.org/whyrefineries.htm)*.

The broader intent of the research is to provide a procedure to manage rotating equipment maintenance strategy in the Nigerian refineries as a positive step in addressing low availability of rotating equipment.

Current maintenance practices will be investigated and recommendations will be provided accordingly.

Aside the field exercise to be embarked upon in the Nigerian environment, the research will also focus upon proven methods and strategies adopted by Sasol Synfuels, South Africa.

These studies, with the summation of expert's literatures, will form a firmer foundation for conclusions and recommendations to be drawn accurately.

1.3 Research Goal and Objective

The goal of this research is to advance the field of rotating equipment maintenance management in Nigerian refineries. The objectives include:

- To provide the Nigerian refineries with an effective procedure to manage rotating equipment maintenance strategy.

- To address the low availability of rotating equipment by investigating the causes of rotating equipments failure in Nigerian refineries while also identifying shortcomings in the implementation of current maintenance procedures.

- To proposes a model framework and approach for training and people development (FATPD) amongst other recommendations to optimize rotating equipment maintenance management in the Nigerian refineries.

1.4 Research Outline

This dissertation work is outlined in six chapters. Chapter two of this dissertation contains relevant literature of existing work that aids to understand the maintenance management culture in the Nigerian refineries.

Chapter three provides a detailed explanation of the research design and methodology, and gives insight into how it was conducted.

The fourth chapter presents the results and findings of the empirical study done at the Nigerian refineries.

Chapter five analyses the results and findings of the research and thereby presents interpretations in line with relevant theory.

An overall outcome of the dissertation, recommendations and conclusion, is presented in chapter six.

1.5 Beneficiaries

Overall, the research goal will help rotating equipment users in Nigeria in many ways by achieving the following objectives:

1. Reduced rotating equipment failure rates and improved productivity and efficiency of the operating department.

2. Establish a standard approach for maintenance strategy development.

3. Ensure that rotating equipment maintenance personnel are equipped with all responsible skills for job performance.

1.6 Definition of Terms

- Maintenance - the sum of activities performed to protect the reliability of the plant (Tom Lenahan, 1999, p.3).

- Optimization – the process of improving the application's performance. (Microsoft Access 97 qiuck reference glossary).

- Preventive Maintenance (PM) – as defined by Patton (1983:XV) means all actions intended to keep durable equipment in good operating condition and to avoid failures.

- Run-to-Failure (RtF) Maintenance – This could also be referred to as "crisis maintenance". Philosophy is just to allow equipment to run until it fails.

- CMMS – This is an indispensable management tool for managing and preservation of equipment or facilities. (Bruton, 2001, www.adbourne.com.au).

2. Literature Review

Chapter 2 contains relevant literature of existing work that aids to understand the maintenance management culture in the Nigerian refineries.

2. Literature Review

2.1 History of the Nigerian Refineries

The holding company that overseas the activity of the Nigerian refineries is the Nigerian National petroleum Corporation. The Nigerian refineries are classified as a downstream function of this corporation.

Other units of the NNPC includes; Finance and Accounts; Exploration and Production; and Corporate Services.

NNPC is responsible for the four (4) solely-owned government refineries currently in Nigeria.

The table below (table 1) depicts a profile of the Nigerian refineries

Location	Commissioning Date	Capacity (epd)	Products
Port Harcourt	1965	60,000	Fuel oil, Petrol, Diesel and Kerosene
Warri	1978	125,000	Polypropylene, Petroleum gas, Carbon black
Kaduna	1980	110,000	Base Oil, Fuel Oil, Petrol, Diesel and Kerosene
Port Harcourt	1989	150,000	Fuel oil, Petrol, Diesel and Kerosene
Total Capacity		445,000	

Table 1 *– Profile of the Nigerian Refineries*

2.2 History of Maintenance

The history of maintenance management is, perhaps, not as old as the practice of maintenance itself. Right from the time man began falling trees and building up assets, an urgent need relating to keeping these assets functional have always been an issue. "That stone axe was a real pain in the neck when it wasn't sharp; so if you owned it, you needed to look after it" *(http://www.groundswell.com.au/articles/mair, Maintenance Journal, Vol. 17 No. 1, February 2004)*.

"The inception of maintenance is dated back to ancient civilization when the development of effective irrigation agriculture to meet food demands and contain famines became necessary. This had an organizing effect on the maintenance of canals which was inevitable to keep water levels adequate. Later on, introduction of the use of iron made it possible for man to invent more sophisticated weapons which resulted in conflicts such as occupation of other empires motivated by military capabilities" *(http://history-world.org/civilization_end%20of%20early%20period.htm)*.

Until recently, maintenance has not always been considered a main-stream function. It has always been seen as a negligible sub-system of production and probably, a necessary and an unplanned overhead.

Maintenance's primary responsibility is equipment reliability. In the present climate of increased globalisation and the obligation to reduce production costs, the assets of a company – capital, buildings and machinery, - are much more critical than ever before. Consequently, the importance of managing assets efficiently and effectively has become a business reality.

However, the maintenance history of the Nigerian refineries only reflects that maintenance has not been prioritized accordingly. "The four plants are grossly inefficient and unprofitable, after years of neglect. They have been shutdown frequently because of accidents resulting mainly from lack of maintenance" (*APS Review Downstream Trends, November 23, 1998)*.

2.2.1 Maintenance Management Philosophy

Maintenance Management involves devising and setting in place methodology and resources, for the planning, organization and control of exercises related to maintenance of an equipment or facility.

Dr. Alan Wilson *(1999:160)* describes the maintenance philosophy as an expression of the role of the maintenance function within a company and the basic approach it will take in fulfilling it.

Anthony Kelly *(1989:1)* states that one way of expressing the objective of an industrial organization is that it exists to optimize its long term profitability – uses plant and employs labour to convert raw materials of a relatively low value into an output of a higher value.

To align effectively to this objective, it is a vital necessity that the maintenance management team evolve a policy document or statement. This would describe in broad terms, the direction in which the maintenance management team intends to lead the maintenance department. The policy document would start, mostly, with a general philosophy and vision of the maintenance organization and should go on to address the policy of individual functional blocks that makes up the maintenance cycle within the organization.

Within an industry, it will be accurate to regard maintenance as a sub-system charged with the responsibility of delivering maintenance services. Anthony Kelly *(1989:52)* used the figure below (Fig. 1), to explain a methodology for understanding maintenance management.

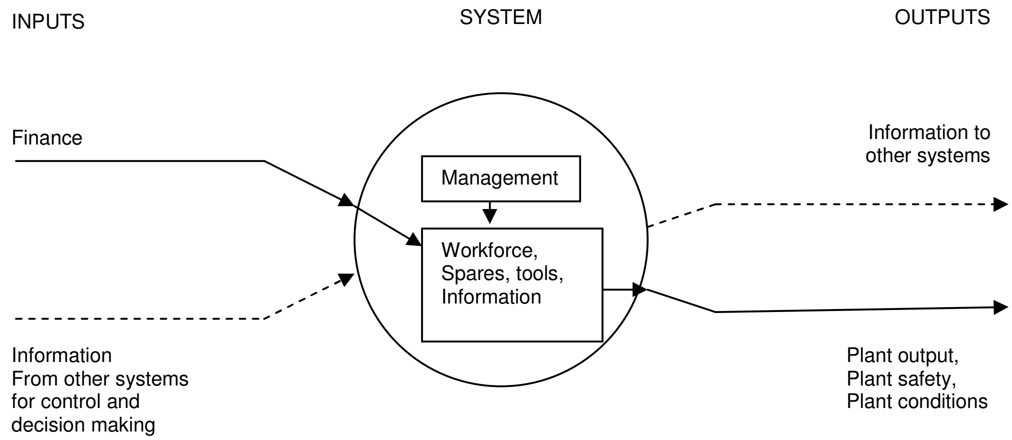

***Figure 1 –** Function of a Maintenance System*

This basic description of the maintenance sub-systems positions management at its centre. It controls and determines how the inputs from other systems should be handle and also the system outputs.

2.2.2 Maintenance Management System

Campbell and Jardine *(2001:38)* describe maintenance as a business process turning inputs into useable outputs. It is, hence, vital that this process be manage for profitability. Management System (MMS) is an approach to ensuring that maintenance activities are well planned, organized, monitored and evaluated for profitability.

"This management system can provide more than management information alone. There are provisions for setting objectives and standards to aid in planning the work, for determining resource requirements, for developing the performance budget, and for scheduling, reporting, and controlling the work. Basically, the MMS is a process for more effective and efficient planning, organizing, directing, and controlling of maintenance work. It begins with setting specific, quantitative work objectives and then follows through the complete management cycle to ensure that actual performance is consistent with objectives" *(http://www.crab.wa.gov/maintenance/Documents/MMProjectReport1.pdf)*.

2.2.3 Objectives of a Maintenance Management System

The primary objective of a maintenance management system is as follows *(http://www.crab.wa.gov/maintenance/Documents/MMProjectReport1.pdf)*:

- Make the best use of budgeted funds, man power and equipment.
- Make available data for maintenance planning.
- Investigate unfunded maintenance backlog for service.
- Methodologically determine maintenance needs or failures.
- Prioritize maintenance activities.
- Maintenance record keeping of corrective procedures, project expenditures and milestones.

2.2.4 Computerized Maintenance Management System (CMMS)

A computerized maintenance management system (CMMS) can be described as a management tool, mostly in software form, that aids monitoring of operations and maintenance exercises. The benefit of CMMS (also often referred to as computer aided maintenance management system) comes from the computer's ability to hold vast quantities of information, retrieve it quickly, process it at high speeds and present it in a form which is of most value to users *(Eade, Wilson, 1999:716)*.

From the foregoing, Eade and Wilson *(1999:716)* says it will be accurate to say computer application in maintenance can allow for easy and quick access to precise data and as such valuable time is being saved.

"With card or paper files, if work was to be separated by urgency, reason, shutdown requirements and so on, it meant that multiple files must be maintained. However

CMMS software made this kind of manipulation of data very simple ….” *(http://www.idcon.com/article-CMMS-Software-Work-Order-Coding.htm, CMMS Software Work Order Coding, Armstrong, 2005:Idcon Inc.).*

2.2.4.1 Selecting a CMMS

If a CMMS is selected for use by a maintenance department, this would be step in the right direction in improving maintenance efficiency. However, maintenance management would first have to arrive at making critical decisions such as:

- Would computerization of maintenance management be appropriate for our facility?
- Which software will be most appropriate?

The choice of a system should be predetermined by the function it intends to serve. “A typical CMMS functions may include the following (http://www.ductbuster.com/):

- Work order generation, prioritization, and tracking by equipment/component.
- Historical tracking of all work orders generated which become sort able by equipment, date, person responding, etc.
- Tracking of scheduled and unscheduled maintenance activities.
- Storing of maintenance procedures as well as all warranty information by component.
- Storing of all technical documentation or procedures by component.
- Real-time reports of ongoing work activity.
- Calendar- or run-time-based preventive maintenance work order generation.
- Capital and labour cost tracking by component as well as shortest, median, and longest times to close a work order by component.
- Complete parts and materials inventory control with automated reorder capability *(http://www.ductbuster.com/)*.

Another factor that greatly influences the selection of a CMMS package for use is the kind of maintenance strategy in operation within the maintenance organization.

2.3 Job Card

Coetzee J. L (1997:356) stated that one of the primary means of communicating with the CMMS is the job card.

If it is generated by the system, it communicates effectively with the supervisor and mechanic the details of the work that should be done and informs on any necessary preparations and the criticality of the task.

"It also communicates to the system what work was done, the time it took, resources used, cause(s), defect(s), sub-assemblies (rotables) exchanged and any comments regarding the condition of the equipment" *(Coetzee J. L 1997).*

It is important that these feedbacks are stored in a computer database for record keeping and to serve as inputs during strategy review or development.

2.4 Evolution of the Need of a Maintenance Strategy

The key to any maintenance activity is its supervision. Maintenance management has long been introduced to manage this process. The early man employed skilled craftsmen or individuals to keep weaponry intact hereby heralding the concept of maintenance without knowing. However, it has since taken a newer dimension since man physical assets such as houses, ships and agricultural equipments.

Anthony Kelly *(1989:28)* noted Parkes summary of maintenance situation in the last century:

"Machinery – whether for agricultural, transport, manufacturing or other purposes – was largely uncomplicated and robust. Even a century ago there were, of course, examples of mechanical ingenuity which made maintenance an interesting challenge; such machinery as Jacquard weaving looms and printing machines had complex mechanisms manufactured and operating to fine limits. But until a decade or so ago the philosophy of built-in obsolescence was far from widely accepted in Britain and

machines were designed and built to last. In turn this meant that it was usually worth repairing any part of the machine which became defective. Often these repairs necessitated a manufacturing job by the craftsman" – Parkes (1970:1).

Over the years, variations of documented strategies have evolved to aid in the management of maintenance.

