

# Maintenance improvement in the petrochemical industry

**OI OLUWASINA**

20977425

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University, South Africa.

Supervisor: Prof. JH Wichers

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## **Dedication**

To my wonderful family

## **Abstract**

Technology is the answer to most of our human needs but every technology is often accompanied by other challenges which often lead to the evolvement of another technology. One of the technologies that have greatly impacted our world is that of energy development out of which the petro-chemical industry is an important one.

The petro-chemical industry remains the main energy hub for our world today through ranges of products coming from its ambit but not without its own challenges too. One of which is the issue of breakdown or shut down which always require maintenance. Shutdown, many a times, may be planned (annual, quarterly, condition-based, time-based, preventive and so on) or unplanned (run-to-failure).

In any case, maintenance personnel (mechanical, electrical and instrument) must perform their duties to fix it. In the process of fixing the equipment several factors affect the effectiveness of the personnel. To improve maintenance activities, factors affecting its effectiveness should be addressed. Some of the factors that are already been considered are; Overall Equipment Effectiveness(OEE), Precision maintenance, Maintainability, Computerized Maintenance Management System (CMMS), Work Order management, Equipment, Logistics, Process optimization, Supply chain management, Maintenance strategies, Continuous Improvement Hours and so on. (*Taylor, 2000; Siemens.com, 2010*)

Of those factors, many people hardly think of ergonomics as a factor of reckoning with maintenance activities. Ergonomics is mostly thought of in relation to operators and office workers.

According to National Institute for Occupational Safety and