2.4.1 Preventive Maintenance

As the name implies, it is aimed at preventing failure from occurring. Planned, scheduled performance of repairs and adjustments that results in fewer major repairs and extends the useful life of equipment and facilities (Maintenance Management System Handbook, http://www.fws.gov/policy/MMSHB_AppA.pdf). Apparently, the focus of preventive maintenance (PM) is reliability and optimization of equipment or facility service life *(O&M Best Practices Series, 1999:33)*.

An advantage of this strategy is that it takes into consideration guidelines to ensure and control normal operation to keep in line with its primary focus on reliability.

2.4.2 Condition-Based Maintenance

This is a preventive maintenance that is triggered by the knowledge of the condition of equipment from continuous monitoring. "CBM is a maintenance approach where the equipment is serviced based on the actual or current operating conditions as determined by various devices, tools or measurements. A properly implemented CBM program will predict the onset of failure early enough to allow the equipment to be shut down and serviced as required" *(http://findarticles.com).*

The advantage of cost saving using CBM reflects on two major areas: Predicting failures and preventive maintenance.

2.4.3 Run to Failure (RtF) Maintenance

This is sometimes linked to corrective (failure) maintenance. Run-to-failure maintenance is also popularly referred to as crisis maintenance, or reactive maintenance. Equipment is not disengaged form the process for maintenance. However, unplanned downtime, damaged machinery, and overtime expenditure have always resulted to relatively high costs (Dundics, 2000:54-61).

2.4.4 Turnaround (TaM) Maintenance

"This is a term meaning a scheduled large-scale maintenance activity wherein an entire process is taken off stream for an extended period for comprehensive revamp and renewal. This operation involves a lot of preparation, and many precautions are taken because this is a dangerous operation, especially at start-up" (http://en.wikipedia.org/wiki/Turnaround).

This view is corroborated by Lenahan *(1999:9)* who stated that ineffective management of the event can add more to its cost than any other factor.

This has been the case with the issue of turnaround maintenance in the Nigerian refineries – "The best way to put to rest the notorious issue of Turn Around Maintenance (TAM) would be to improve the refinery management approval limits to enable them do much more work outside TAM, and thus reduce the TAM work load. The TAM budgets and duration would then reduce to the industry standard of less than US$ 50 million and four weeks, respectively" *(Vanguard Online Edition, October 22, 2007)*.

2.4.5 Reliability-Centred Maintenance (RCM)

John Mouraby, Trevor Foltyne and Alan Wison *(1999:283)* agreed that RCM is a process that can be used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context.

Hence, the first step to implementing an RCM process will be to define the function of each asset in its operating context in line with its expected performance standard.

RCM combines some other maintenance procedures resulting in a more reliable strategy.

2.4.6 Condition Monitoring

Condition monitoring has been defined by Callacott R.A *(1980:173-178)* as follows:

“The performance of regular comparative measurements of suitable parameters which respond to changes in the behavioural condition of a component, sub-system or system. An indication of past alterations may be extrapolated to monitor and appraise possible future trends in deterioration.”

Anthony Kelly *(1989:36)* stated that the objectives of a condition monitoring policy were outlined by Birchon D. *(1972)* to be:

- To reduce the risk of unexpected breakdowns.
- To predict the amount of maintenance required at pre-determined periods in order to maintain a given level of reliability.
- To diagnose the state of health of a defective machine and thereby specify the work that must be done to bring the machine back to a pre-determined level of reliability.

Dawson B *(1976)*, as reported by Anthony Kelly *(1989)*, categorized inspection procedures into:

- Simple inspection (qualitative checks based on look, listen and feel).

- Condition checking (done routinely and measuring some parameter which is not recorded but is only used for comparison with a control limit).
- Trend monitoring (measurements made and plotted in order to detect gradual departure from a norm).

2.5 Staffing and Training for Preventive Maintenance

Implementing a preventive maintenance program demands competent and adequate staffing. In the Sasol Synfuels' rotating equipment maintenance department, engagement is most times based on prevailing and anticipated skill requirements backed by a vision for people development.

Wilson and Booth (1999:354) also agreed that It is essential to have a highly developed, trained and motivated workforce (including management) contributing to their full potential as a team. As a matter of fact, training is incorporated into maintenance planning in Sasol Synfuel as a vehicle to drive continuous improvement.

2.6 Planning

Planning requires a holistic approach to ensure all possible maintenance issues are identified within proposed equipment purchase and maintenance. Maintenance cost can be significantly reduced if maintenance issues are projected and evaluated in the planning stage of maintenance activity. From the foregoing, the responsibility of a planner involves the ability to project into the future (with the aid of information and instructions) and anticipate the resource and organizational requirements of a maintenance task or assignment.

Planning can be said to cover two indispensable areas namely *(Wilson, 1999:429)*:

- Resource planning and,
- Organizational planning

“Resource planning involves the preparation of the work activities into defined and scheduled tasks and the organization and co-ordination of the personnel, spares and instruments essential for execution. Organizational planning plays a significant role in identifying how resources will be deployed in a most cost effective manner to achieve client goals” (Wilson, 1999:429). To achieve this, consideration need to be given to the magnitude, scope and technicalities of maintenance service to be rendered, and of the organizational structure, materials supply and finances.

An overview of the typical activities needed for structuring the planning procedures can be seen in the figure below (Fig. 2).

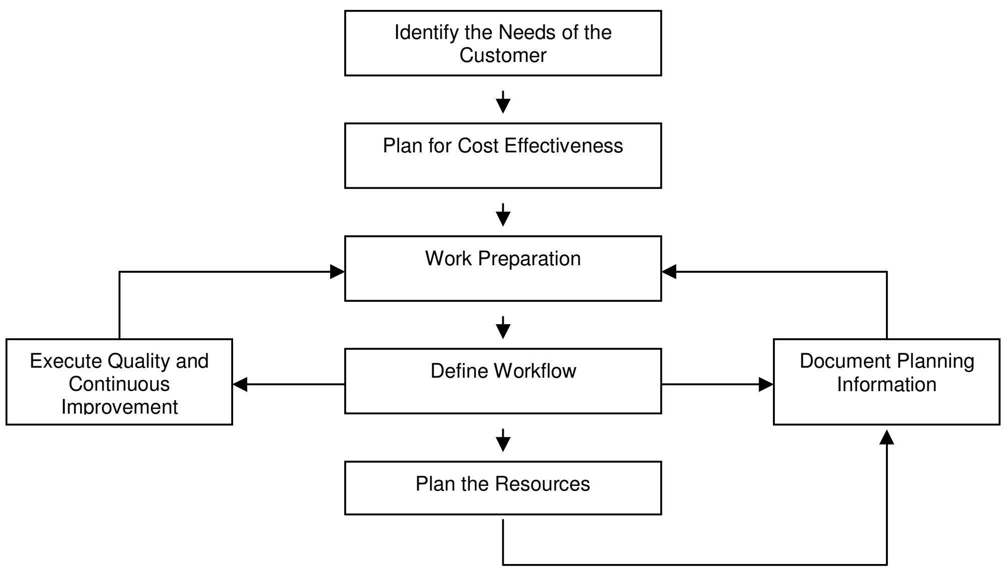

***Figure 2** – Maintenance Planning*

More importantly, the best approach towards the planning process is to consider available alternatives to the approach that has been adopted to seek which would yield a better service delivery, often, with respect to cost.

Formalities to seeking approvals for the development of maintenance activities are also a serious issue in the Nigerian refineries. “Because of continued maintenance delays, various units at the four refineries are prone to sudden breakdowns. Matters are complicated further by red tape, political interference and incompetence at PPMC" *(APS Review Downstream Trends, August 6, 2007)*.

2.7 FMEA and Root Cause Analysis

The Failure Modes and Effects Analysis (FMEA) seeks to identify potential equipment or system failure and their impacts (effects).

"FMEA is applied in maintenance tasks, such as reliability-centered maintenance (RCM) and risk-based maintenance (RBM). The effects are generally classified as operational (production), environmental, and safety effects. This procedure is used to plan tasks to find minimum ratio between maintenance cost and cost due to failure effects" *(SKF, Glossary of "Maintenance Terms").*

Root Cause Analysis is a problem solving technique that seeks to identify the root causes of non-conformances or undesired events.

Winter and Zakrzewski *(1984:17)* argues that the primary need in a successful preventive maintenance program is for problem solving and analytical ability and that no preventive maintenance system of procedure will appreciably reduce maintenance costs or **equipment downtime** unless it is accompanied by problem solving ability.

2.7.1 Root Cause Analysis – The Team

Dean L. Gano *(2007)* argues that every individual has a peculiarity that makes that individual unique and that this uniqueness is often evident in perceptions, values and beliefs, and that this leads us as individuals to reach a different conclusion even when disposed to the same facts and evidence.

What is a team?

"A team is a small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable" (Katzenbach and Smith, Team Building Encyclopaedia,
http://www.informaworld.com/smpp/content~content=a792044211~db=all~tab=content~order=title).

There ought to be no anomaly in the selection of a RCA team. The selection of this team often times influences the conclusion of a RCA. "When a RCA team is made up of experts, the team could tend to focus almost exclusively on addressing the physical causes of problems. This can be attributed to their specialist knowledge in this area, and the biases that this brings to the problem solving process" *(http://www.plant-maintenance.com/).*

This is not to say that there is no place in effective root cause analysis for specialists. However, the RCA team should also open up to accommodate technical diversity while allowing experts to lead teams on events of area of specialization.

The most effective sustainable solutions as stated by Latino and Latino *(1999:87-88)* will need to focus on the latent root cause of undesired outcomes and furthermore, that these causes can be categorized into three (3) major classes:

- **Physical Root Causes** are the component-level roots or tangible roots.
- **Human Root Causes** can be responsible for activating a physical cause of an undesired outcome.
- **Latent Root Causes** sometimes referred to as organizational root causes. These are organizational resources or systems that are used as tools by management for decision making.

2.8 Maintenance Audit

"The maintenance department plays an indispensable role in attaining the objective of optimizing productivity and cost effectiveness because this would ascertain the effectiveness of the maintenance department and to identify its status and that of its maintenance activities and how they are carried out" *(http://www.forcetechnology.com/en/Header/Download/Product+sheets/Integrity+Management/2488-1-en.htm, Asset Integrity Management and Consulting, Page 1)*.

Brissendon, Idhammar and Wilson *(1999:832)* agreed that the audit should measure the effectiveness of normal operations that are in place and reveal whether improvements are required.

2.8.1 Importance of Maintenance Auditing

Before any control system can be adjudge to be functionally successful and efficient, performance measurement would really be the key for it to earn that verdict. The merits of this verdict will be on the basis that the measurements tells what improvements are needed to enable one attain desired goals and objectives.

Maintenance auditing is nothing different from that. "It is well known that the maintenance manager who is allowed to implement his maintenance strategy and develop his operation without hindrance is an endangered species – external influences can cause even the best laid plans to go astray" *(Alan Wilson, 1999:832, http://www.reliabilityweb.com/excerpts/index.html)*.

2.8.2 Physical and Systems Audit

Before any maintenance audit can be measured to be hundred percent, there are two areas that needed to be focused upon:

- The physical audit
- The systems audit

The physical audit is a representation of the physical evidence of maintenance performance, responsibilities and services. The success of a physical audit will be measured against plant availability and operability of the facilities of a maintenance organization. The systems audit examines what systems have been allocated to the attainment of the evident maintenance performance and results.

2.9 Accountability and Transparency

Undue interference of government in the affairs of the Nigerian refineries during the military regime has terribly crippled the refinery operations. This evidently affected refinery management.

As reported by James Rupert of the Washingtonpost "In Nigeria, corruption isn't part of government, it's the object of government, said a Nigerian political scientist who asked not to be named”.

“The critical issue here, according to watchers of the sector, is maintaining equilibrium, between the need for due process, transparency and accountability on one hand, and the needed empowerment for speedy and proactive response to the technical problems of running a refinery on the other hand - goals which should not necessarily be mutually exclusive” *(Vanguard, 2008).*

3. Methodology

Chapter 3 provides a detailed explanation of the research design and methodology and gives insight into how it was conducted.

3. Introduction

3.1 Analysis of Dissertation Topic

"That which we call a Rose by any other name would smell just as sweet" (William Shakespeare).

Regardless of the conclusive statement coined by Shakespeare that a thing cannot be what it is not but only what it is, it can be valid to say any research work without a thorough concept understanding would result in the unexpected. Hence, it is important to briefly enumerate and define the key terms of the dissertation topic for this research to be properly focused.

The primary focus of this research is rotating equipment maintenance management optimization as it relates to rotating equipment in Nigerian refineries. *Chapter 3.5* introduces viable recommendations in this direction.

3.1.1 Optimization

Optimization is applied in virtually all areas of human endeavours. Mathematically, this is described by Sci-Tech Dictionary (www.sci-tech-today.com) as the maximizing or minimizing of a given function possibly subject to some type of constraints. "From a different source, a systems engineering definition of it describes optimization as the efforts and processes of making a decision, a design, or a system as perfect, effective, or functional as possible" *(McGraw-Hill's Engineering Companion – Google Books Results)*. This systems engineering concern of optimization rightly describes the concept of optimization in this research.

Optimization is a process that seeks the best solution given competing priorities and this entails setting priorities and making compromises for what is most important *(Campbell and Jardine, 2000:239-254).*

3.1.2 Rotating Equipment

This includes process equipment such as pumps, gearboxes, compressors and turbines, the function of which is based on rotational motion *(http://www.citgo.com/CommunityInvolvement/Classroom/Glossary.jsp)*.

Clearances and alignments (often required to be within hundredths of a millimetre), of these equipment types, is so critical that it often affects equipment performance and reliability. Far more, the diagnostic techniques to determine the condition of rotating equipment are far from mature, and reliable prediction of the condition is difficult.

3.1.3 Optimizing Rotating Equipment Maintenance Management

Management is the umbrella over all operational aspects of a facility *(CAN, www.cna.com)*. The objective of every maintenance program for equipment is to make available a good equipment use for a stipulated period of time while still being cost effective.

Determining the equipment to be maintained and at what maintenance level or time is decisive. Wilson and McAllister *(1999:147-153)* states that in maintenance management there are major challenges in understanding and making decisions on a wide range of issues which involve technology, people and operations.

3.2 Research Design

Research can be defined as scientifically and methodically delving into the unknown in order to provide information for solving problems (http://www.referenceforbusiness.com/management/Pr-Sa/Research-Methods-and-Processes.html).

This study is based on the need of user's of rotating equipment in Nigeria, specifically, the Nigerian refinery sector.

Selecting a right research approach to deliver the research goals and objectives was not be compromised. The foundation of the study will rely on case studies of the Nigerian refineries. As Zikmund *(2000)* suggests, explanatory research is a useful *preliminary* step that helps ensure that a more vigorous, more conclusive scientific study will not begin without an adequate understanding of the problem. This idea is driven by the problems to be investigated based on proven theories and dissertation purpose.

This research question forms the base of the investigation embarked upon. It is also intended to adopt a scientific approach/method. To narrow down, a quantitative method of research, such as the use of survey, may also be adopted. Web based research will not be spared. The data that shall be presented in this research report shall be the result of the above methods of investigations. Hence this research method encompasses different angles of approach: Mixed methods. This research will be non experimental (ex-post-facto) in design. This form of scientific exploratory research will aim to source primary data from the field by direct communication with respondents and observation both, in Nigeria and South Africa. Working in Sasol environment would also enable me to observe proven facts concerning rotating equipment management. I may combine with a form of survey only where necessary.

In order to accomplish the purpose of this research, there is one basic research problem that needs to be defined and analyzed in the Nigerian refineries:

'How can rotating equipment maintenance management be optimized in the Nigerian refineries?'

An attempt to define, analyze and solve this research problem has emanated a few research questions that should be focused upon.

1. Do maintenance personnel in the Nigerian refineries perceive the maintenance management strategy and its implementation as adequate?

2. What are the technical training needs that can enhance maintenance and its management?

This research questions will be the pivot of my qualitative and quantitative study at the Nigerian refinery and at Sasol Secunda.

Validation of my research outcomes will be against proven theories and my studies of the Sasol Synfuels system. To further validate research findings, questionnaires were also administered to experts.

3.3 Data Collection Method

The research evolved around a case study of four (4) petrochemical refineries with a critical focus on three (3) Nigerian refineries as a critical case study.

3.3.1 Identification of Case Studies

Distinguished researcher, Yin *(1981)*, states that the application of the case study method to research is not limited to qualitative data since the evidence can be obtained from fieldwork, observation and archival records.

Feagin and Sjoberg *(1991)* describe the case study method of research as an ideal research methodology when a holistic and in-depth investigation is to be carried out.

The three (3) case studies identified in Nigeria for the purpose of this research are;

- Rotating equipment department of KRPC (Kaduna Refining and Petrochemical Company).
- Rotating equipment department of WRPC (Warri Refining and Petrochemical Company) and,
- Rotating equipment department of New PHRC (Port Harcourt Refining Company).

The case study adopted for data and result comparison is the rotating equipment department of Sasol Synfuels in South Africa.

Documented evidences would mainly be qualitative and if need be, also quantitative. Methods that would be used to assemble data include observation, the use of questionnaires and interviews.

3.3.2 Observation

The application of this method of data gathering in the Sasol Synfuel environment yielded outstanding results unlike the Nigerian environment. The reason for this can attributed to my unrestricted access to respondents as a result of my eligible presence as a worker within the Sasol Synfuel environments.

3.3.3 Questionnaires

This instrument has also been used to gather descriptive and qualitative information on the current practices of rotating equipment maintenance management. That is, survey was employed to complement and support the cases investigated in this study.

The adopted questionnaire was designed specifically for the Nigerian study environment. Questionnaires were distributed among the three (3) refineries in Nigeria. The population target was maintenance managers, engineers and supervisors with a projected sample population of 80 persons.

The target group were managers, engineers, supervisors. The questionnaire is made up of fifty-one (51) questions and is six (6) pages long.

The work of this questionnaire is to investigate and receive feedbacks on rotating equipment maintenance management problem(s) and performance in the Nigerian refineries.

An accompanied questionnaire letter, with samples of the survey questionnaire adopted for this research is as shown in *Appendices A and B* attached, respectively.

The design of the questionnaire evolved with contributions from experts with vast experience in the field of rotating equipment maintenance management. In other to prevent bias in terms of responses, the questionnaire is subjective in nature.

3.3.4 Interviews

The use of interview was employed effectively in both the Nigerian study environment and Sasol Synfuels. Interviews conducted with managers and supervisors in the Sasol Synfuels environment is not as formalized as in the Nigerian environment. The procedures attached to having an interview in the Nigerian environment has proven very time consuming. However, major views received on critical issues have generated broad based answers to prodding research questions.

3.4 Rotating Equipment Availability – (Nigerian Refineries vs. Sasol)

Comparison of the Nigerian refineries and Sasol Synfuels, Secunda, will be drawn under this section in *chapter 4.*

Basis for comparison will be rotating equipment availability in the Nigerian and Sasol refineries. Variances will be highlighted and drawn under the following sub-sections:

- Maintenance Strategy
- Internal Job Card
- Root Cause Analysis
- Computerized Maintenance Strategy

3.4.1 Maintenance Strategy

Rotating equipment maintenance management practices and procedures in Nigerian refineries and Sasol will be investigated.

Rotating equipment maintenance records of both companies will also provide valid contributions to data gathering.

The Department of Petroleum Resources in Nigeria will also be a valid source of data gathering for maintenance practices in the Nigerian system.

Issues identified in the Nigerian refineries and Sasol will be highlighted in *chapters 4 and 5* of this dissertation.

3.4.2 Internal Job Card

The effectiveness of the current internal job card in both systems (Nigerian refineries vs. Sasol) will be investigated. The research instruments; observation, interviews and questionnaires will also be used to gather information in this regard.

Recommendations will be drawn based on the outcome of the above investigations.

3.4.3 Root Cause Analysis

The application of Root Cause Analysis will be investigated in the Nigerian refineries and Sasol. This will be done by interviews and questionnaires.

Recommendations will be made based on the outcome of the research.

3.4.4 Computerized Maintenance Management System (CMMS)

The application of CMMS in the rotating equipment maintenance department of the Nigerian refineries and Sasol will be investigated.

The effectiveness or ineffectiveness of this application in both environments will be highlighted from research findings.

Recommendations will be made accordingly.

3.5 Optimizing Rotating Equipment Availability – Recommendations

The presentation in this section highlights suggested solution to increase rotating equipment availability in the Nigerian refineries.

An overview of the suggested solution is presented in the following sub-sections.

3.5.1 Manage Rotating Equipment Maintenance Strategy (MREMS) Procedure

Research findings confirm that the availability of rotating equipment is dramatically improved by following a RCM based maintenance strategy instead of a "run-to-failure" maintenance strategy.

"Sasol Engineering Manager, Johan Claassen, affirmed that the Sasol plant uses Hart communication for continuous full-time monitoring of 3,500 Hart-enabled instruments and control valves. One of the plant's main objectives was to move from a "run-to-failure" maintenance philosophy to a predictive maintenance strategy. The goal was to lower fixed costs and to avoid or prevent unscheduled plant shutdowns by using device diagnostics to warn of pending problems" *(Wes Iversen, Automation World).*

"A Reliability Group was established to coordinate and facilitate the adoption of such methods, and a more systematic roll-out of RCM and RBI studies ensued" *(Vitalink, 2004).*

"That goal has apparently been met. Helson said that $1.66 million in savings for Sasol came through the avoidance of three plant shutdowns that would have been unplanned" *(Wes Iversen, Automation World).*

The MREMS procedure is expected to assist rotating equipment departments in the Nigerian refineries to evolve a more effective maintenance strategy based on reliability-centred maintenance principles of condition based maintenance. This is presented in *chapter 5* of this dissertation.

3.5.2 New Internal Job Card

According to Eagle environmental *(2007),* even inspections are initiated to a job card system to ensure effective response and follow-up actions. The use of the job card system in Sasol is quite extensive.

A design of a new job card is expected depending on the results and findings of this dissertation. The findings will be outlined in *chapter 4*.

The new job card will be presented in *chapter 5* of this dissertation.

3.5.3 Training and People Development

Similarly, recommendation will be submitted with respect to training and people development. These recommendations will only be initiated by the results and findings of this research presented in *chapter 4.*

A proposed Framework and Approach for Training and People Development is expected. This will be presented in *chapter 5* of this dissertation.

3.5.4 Other Recommendations

Other recommendations that is presented in *chapter 6* of this dissertation include; adoption and implementation of CMMS in the Nigerian refineries; integration of condition monitoring and preventive maintenance.

3.6 Summary

This chapter adequately highlighted the research methodology and design adopted for data and information gathering for this dissertation.

The results and analysis of the research conducted, is presented in the next chapter.

4. Results and Findings

Chapter 4 contains the results and findings of the empirical study done at the Nigerian refineries

4. Results and Findings

The preceding chapter highlighted the research methodology and design adopted for this dissertation.

This chapter contains the empirical results and findings flowing from the research. The results and findings documented are based upon four (4) case studies of petrochemical refineries (users of rotating equipment) based in Nigeria and South Africa.

The study properly focused on investigations to provide answers to research questions posted in *chapter 3* with the aim of solving the research problem at hand.

4.1 Case Study

4.1.1 Case Study A

This Case Study refers to a case study of Kaduna refining and Petrochemical Company (KRPC).

"This company (Company A) was commissioned in 1980 as Nigerian National Petroleum Company (NNPC) Refinery Kaduna. It was commissioned with an initial capacity of 100,000 barrels per Stream Day (BPSD). This infrastructure was put in place to cope with the growing demands of petroleum products, especially in the Northern part of the country. The refinery was designed to process both Nigerian and imported crude oils into refined petroleum products. The objectives of KRPC are to optimize the capacities of the existing plants, reduce the plants' operating costs, develop new products from existing facilities for use in downstream industries and extend refining services to the West African sub-region. Like other subsidiaries of NNPC, KRPC is owned 100% by NNPC" *(http://www.nnpc-nigeria.com/krpc.htm).*

Engr. S. U. Liman (Maintenance Manger, Kaduna Refining and Petrochemiical Company Limited: Interview 15th July 2008).

According to the above:

- Maintenance strategy adopted for rotating equipment is solely scheduled Preventive Maintenance (PM) checks. This does not seem adequate for rotating equipment maintenance. There is a total absence of online monitoring system.
- Pipeline sabotage sometimes results in plant shutdowns.

Investigations further revealed the following:

- Root Cause Analysis (RCA) of equipment breakdown often began quite late and is inconclusive.
- The number of rotating equipment mechanic with skills is insufficient.
- Fifty-one percent of maintenance mechanics lack additional, supplementary and specialist skills.
- Undue government influence within the system.
- Absence of computerized maintenance management system in place. This affects maintenance planning, establishment of order points and prioritization of job/tasks. This has also made it difficult to monitor backlogs.
- No proper audit system in place.
- Planning procedure is inadequate. The job card flow is almost one-directional.

4.1.2 Case Study B

Case Study B (Company B) refers to a case study of Warri Refining and Petrochemical Company Limited, founded in March 1988. "The company was actually commissioned in September 1978 with an initial capacity of 10,000 barrels per stream day of crude oil and was further de-bottlenecked in 1987 to a capacity of 125,000 barrels per stream day. The petrochemical plant (polypropylene and carbon black), which were built to optimize the refinery, were commissioned in March 1988.

The plant was later expanded to accommodate an HF-alkylation unit in 1988" (http://www.nnpc-nigeria.com/wrpc.htm).

Engr. A. B Okedairo (Department of Petroleum Resources: Interviewed January 2008).

The above speaking on rotating equipment maintenance practices in WRPC stated that:

- The absence of online condition monitoring of rotating equipment does not adequately complement the scheduled Preventive Maintenance (PM) program.
- Crude pipeline vandalizations in the Niger-delta region in the last 2 years have affected rotating equipment and plant availability in general.
- The number of rotating equipment maintenance personnel with adequate skills is suspect.
- Sixty-eight percent of maintenance mechanics lack additional, supplementary and specialist skills.
- Absence of computerized maintenance management system. This affects maintenance planning, establishment of order points and prioritization of job/tasks. Maintenance backlogs have been difficult to monitor.
- Turn around maintenance as compared to reliability-centred maintenance for rotating equipment is insufficient.

4.1.3 Case Study C

New Port Harcourt Refining Company (PHRC) represents Case Study C. "The new refinery commissioned in 1989 with an installed capacity of 150,000 BPSD. The combined crude processing capacity of PHCN therefore amounts to 210,000 BPSD. PHCN is responsible for the provision of the Liquified Peteroleum Gas (LPG), Premium Motor Spirit (PMS), Kerosene (aviation and domestic), Automotive Gas Oil (AGO - diesel), Low Pour Fuel Oil (LPFO) and High Pour Fuel Oil (HPFO)" (http://www.nnpc-nigeria.com/phrc.htm).

Mr S.B Abdullahi (E.D Operations, Port Harcourt Refining Company, August, 2007).

The above stated that:

- Insecurity of supply pipelines to refineries has affected rotating equipment and plant availability.
- "Inadequate empowerment of refinery management in terms of authority over finances, staffing and turn around maintenance".

Investigations further revealed that:

- Lack of a computerized maintenance management system in place affects maintenance planning, establishment of order points and prioritization of job/tasks to a large extent.
- Corrective maintenance is sometimes practiced for rotating equipment.
- Root Cause Analysis (RCA) of equipment breakdown often began quite late and is inconclusive.
- The number of rotating equipment mechanic with adequate skills is insufficient.
- Eighty-nine percent of maintenance mechanics lack additional, supplementary and specialist skills.
- Rotating equipment maintenance record keeping in the department is poor. The importance of records cannot be over emphasizing. Even the smallest maintenance department within an organization should keep basic maintenance records.
- Accountability and transparency is not grounded within the system.
- Planning procedure is inadequate. The internal job card flow is almost one-directional.

4.1.4 Case Study D

Case Study D (Company D) is a fourth case study of a rotating equipment maintenance department at Sasol Synfuel, South Africa. "Sasol Synfuels operates the world's only coal-based synthetic fuels manufacturing facility at Secunda. It produces synthesis gas through coal gasification and natural gas reforming, and uses propriety Fischer-Tropsch technology to convert synthesis gas into synthetic fuel components and other chemical products" (http://www.mpumalangatopbusiness.co.za/2006/TopBusinesses/Sasol.htm).

Engr. Thomas Nukeri (Maintenance Engineer) Rotating Equipmet Department, Turbo 1, Sasol Synfuels.

The above affirmed that:

- Maintenance strategy adopted for rotating equipment is Reliability Centred Maintenance (RCM) Management. Condition monitoring (CM) is employed where necessary and applicable.
- Root Cause Analysis (RCA) of equipment breakdown has been stipulated to begin within 24 hours after failure. This has ensured that all contributing events and details that led to failure is not forgotten or neglected. A success rate of 90% is recorded.
- Eighty-seven percent of maintenance personnel possess additional, supplementary or specialist skills required for their job.
- The job card flow path has made communication with computerized maintenance management system quite effective. This shows positive results on maintenance planning, establishment of order points and prioritization of job/tasks. Backlogs are quite flexible to keep up with and monitor.
- Equipment history is available. This has positively guided maintenance scheduling.

Mr. Ernest Kumalo (Section Leader) – Rotating Equipment Department of Turbo 1

In a semi-structured interview, the above stated that:

- CMMS applications have a positive impact on maintenance planning, and job scheduling for rotating equipment.

4.2 Case Study Comparison

The table above displays similarities and differences between the selected case studies.

Critical Case Findings	Case Study A (KRPC)	Case Study B (WRPC)	Case Study C (New PHRC)	Case Study D (Sasol)
Case Study Description	A subsidiary refinery of NNPC located in Nigeria. Specifically the rotating equipment maintenance section/department.	A subsidiary refinery of NNPC located in Nigeria. Specifically the rotating equipment maintenance section/department.	A subsidiary refinery of NNPC located in Nigeria. Specifically the rotating equipment maintenance section/department.	Rotating equipment department (Turbo 1) of Sasol Synfuels in Secunda, South Africa
Maintenance Strategy in Place for rotating equipment	Scheduled preventive maintenance strategy	Scheduled preventive maintenance strategy	Scheduled preventive maintenance strategy. Corrective actions are sometimes applied.	Reliability Centred Management (condition monitoring is employed where applicable or necessary
Training and Competence	There is no evidence to portray technical development by training and re-training. No up-to-date technical competence for bottom level personnel to align with equipment needs.	There is no evidence to portray technical development by training and re-training. Budget commitment by management is not usually implemented. No up-to-date technical competence to align with equipment needs	There is no evidence to portray technical development by training and re-training. No enough cost commitment to training. No up-to-date technical competence to align with equipment needs	Solely owned technical training school. Part of the salary upgrade requirement is that employees complete a certain training matrix. Emphasis is placed on training and competence
Root Cause Analysis (RCA)	Untimely and always inconclusive	Untimely and always inconclusive	Untimely and always inconclusive	Timely and mostly conclusive
Computerized Maintenance Management System	CMMS is not in use	CMMS is not in use	CMMS is not in use	CMMS is available

Maintenance Assessment (audit)	There is no valuable equipment history/record for rotating equipment	There is no valuable equipment history/record for rotating equipment	There is no valuable equipment history/record for rotating equipment	Adequate record on all rotating equipment
Supply pipelines to refineries	Pipeline sabotage sometimes results to plant shutdown	Pipeline sabotage causes plant disruptions	Insecurity of supply pipelines.	Plant disruption is rarely recorded
Accountability and Transparency	This is suspect	Undue government influence makes this difficult.	Undue government influence makes this difficult.	
Jobcard	Jobcard flow is one-directional	Feedback is slow. Difficult to monitor backlogs.	Jobcard is slow as well as feedback.	All stake-holder departments can request work. Jobcard is okay

***Table 2** – Case Comparison and Critical Findings*

4.3 Survey Questionnaire Poll

A sample of the questionnaire attached as *Appendix B (Rotating equipment maintenance management questionnaire),* was distributed among rotating equipment maintenance personnel of the four refineries. The target population, specifically, includes: Maintenance Managers, Engineers and Supervisors.

The figure below depicts the questionnaire distribution for the rotating equipment departments of the Companies.

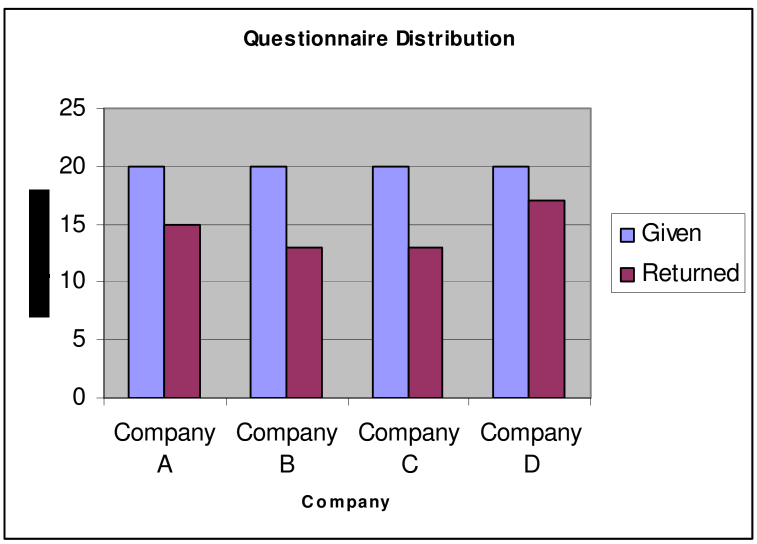

***Figure 3** – Questionnaire Distribution*

Ninety percent (90%) of the total distributed questionnaires was completed and returned. Company A completed eighty (80) percent of received questionnaires, Company B completed ninety (90) percent, Company C completed all questionnaires and Company D completed ninety (90) percent.

4.3.1 Presentation of Results

For the rotating equipment department of the Nigerian refineries:

Ninety-three percent of respondents acknowledged the availability of up-to-date organizational charts. Seven percent are not aware of the job description of some key positions.

Communication with top management is considered effective by sixty-four percent. Thirty percent acknowledge that communication is slow, most especially, feedbacks. Six percent considered communication as not effective.

No.	Investigations	Company A	Company B	Company C	Company D
1	**Up-to-date organizational charts and job description for all key positions**	Available	Available	Available	Available
2	**Communication with top management and operating departments**	Effective Communication	Effective Communication	Effective Communication	Effective Communication
3	**Maintenance strategy adopted for rotating equipment**	Scheduled Preventive Maintenance Checks	Scheduled Preventive Maintenance	Scheduled Preventive Maintenance.	Reliability Centred Management (condition monitoring is done and will work on machine if it indicates a need. However, most of it is time base general overhauls)
4	**Success with analysis of rotating equipment failures**	Failures are often investigated. Success rate is 75%	Failures are often investigated. Success rate is 75%	Failures are often investigated. Success rate is 75%	Root cause analysis is usually done to determine failures. 90% Success
5	**Application of condition-based monitoring technologies for maintenance of rotating equipment**	Not Applicable	Not Applicable	Not Applicable	Applicable to rotating equipment
6	**Detailed**	Available	Available	Available	Available

	maintenance inspection check sheets/lists outlining what should be inspected on rotating equipment				
7	**Established lubrication routes and procedures**	Lubrication Routes are Established	Lubrication Routes are Established	Lubrication Routes are Established	Lubrication Routes are Established
8	**Maintenance budgets for key equipment**	Available	Available	Available	Available
9	**Identification of critical equipment on plant(s)**	Identified	Identified	Identified	Identified
10	**Use of computer support for maintenance program**	Not Applicable	Not Applicable	Not Applicable	Available. Computer support is critical
11	**Rely on maintenance supervisors for all maintenance work coordination**	Yes	Yes	Yes	Yes
12	**Have difficulty coordinating maintenance inspections with production**	No	Sometimes	Sometimes	Sometimes
13	**Work request**	Not anyone	Not anyone	Not anyone	Anyone can request work. All stake holders are responsible.
14	**Only operating departments that can request work**	Yes	Yes	Yes	No
15	**Work-order system**	In Place	In Place	In Use	In Use
16	**Satisfaction with work-order system**	100%	Not 100% One-directional	Not 100% One-directional	100%
17	**Approval of work orders**	Work Manager, General Manager	Work Manager, General Manager	Work Manager, General Manager	Maintenance Supervisor
18	**Average man-hours of work estimated from work-orders**	15 – 20% of Available In-house Man-Hours	15 – 20% of Available In-house Man-Hours	15 – 20% of Available In-house Man-Hours	42 hours per week, but 85% of that is used for normal maintenance and 15% for breakdown (per artisan).
19	**Use of some type of priority coding in placing work-orders**	Not Applicable	Not Applicable	Not Applicable	In Use 1 = Emergency 2 = Urgent 3 = Planned
20	**Weekly reports available on the backlog of work-orders**	Sometimes	Sometimes	Sometimes	Yes
21	**Use of general backlog data for scheduling over time and subcontracting**	Sometimes	Sometimes	Sometimes	Backlog data forms the basis for scheduling overtime and subcontracting
22	**Backlogs**	Unknown	Unknown	Difficult to say	Between 2 and 8 weeks backlog
23	**Are plant engineers and maintenance supervisors satisfied with their work-order systems**	Yes	Yes	Yes	Yes
24	**Use of standing work-order numbers for preventive**	Not Applicable	Not Applicable	Not Applicable	Yes

	maintenance				
25	**Established tickler files or generate maintenance work-orders by computer**	Not Applicable	Not Applicable	Not Applicable	Yes, system is in Use
26	**Use of computers to establish order points and order quantities**	Not Applicable	Not Applicable	Not Applicable	Yes, system is in Use
27	**Use of informal systems based on the experience of the storekeeper and maintenance foreman**	Yes	Yes	Yes	Only Sometimes
28	**Use of foreman's estimates for most jobs**	Yes	Yes	Yes	Yes
29	**Availability of maintenance performance record for rotating equipment department**	Sometimes	Sometimes	Sometimes	Yes, always
30	**Receive weekly reports on the backlog of work-orders**	No	No	No	Yes
31	**Quality of maintenance staff**	Bottom level is very poor	Fair	Quality has not been sustained over time	Good. The company believes in winning with people
	Maintenance personnel training	On the job training is only given	Depends on the maintenance budget	Yes. A high deficiency in technical training exists	Yes
	Availability of history cards on all major equipment	Sometimes	Sometimes	Sometimes	Available
32	**Development and coordination of maintenance activities: management and supervision of maintenance workforce**	All maintenance works must be initiated through a pre-designed maintenance work request. Daily Jobs are scheduled on a schedule form. Work permits system is in place.	Work permits system is in place	Work permits system is in place	Section manager and foremen drafts program for maintenance together with the operations management
33	**Planning Procedure**	Material management department procures all needed spares. Maintenance department procures labour services.	Maintenance department procures labour services	Maintenance department procures labour services	It is called T-7. It is a planning process whereby backlog of 6 weeks is monitored through
34	**Maintenance Progress Assessment (Audit)**	Cannot say	Not efficient	Not efficient	Generally efficient but also depends on the auditors knowledge and focus

Table 3 *– Survey Results*

Seventy-three percent agreed that scheduled maintenance has been adopted for rotating equipment. Twenty-seven percent says a lot of corrective actions take place also as most maintenance tasks are scheduled for TAM and that these schedules decision negatively affects the availability of rotating equipment.

Seventy-one percent confirmed the availability of maintenance budgets for key equipment. Twenty-nine percent are unsure.

Fifty-four percents says a success rate of seventy-five percent has been achieved in analysing equipment failures. Thirty-two percent said root cause analysis often stops at identifying direct causes of an undesired outcome. Fourteen percent disagreed totally by saying the analysis process is haphazard. All respondents agreed on the following:

- Only operating department can request work.
- Absence of condition-based monitoring application for rotating equipment. However, all agreed that its introduction would complement maintenance program and boost rotating equipment availability.
- Established lubrication routes.
- Satisfaction with work-order system
- Adoption of foreman's estimates for most jobs.
- Unavailability of some type of priority coding for placing work orders.
- Maintenance backlogs are not well monitored. Jobcard system does not provide adequate feedbacks.
- Inadequate training for maintenance personnel.
- Absence of computerized maintenance management system (Computer support).

For the rotating equipment department of Sasol:

Availability of up-to-date organizational charts is acknowledged by Ninety-two percent. Eight percent are not sure if it is up-to-date.

Communication with top management is considered quite effective by Eighty-four percent. Sixteen percent agreed that feedbacks are slow.

Ninety-one percent confirmed the availability of maintenance budgets for key equipment. Nine percent are unsure.

Eighty-nine percent agreed that core job training for maintenance personnel is adequate. Eleven percent says supplementary skill training is lacking.

Ninety-four percent acknowledged that a success rate of Ninety percent has been achieved in analysing equipment failures. Six percent are unsure. All respondents agreed on the following:

- Stakeholder departments can request work.
- Reliability-centred maintenance has been adopted for rotating equipment. Application of condition-based monitoring for rotating equipment is effective.
- Established lubrication routes.
- Satisfaction with work-order system
- Effective priority coding in placing work-orders.
- Adoption of foreman's estimates for most jobs.
- Maintenance backlogs are well monitored.
- Availability of computerized maintenance management system.
- Quality of staffing is good.
- Availability of equipment performance record

4.4 Rotating Equipment Availability – (Nigerian Refineries vs. Sasol)

4.4.1 Maintenance Strategy

The maintenance strategy adopted by Sasol is Reliability-centred Maintenance *(Source: Interviews, questionnaires and manuals).* This is based on the principle of condition-based maintenance.

The figures below (fig. 4, 5, 6 and 7) show some condition monitoring applications at Sasol Synfuels for rotating equipments.

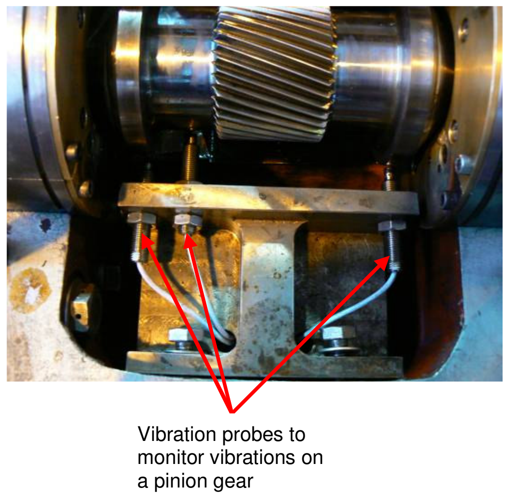

Figure 4 *– Condition Monitoring – Pinion Gear (Source; Sasol)*

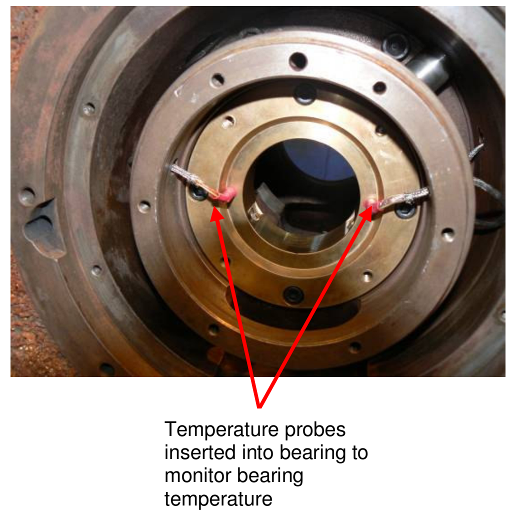

Figure 5 *– Condition Monitoring – Bearing (Source; Sasol)*

Figure 6 *– Condition Monitoring – Steam Turbine (Source; Sasol)*

Figure 7 *– Steam Turbine Maintenance (Source; Sasol)*

Examples of other on-line rotating equipment monitoring devices include:

"A set of sensors, such as temperature, speed, pressure, and vibration sensors, locally connected to a diagnostic unit having a plant communication interface and a processor that implements one or more diagnostic routines. The diagnostic unit collects data from the sensors and performs diagnostics thereon to detect actual or potential problems with the device on a continuous or semi-continuous basis. Using the communication interface, the diagnostic unit automatically sends signals indicating problems or other messages about the rotating equipment to a maintenance system or a control system via standard or common communication network, such as a HART or Fieldbus network. The diagnostic unit may also be intermittently coupled to an off-line computer, such a one associated with a service provider who may verify or further define the diagnostics provided by the diagnostic unit" (Eryurek, Bouse and Reeves, 2005: Abstract, *Paragraph extract from http://www.freepatentsonline.com/6839660.html*).

The Nigerian refineries rely on scheduled preventive maintenance and turn around maintenance for rotating equipment *(Source: Interviews and questionnaires).* Corrective maintenance actions are is also applied in some cases.

4.4.2 Internal Job Card

Rotating equipment maintenance personnel in Nigerian refineries find backlogs difficult to monitor as a result of the job card system. Feedbacks from tasks are also not documented. Since only operating (production) departments are allowed to request work, job card flow path is more one-directional.

Rotating equipment availability can be said to be positively affected by the system at Sasol. All equipment stakeholders have the responsibility to keep rotating equipment at optimal performance. Job requests can also originate from inspections conducted by rotating equipment maintenance personnel.

4.4.3 Root Cause Analysis (RCA)

The application of reliability-centred maintenance by Sasol made certain that failure modes effect and analysis of rotating equipment are known. Root cause analysis of undesired events is often detected on time. A success rate of ninety-percent has so far been recorded.

Respondents in the Nigerian refineries are not satisfied with the conduct of root cause analysis of rotating equipment events.

4.4.4 Computerized Maintenance Management System (CMMS)

Monitoring of maintenance backlogs is an issue at the rotating equipment departments of the Nigerian refineries. This has often led to corrective actions on some rotating equipment.

In Sasol, maintenance backlogs are easily accounted for and are not allowed to exceed between 2 – 8 weeks at Sasol.

4.4.5 Training and Competence

The rotating equipment department of the Nigerian refineries emphasizes more on continuous training and development for top levels maintenance personnel (managers and engineers) than bottom levels (mechanics). In cases of *'tight budget'*, trainings are even deferred. Mechanics do not receive continuous training and development.

Training of artisans in Sasol is done at the Technical Training Centre (TTS). A maintenance learner is required to complete extensive practical and theoretical assessments in a space of two years to be declared qualified as an artisan.

Afterwards, this is often supplemented with trainings received on specific equipments from training consultants. This has developed skills competence in the Sasol environment.

4.4.6 Supply Pipelines

The social issue of sabotage and destruction of supply lines to refineries in Nigeria has often led to plant disruptions.

This social issue is non-existent in the Sasol environment.

4.4.7 Accountability and Transparency

Undue government interference is a potential problem to plant stability. “Insufficient empowerment of their management teams, in terms of authority over finances, staffing, and turnaround maintenance” *(Source: Vanguard, 2008)*.

4.5 Correlation of Research Instruments and Suggestions for Rotating Equipment Availability

1. Most rotating equipment maintenance personnel in the Nigerian refineries suggested that the integration of condition monitoring and preventive maintenance program would positively affect rotating equipment availability. *(Source: Interviews and Questionnaires)*.

2. Most maintenance personnel in the Nigerian refineries acknowledged that maintenance backlogs are unknown and that job card flow is mostly one-directional. *(Source: Questionnaires)*.

3. A large number of rotating equipment maintenance personnel in the Nigerian refineries agreed that approval limits for more maintenance activities outside TAM is essential to prevent unplanned plant outage. *(Source: Interviews and Questionnaires)*.

4. “Refinery experts are canvassing that: Refinery should commit to a Quality Management System that would amongst many other, deliver the following:
    - Determines means of preventing non-conformities;

- Establish methods to measure the effectiveness and efficiency of each process;
- Establishing the quality policy and policy objective of the organization".

(Source: Interview, Vanguard, 2008).

5. A large number of Sasol personnel agreed that condition monitoring of rotating equipment have aided early fault detection. Personnel in the Nigerian refinery suggest the integration of condition monitoring and preventive maintenance program for better results *(Source: Interviews and Questionnaires)*.

6. Most rotating equipment maintenance personnel in the Nigerian refineries believe that the use of Computerized Maintenance Management System (CMMS) will properly coordinate the development of maintenance activities. Filing system is poor. The 'Fat File' system is not well augmented with computer support. *(Source: Interviews and Questionnaires)*.

7. Most rotating equipment maintenance personnel in the Nigerian refineries suggested improvement on training and people development for bottom level maintenance personnel.

8. Most rotating equipment maintenance personnel in the Nigerian refineries are wary of government influence on the refinery management. *(Source: Interview)*

4.6 Summary

This chapter presented results of research work and presented likely problems that could be responsible for rotating equipment availability in the Nigerian refineries. These identified outcomes were prompted by the research question raised by this dissertation in c*hapter 3.2*; how can rotating equipment maintenance management be optimized in the Nigerian refineries?

The next chapter discusses these findings.

5. Discussion and Interpretation

Chapter 5 discusses the correlation of the findings of the research instruments, and also suggests a way forward.

5.0 Discussion and Interpretation

The previous chapter presented the results and findings of the research. This chapter discusses the findings of the study and derives at interpretations guided by relevant theories and from the literature review, with respect to the data gathered.

5.1 Analysis of Observations and Interviews (Nigerian Refinery vs. Sasol)

5.1.1 Maintenance Strategy

From the findings as highlighted in *chapter 4.3.1*, comparisons between the maintenance strategy adopted for rotating equipment by the Nigerian refineries and Sasol are well highlighted.

The application of RCM principle based on condition-based monitoring, in Sasol, was clearly shown.

Rotating equipment maintenance personnel interviewed in the Nigerian refineries acknowledge that quite a few maintenance activities takes place outside scheduled turnaround maintenance. This has often led to unplanned shutdowns of rotating equipment.

A procedure to effectively manage rotating equipment maintenance strategy is included in this chapter.

5.1.2 Root Cause Analysis

Many Root Cause Analysis performed by rotating equipment maintenance personnel in the Nigerian refineries often stops at identifying the proximate cause (direct cause) of many undesired outcomes.

Root cause analysis in Sasol has effectively prevented repetitive undesired outcomes. Multiple causal factors of an undesired outcome are often identified on time. Data gathering begins immediately after an undesired outcome/event takes place. This has ensured a collation of stable data forms.

Employees in Sasol have a commendable understanding of the importance of the root cause analysis exercise and are willing to provide information and data when required of them.

Some rotating equipment maintenance personnel in the Nigerian refineries do not know the importance of event data to the root cause analysts.

Some are deliberately unyielding to the gathering exercise due to the patterns that exists in line with witch hunting and management expectations.

5.1.3 Computer Support for Maintenance Management

The scenario in Sasol shows that maintenance work scheduling can be generated efficiently for a wider coverage of work centres. Also, backlogs are adequately monitored and job cards are generated seamlessly with priority coding accorded to specific job cards.

The use of computerized maintenance management system has enhanced the maintenance strategy adopted.

In unavoidable cases, Sasol personnel affirmed that backlogs are not allowed to exceed two (2) to eight (8) weeks. Coordination and development of maintenance activities seldom has any hitch. There are however occasions when priority conflicts between production and maintenance have caused minor disruptions.

Rotating equipment maintenance personnel in the Nigerian refineries do not have any computer support for the maintenance strategy adopted. Planned jobs are often rescheduled.

Even more troublesome is the fact that maintenance managers are not abreast with maintenance backlogs. This could be the reason why rotating equipment maintenance supervisors do find the coordination of maintenance activity troublesome in addition to inability to estimate of maintenance jobs adequately.

5.1.4 Internal Job Card

From the investigations in chapter *4.3.7*, the internal Job card in use by the rotating equipment maintenance department in the Nigerian refineries is not quite efficient. It does not carry feedbacks on maintenance tasks.

Maintenance mechanics are not committed to signing on their own job cards.

5.1.5 Condition Monitoring of Rotating Equipment

In Sasol, condition monitoring provides on-line equipment condition and at the same time compares on-line data with expected values. This innovation has very well complemented the maintenance program for rotating equipment in this company.

5.1.6 Training and People Development– The Shortcomings on Maintenance Strategy

The first hurdle to running a successful preventive maintenance (PM) is having the right people; that is, staff with sufficient capacity, capability, competence and analytical abilities that surpasses that of the best-tear down rotating equipment mechanic.

The scenario at the rotating equipment department of the Nigerian refineries is unclear in this regard. The availability of personnel does not present a major issue but rather disturbing, is the level of competence of bottom level maintenance personnel.

The Nigerian refineries do not have any form apprentice programs in place. Even though some of the employees agree that it would produce excellent results by preserving technical knowledge and building a solid maintenance culture in its rotating equipment department. However, it is non-existent as a result of short sighted cost savings initiatives on the part of rotating equipment maintenance management.

There is also wisdom in including rotating equipment maintenance mechanics in reliability and basic maintenance management training. This would help in optimizing the preventing maintenance program for better results.

Accessibility of equipment manual would also go some way to simplify preventive maintenance. However, equipment manuals are not within the reach of maintenance mechanics in the Nigerian refineries. This has not helped in the development of the analytical ability of the maintenance workforce at the bottom levels.

Training should be taken seriously as an investment by rotating equipment maintenance management.

5.2 Analysis of Questionnaires

Table 3 in *chapter 4.5.1* depict the findings of the questionnaire adopted for this research. The bar graph, *(fig. 3)*, pictorially shows the questionnaire distribution across the selected case studies.

Most rotating equipment personnel in the Nigerian refineries suggest the integration of condition monitoring techniques and the preventive maintenance in use, as a solution to low availability rotating equipment.

The questionnaire further confirms that maintenance backlogs are difficult to account for in the Nigerian refineries. The job card format is one-directional and does not provide feedback as to the status of the maintenance task. The questionnaire also confirmed the low availability of rotating equipment, absence of computerized maintenance management system, inadequate training for personnel and the ineffectiveness of root cause analysis process.

5.3 Optimizing Rotating Equipment Availability

To effectively tackle the issues associated with low availability of rotating equipment in the Nigerian refineries, included in this dissertation are; a procedure to effectively manage rotating equipment maintenance strategy; a new internal job card and a proposed framework and approach for training and people development.

5.3.1 The Manage Rotating Equipment Maintenance Strategy Procedure

The **M**anage **R**otating **E**quipment **M**aintenance **S**trategy (MREMS) procedure was developed to address low availability of rotating equipment in the Nigerian refineries.

The MREMS procedure also shares some common features with the Maintenance Strategy Review (MSR) process which is a "systematic review of plant or equipment, evaluating the manner in which it fails within a given operational context, the consequences of failure and the identification of technically feasible and cost effective maintenance strategies to minimize the consequence and or frequency of failure" *(SKF, http://www.skf.com/aptitudexchange/glossary.html).*

More to the MREMS procedure is that its other sub-processes would aid it to be a balancing or linking point between the Nigerian refineries' operational reliability strategy, and optimum availability of rotating equipment.

The block diagram for the MREMS procedure is as shown in the figure below (fig. 10).

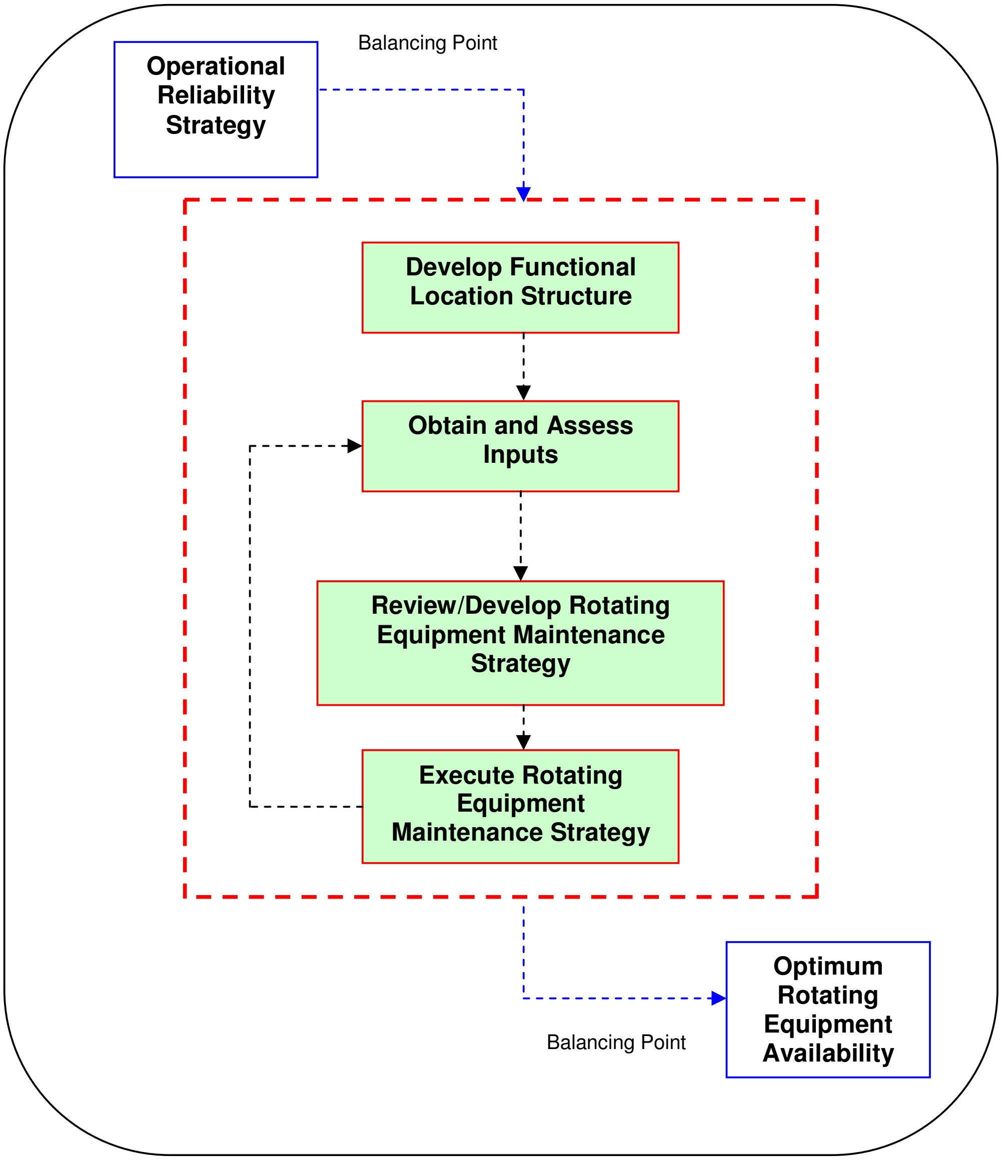

***Figure 8** – MREMS Block Diagram (Courtesy: O. Odeyinde)*

STEP 1

- DEVELOP FUNCTIONAL LOCATION STRUCTURE (FLS)

This involves setting in place a functional hierarchical representation of the rotating equipment on the plant. It is essential for managing costs or reliability reporting and for managing schedules in the Computerized Maintenance Management System (CMMS).

STEP 2

- OBTAIN AND ASSESS INPUTS

This involves data and information assembling required to reviewing or developing the rotating equipment maintenance strategy.

The feedback loop consists of performance measurements obtainable from rotating equipment maintenance personnel or the Computerized Maintenance Management System (CMMS). A job card that would also facilitate appropriate feedbacks is presented in *chapter 5.32.*

This step will be initiated by any event that causes the review or development of a new rotating equipment maintenance strategy. It can also be facilitated by periodic reviews as well as unpredicted rotating equipment failure.

This step will also be vital in the event of a change in the functionality of existing rotating equipment.

STEP 3

- REVIEW/DEVELOP ROTATING EQUIPMENT MAINTENANCE STRATEGY

The review or development of the rotating equipment maintenance strategy will be executed by adopting a selective approach. This involves identifying rotating equipment based on criticality.

The review or development of a specific rotating equipment maintenance strategy will be based on the answers provided for by the following Failure, Mode, Effect and Analysis questions:

- What is the rotating equipment number?
- What is the process function of the rotating equipment?
- What are the failure modes of the rotating equipment?
- What are the direct causes of failure?

- What maintenance technique, in line with Reliability-Centred Maintenance (RCM) principle of condition-based maintenance, will be most suitable to address the failure mode?
- What will be the frequency of maintenance task?
- Who will be responsible for maintenance task?

STEP 4

- EXECUTE ROTATING EQUIPMENT MAINTENANCE STRATEGY

  Execution of the rotating equipment maintenance strategy will involve job grouping and schedule loading into the Computerized Maintenance Management System (CMMS).

  Job grouping will involve the classification and assembling of all rotating equipment maintenance tasks that can be executed together at the same period. This is compiled as a task sheet the rotating equipment maintenance mechanic will be required to complete at specified times.

  Every job group will be loaded as a schedule into the Computerized Maintenance Management System (CMMS).

The MREMS procedure has the potential of achieving the following in the Nigerian refineries:

- Establish a standard approach for rotating equipment strategy review or development.
- Improve maintainability and availability of rotating equipment.
- Optimize rotating equipment maintenance and availability.
- Significantly cuts down on unscheduled rotating equipment downtime and undesired events.
- Improve the life expectancy of rotating equipment and refinery.
- Improve control of refinery operations by assuring rotating equipment availability.

5.3.2 Internal Job Card

Job card, as described in *chapter 2.3*, is "one of the primary means of communication with the CMMS" *(Coetzee 1997)*.

From the issues highlighted in *chapter 4.3.3 and 5.1.5*, it is difficult to account for maintenance backlogs with the job card system currently in use *(Source: Interview, Questionnaire).*

To optimize rotating equipment maintenance management in Nigerian refineries, an Internal Job Card is included in this dissertation.

The new internal job card shown in the figure below, (fig. 9) would assist to build a periodic equipment maintenance history and also commit maintenance personnel to assume responsibility on a wider platform.

With this Job card, backlogs will be easily monitored from feedbacks received from mechanics. Job cards are expected to be signed off only on completion of task.

Company Internal Jobcard

Functional Location:	**Description**
Equipment No:	**Equipment Type**
Technical ID:	

Main Description of Work Order

Maintenance Plant:	**Priority:**	**Required Date:**
Work Order No:	**Date:**	**Created By:**
Main Work Centre:	**Description:**	
Notification No:	**Date:**	**Created By:**
Planner Group:	**Tel. No.**	
Originator:	**Originator Tel:**	

OPERATION TASK INSTRUCTIONS

Operation Number	Perform Work Centre	Scheduled Start Date	Scheduled End Date	Scheduled End Time	Scheduled Hours	Quantity

MECHANIC TASK FEEDBACK (Hours)

Mechanic Name	Mechanic ID. No.	Actual Start Date	Actual Start Time	Actual End Date	Actual End Time	Actual Hours	Quantity

MECHANIC EQUIPMENT FEEDBACK (Record)

Object Part	
Damage	
Cause	
Activity	

MECHANIC LOST TIME FEEDBACK (Hours Lost)

Mechanic ID. No.	Lost Time	Lost Time Reason

CONFIRMATION OF WORK PERFORMED
I hereby certify that to the best of my knowledge, this work has been performed in accordance with Company codes and regulations.

Supervisor name: ……. ID. No. ………… Signature: ……… Date: ………

Figure 9 *–Internal Job Card Form Courtesy: O. Odeyinde)*

- COMPANY INTERNAL JOB CARD: The word ‘Company’ would bare the Nigerian refinery name as the proprietary and responsible owner of the job card.
- FUNCTIONAL LOCATION: This is a functional hierarchical location of the plant.
- DESCRIPTION: This gives detail of the plant function or name *(Example: Oxygen plant or Unit 059)*.
- EQUIPMENT NO.: This is a unique equipment identification number that shows precise equipment on which to perform task. *(Example: Unit 059 TX101)*.
- TECHNICAL ID.: This is a technical description of the equipment. *(Example: Turbine Expander)*.
- MAIN DESCRIPTION OF WORK ORDER: This highlights the job to be performed and further categorises the work as a ‘cold work’, ‘hot work’ or ‘confine space entry work’. This will give the rotating equipment mechanic a quick insight to the task at hand and also tools and resource(s) he/she may need.
- PRIORITY: This requires some type of priority coding to determine how soon task is desired completed. *(Example: Emergency = 3, Urgent = 2, Planned Maintenance = 1).*
- REQUIRED DATE: Specifies the date plant/ rotating equipment reliability is expected.
- JOB ORDER NO.: This is a unique task identification number that is sent to operating department for the task to be performed.
- MAIN WORK CENTRE: This is a description of the responsible shift or department responsible for performing task.
- NOTIFICATION NO.: This is a documented number that notifies the planner of the main work centre of non-conformance and expected maintenance.
- PLANNER GROUP: This is description of the main work centre responsible for planning the work for the main work centre.
- ORIGINATOR: This is the identity of the department that requested work. This job card system would also that even maintenance department can issue notification for repairs on sighting or detecting non-conformance during condition monitoring of equipment.

- ORIGINATOR TELEPHONE: This is the telephone number of the department that originated the task request.
- OPERATION TASK INSTRUCTIONS: This highlights some major issues regarding the task to be performed;
  - This records the number of times this operation is being performed.
  - The work centre responsible within the main work centre for task to be performed.
  - Expected schedule start date.
  - Expected schedule end date.
  - Expected schedule end time.
  - Scheduled hours.

  The operation task instruction is expected to monitor the Mean-Time-To-Repair.
- MECHANIC TASK FEEDBACK: This is would be an integral step that would assist the rotating equipment maintenance managers in the Nigerian refineries to keep up-to-date with backlogs in case where tasks are not executed. It also allocates responsibility to individuals rather than a group. This does not necessarily imply that a task to be performed is a one-man task. This takes note of the following:
  - Name of rotating equipment mechanic responsible for task execution;
  - Mechanic Identification Number;
  - Actual start date;
  - Actual start time;
  - Actual end date;
  - Actual end time;
  - Actual hours spent on the job;
  - Signature of mechanic confirming the information provided;

  This is expected to introduce accountability and measure personnel performance.
- MECHANIC EQUIPEMENT FEEDBACK: This is expected to aid in building a reliable maintenance record for the rotating equipment maintenance department of the Nigerian refineries. It highlights;
  - It requires that the mechanic take note of the area of the equipment on which maintenance was executed;

- If there is any damage or not;
- Cause(s) of non conformance;
- Maintenance activity carried out on rotating equipment.

- MECHANIC LOST TIME FEEDBACK: This is expected to prevent re-occurrence of lost time on the same or similar task. It could help to assess personnel skill and competence on the job.
- CONFIRMATION OF WORK PERFORMED: The responsible supervisor is expected to confirm that rotating equipment reliability has been restored.

5.3.2.1 Internal Job Card Flow

A job card system will only be effective if the job card flow is properly understood by all personnel.

The figure below (fig. 10) is a recommendation of a descriptive job card flow chart that can be adopted by the rotating equipment maintenance department of the Nigerian refineries. *(This is as derived and modified from Maintenance, Compiled by Coetzee J. L, 1997:357).*

- PLANNER: The planner is responsible for creating job cards. The created job cards are channelled to the maintenance supervisor for priotizing and task execution management.
- PRODUCTION: The facility operator/owner is referred to as production. Production reports defects directly to maintenance foreman.
- SUPERVISOR: The maintenance supervisor is responsible for priotizing and managing the execution of maintenance activities. The supervisor receives job cards from planners and information on defects from foreman. He is also laden with the responsibility of checking and monitoring, every assigned tasks to mechanics, for completeness and correctness.
- MECHANIC: Mechanic receives the internal job card from his/her supervisor. He is assigned a task and would be accountable for completing the job card for relaying feedback to the maintenance supervisor.

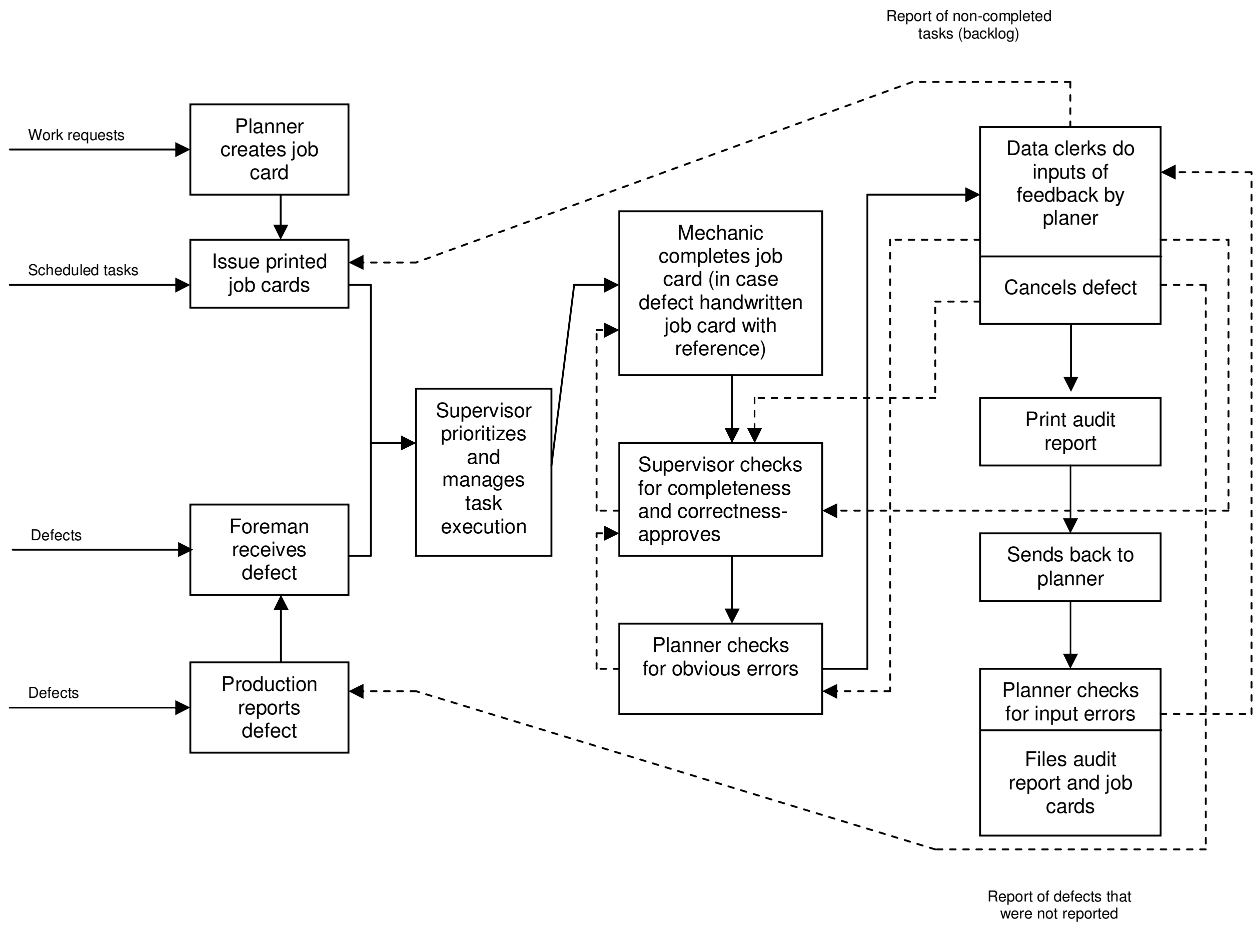

***Figure 10** – Internal Job Card Flow*

- FOREMAN: The foreman receives defects from the facility operator and notifies maintenance supervisor.

5.3.3 Framework and Approach for Training and People Development

A model framework and approach for training and people development (FATPD) for the Nigerian refineries is proposed based on research findings. Table 3 and figure 11 below make up the FATPD.

In developing the model FATPD, the identification of rotating equipment types and core skill requirements for important tasks in the rotating equipment maintenance departments of the Nigerian refineries became essential.

Based on the findings of the research, healthy training and people development vision proves to have a positive impact on rotating equipment maintenance management in one of the case studies environment. The potential viability of the FATPD was also validated by comparing it with the existing training plan in this case study environment.

DEPARTMENTAL STRUCTURE	Course ID	Frequency (Years)	Competency Required	Practical	Theory	Critical Task	Departmental Manager	Area Manager	Manager	Engineer	Technician	Rotating Equipment Mechanic I	Rotating Equipment Mechanic II	Mechanic	Apprentice	Driver
Framework																
General Skills																
Light Crane	ROTECT1		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	Y	Y
Fork Lift	ROTECT2		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	Y	Y
Basic Rigging	ROTECT3		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	Y	Y
Inspection of Lifting Equipments and Logbooks	ROTECT4		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	Y	N/A
Vibration Analysis Fundamentals	ROTECT5		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	Y	N/A
Laser Alignment	ROTECT6		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	Y	N/A
Fitting of hydraulic Couplings	ROTECT7		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	Y	N/A
Root Cause Analysis	ROTECT8		Y			N	Y	Y	Y	Y	Y	Y	Y	Y	N/A	N/A
Management of Change	ROTECT9		Y			N	Y	Y	Y	Y	Y	Y	Y	Y	N/A	N/A
General Skills for Rotating Equipment Mechanic																
Turbines	ROTECT10		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Compressor Basics	ROTECT11		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Compressor Centrifugal	ROTECT12		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Compressor Reciprocating	ROTECT13		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Compressor Screw	ROTECT14		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Pumps Fundamentals	ROTECT15		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Pumps Intermediate	ROTECT16		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Bearing Fundamentals	ROTECT17		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Bearing Intermediate	ROTECT18		Y			N	N/A	N/A	N/A	N/A	N/A	Y	Y	Y	N/A	N/A
Disassembling and Assembling of Rotating Equipment																
Air Compressor	ROTECT19		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A
Steam Turbine	ROTECT20		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A
Expander	ROTECT21		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A
Oxygen Compressor	ROTECT22		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A
Isopac Compressor	ROTECT23		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A
Gearboxes	ROTECT24		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A
Fluid Drive	ROTECT25		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A
Centrifugal Pumps	ROTECT26		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A
Positive Displacement Pumps	ROTECT27		Y			Y	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A

Table 3 – *Proposed Framework for Training and People Development (TPD) in the Nigerian Refineries (Courtesy: O. Odeyinde)*

The FATDP was developed to take after the training plan I have followed, as a rotating equipment maintenance personnel, at Sasol.

The training framework consists of training or learning areas that rotating equipment maintenance personnel are required to build progressive skills and competence. The training frame work is subdivided into three (3) sections; general skills; general skills for rotating equipment mechanic; Disassembling and assembling of rotating equipment.

The requirement for each personnel under the refineries' departmental structure is identified and indicated as applicable. Identifying personnel training need(s) is a crucial step.

Personnel assessment or evaluation is required at this stage. The approach for training and people development, as outlined by the descriptive flow mat in figure 11, would be helpful.

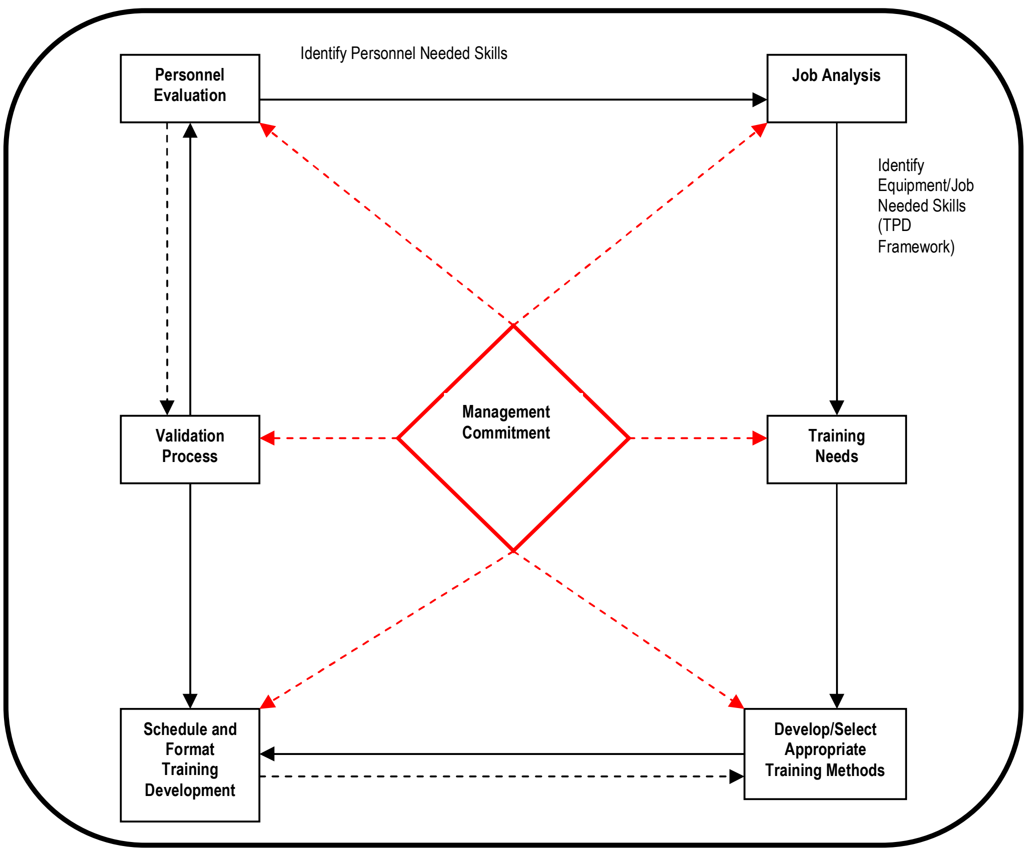

Figure 11 *– Proposed approach for Training and People Development (TPD) in the Nigerian Refineries (Courtesy: O. Odeyinde)*

5.4 Accountability and Transparency as a Problem

From the results obtained, most people are not pleased with undue government influence on the affairs of the Nigerian refineries.

Nigerian refinery managements do not have sufficient control over finances and staffing. This overbearing influence has led to attempted refinery privatizations by the past civilian government.

5.5 Summary

This chapter discussed the outcome of the findings of the research and also presented possible solutions to perceived problems of low rotating equipment availability in the Nigerian refineries.

The next chapter will provide an overall outcome and conclusion of this dissertation.

6. Recommendations and Conclusions

An overall outcome of the dissertation, recommendations and conclusion, is presented in this chapter.

6.0 Recommendations and Conclusions

The content of this chapter is derived from the significance of the results analysis and discussions of the research work carried out. Furthermore, a recommendation for future work is also presented.

6.1 Conclusions

This chapter presented a concise summary of the research dissertation. This dissertation has highlighted problems associated with rotating equipment maintenance management in the Nigerian refineries. Research findings sufficiently presented evidence to prove that three (3) key elements are vital to optimizing rotating equipment maintenance management in the Nigerian refineries. These elements are:

- A procedure to Manage Rotating Equipment Maintenance Strategy (MREMS).
- The new Internal Job Card.
- Training and development (Framework and Approach for Training and People Development).

These vital elements, if properly positioned, have the potentials to revitalize maintenance strategy adopted and optimize rotating equipment maintenance management in the Nigerian refineries.

6.2 Recommendations on Procedure to Manage Rotating Equipment Maintenance Strategy (MREMS)

Recommendations on the procedure for MREMS, discussed in *chapter 5.3.1 of this dissertation,* are highlighted as follows:

- Computer support is vital for the successful implementation of the MREMS procedure. A computerized maintenance management system should be adopted and set in place.
- The internal job card discussed in *chapter 5.3.2* should be adopted to contribute to feedbacks and inputs required for review or develop strategy in the MREMS procedure.
- Personnel should be assigned and be made responsible for setting up this procedure. The various sub-processes of the MREMS procedure should be handled by different individuals or departments for better performance.
- A "Responsible, Accountable, Consult and Inform" (RACI) structure would ensure that the procedure is not abandoned mid-way implementation.
- It is advisable that this procedure be adopted for implementation by the rotating equipment departments of the Nigerian refineries. Implementation of this procedure should be progressive across the rotating equipment departments of the Nigerian refineries and not simultaneous.

6.3 Recommendations on Internal Job Card

Recommendations on the proposed internal job card, discussed in *chapter 5.3.2* of this dissertation, are highlighted as follows:

- The internal job card should be well explained to all maintenance personnel. A commitment for adherence should be obtained as this is essential for feedbacks into the computerized maintenance management system (CMMS).
- Operation task instructions should be properly outlined on the Internal Job Card.
- Rotating equipment mechanic should provide three (3) comprehensive feedbacks on; task; rotating equipment; and lost time if applicable.
- Lost time should be investigated and dealt with appropriately.

- These feedbacks should be stored in a computer database.
- All job cards must be signed on or off when required.
- I will strongly recommend the adoption of the internal job card, highlighted in *chapter 5.3.2* by the rotating equipment department of the Nigerian refineries.

6.4 Recommendation on Training and People Development

The Framework and Approach for Training and People Development (FATPD), highlighted in *chapter 5.3.3,* will provide a platform for the rotating equipment maintenance department to evolve there own, more specific, training and development plan.

The following recommendations will support the implementation of the FATPD:

- Training needs of individual personnel should be identified. An assessment on core job skill will be proper. The objective of the assessment should be explained to the personnel.
- Management should ensure that personnel develop skill and competence where it is identified as required. Management flexibility with time will be an important factor here.
- Management commitment to training and people development should reflect on budgets.
- I recommend that the rotating equipment maintenance department of the Nigerian refineries adopt the FATDP. This will evolve a well skilled and competent work force.

6.5 Other Recommendations

- Adoption and implementation of computerized maintenance management system (CMMS).

- Condition monitoring should be assimilated into the preventive maintenance program of the rotating equipment maintenance department of the Nigerian refineries.
- Most importantly, accountability and transparency should be promoted within the system.

6.6 Future Research

In summary, proposed studies like, adoption and implementation of computerized maintenance management systems for the Nigerian refineries would create a viable continuum for this research dissertation.

This would, furthermore, be a gainful exercise towards optimizing maintenance management in the Nigerian refineries.

6.7 Limitations of the Study

The major part of this research work can be said to be limited to the major refineries in Nigeria and Sasol Synfuels in Secunda, South Africa. Not all data pertaining to this study can be documented for Sasol Synfuels and the Nigerian refineries because the Synfuels environment has strict confidentiality and security procedures tied to obtaining answers to certain questions while the Nigerian refineries does not have in place a comprehensive maintenance record. However, my physical presence in my work environment (Sasol Synfuels) has given me the opportunity to have some information released formally and some informally.

Furthermore, the slow response to survey and few interviewees caused by bureaucracy and protocols in the Nigerian environment may have prevented the presentation of a broader view.

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Annexure

Annexure A: Questionnaire Letter

ACADEMIC RESEARCH PURPOSES ONLY

(PRIVATE & CONFIDENTIAL)

For further contact call +27845041775
OR
Faculty of Engineering Centre for Research & Continued Engineering Development

Department of Petroleum Resources
Lagos
Nigeria

Dear Sir/ Madam,

SUBJECT: Academic Research on the Nigerian Refinery Sector; OPTIMIZING ROTATING EQUIPMENT MAINTENANCE MANAGEMENT

I am at present registered for the degree Masters of Engineering in Development and Management Facilities at the North West University, Potchefstroom, South Africa. I intend to complete my studies at the end of the year 2008.

I kindly solicit your support, for my current dissertation purpose, that the attached questionnaire, be completed by your organization. My chosen field of study is on 'Rotating Equipment Maintenance: Optimizing Rotating Equipment Maintenance in Nigerian Refineries'.

The research focuses on the current situation of rotating equipment in the Nigeria refineries and likely problems responsible for the decline in the operability of these equipments. A procedure which aims at improving the management rotating equipment maintenance and subsequent improved refinery availability will be recommended.

I will be glad if separate questionnaires are completed, per refinery field office, by maintenance management personnel.

Questionnaires can be completed and returned as early as 28th, April 2008. Completed questionnaires can also be returned by email to odeysesan@yahoo.com on or before 28th, April 2008. Also enclosed with the hard copy questionnaire is a CD copy (electronic copy) of same.

I assure that data confidentiality and security is strictly guaranteed. Also kindly indicate if you will like to have details of my findings, once it is approved by the University.

Your support is highly anticipated.

Thank you

Annexure B: Questionnaire

ROTATING EQUIPMENT MAINTENANCE MANAGEMENT QUESTIONNAIRE

ACADEMIC RESEARCH PURPOSES ONLY

(PRIVATE & CONFIDENTIAL)

MAINTENANCE MANAGEMENT STRATEGY- A managed process of delivering timely maintenance can assure capacity (Joel Levitt 1997)

1. Do you have up-to-date organizational charts and job description for all key positions?

   YES ☐ NO ☐ NOT SURE ☐

2. How effective is communication with top management and operating departments?

   EXCELLENT ☐ V. GOOD ☐ GOOD ☐

   FAIR ☐ BAD ☐

3. What maintenance strategy have you adopted for rotating equipment? Briefly describe.

4. Do you analyze causes of rotating equipment failures?

   YES ☐ NO ☐ SOMETIMES ☐

5. Do you employ condition-based monitoring technologies for maintenance of rotating equipment?

   YES ☐ NO ☐ SOMETIMES ☐

6. Do you have detailed maintenance inspection check sheets/lists outlining what should be inspected on rotating equipment?

   YES ☐ NO ☐ NOT FOR ALL ☐

7. Do you have established lubrication routes and procedures?

   YES ☐ NO ☐ NOT SURE ☐

8. Do you have specific repair and maintenance budgets for key equipment?

YES ☐ NO ☐ NOT SURE ☐

9. Have you identified critical equipment on your plant(s)?

YES ☐ NO ☐

If YES, what is the identification criteria(s) adopted?

10. Do you use computer support for maintenance program?

YES ☐ NO ☐ NO SURE ☐

COORDINATION AND DEVELOPMENT OF MAINTENANCE ACTIVITIES- Maintainability is a characteristic of machinery design which is expressed in terms of ease and economy of maintenance, availability of the machinery, and safety and accuracy in the performance oft the maintenance actions (Dr. Alan Smith)

11. Do you rely on maintenance supervisors for all maintenance work coordination?

YES ☐ NO ☐ SOMETIMES ☐

12. Do you rely on engineering for all maintenance work coordination?

YES ☐ NO ☐ SOMETIMES ☐

13. Do you rely on planners for all maintenance work coordination?

YES ☐ NO ☐ SOMETIMES ☐

14. How would you describe the quality of maintenance staff?

15. How would you describe maintenance management commitment to training and people development?

16. DO you have difficulty coordinating maintenance inspections with production?

YES ☐ NO ☐ SOMETIMES ☐

17. Can anyone request work?

YES ☐ NO ☐

18. Is it only operating departments that can request work?

YES ☐ NO ☐ NOT SURE ☐

PLANNING (Dr Alan Smith)- Planning includes two major ingredients; resource planning and organizational planning

19. Do you use planners?

YES ☐ NO ☐

20. Do you use full-time maintenance clerks?

YES ☐ NO ☐

21. Do you use work-order system?

YES ☐ NO ☐

22. Are you satisfied with work-order system?

YES ☐ NO ☐ NOT IN USE ☐

23. Work orders are approved by:

- Plant Engineers ☐
- Maintenance Supervisors ☐
- Work Manager, General Manager ☐
- Operating Supervisors ☐
- Any Supervisors ☐
- Any Other ____________

24. What are the average man-hours of work estimated form work-orders?

25. Do you use some type of priority coding in placing work-orders? If yes, please state.

26. Do you break work order estimates into man-hours per job/task?

YES ☐ NO ☐ SOMETIMES ☐

27. Are actual times eventually compared to estimated or planned times?

YES ☐ NO ☐ SOMETIMES ☐

28. Do you have weekly reports on the backlog of work-orders?

YES ☐ NO ☐ SOMETIMES ☐

29. Do you use general backlog data for scheduling over time and subcontracting?

YES ☐ NO ☐ NOT SURE ☐

30. Are backlogs expressed in man-hours per job/task?

YES ☐ NO ☐ OTHER ☐

31. Backlogs:

- Less than 2 weeks backlog ☐
- Between 2 and 8 weeks backlog ☐
- Between 8 and 16 weeks backlog ☐
- Between 4 and 12 months backlog ☐
- Over 1 year's backlog ☐
- Status of backlog is usually unknown ☐

32. Do you identify and purchase parts and maintenance materials before work order is released to workers?

YES ☐ NO ☐ NOT SURE ☐

33. Are plant engineers and maintenance supervisors satisfied with their work-order systems?

YES ☐ NO ☐ NOT REALLY ☐

34. Do you use developed labour time standards for repetitive jobs?

YES ☐ NO ☐ NOT SURE ☐

35. Do you use foreman's estimates for most jobs?

YES ☐ NO ☐ NOT SURE ☐

36. Do you use standing work-order numbers for preventive maintenance?

YES ☐ NO ☐ NOT SURE ☐

37. Have you established tickler files or generate maintenance work-orders by computer?

YES ☐ NO ☐ NOT SURE ☐

38. Do you use computers to establish order points and order quantities?

NOT SURE ☐

39. Do you use informal systems based on the experience of the storekeeper and maintenance foreman?

YES ☐ NO ☐ SOMETIMES ☐

40. Do you re-order when an item is out of stock?

YES ☐ NO ☐ SOMETIMES ☐

CONTRACTING- Contractors should be used only where they add value to the current situation (Dr. Alan Smith)

41. Do you use backlog trend date for increasing or decreasing work force?

YES ☐ NO ☐ NOT SURE ☐

42. Do you use developed labour time standards for repetitive jobs?

YES ☐ NO ☐ NOT SURE ☐

43. Do you use foreman's estimates for most jobs?

YES ☐ NO ☐ NOT SURE ☐

MAINTENANCE AUDIT- It is well known that the maintenance manager who is allowed to get on and implement his maintenance strategy and develop his operation without let or hindrance is an endangered species – external influence can cause even the best laid plans to go astray (Dr. Alan Smith)

44. Do you keep a maintenance performance record for rotating equipment department?

YES ☐ NO ☐

45. Do you have weekly reports on the backlog of work-orders?

YES ☐ NO ☐ SOMETIMES ☐

48. Do you have some type of productivity report to compare actual performance to planned performance?

YES ☐ NO ☐ NOT SURE ☐

49. Do you keep history cards on all major equipment?

YES ☐ NO ☐ NOT SURE ☐

50. What is usually the average percentage of material cost range of total maintenance cost?

NOT SURE ☐

51. What is the average cost of carrying out maintenance inventory per month?

NOT SURE ☐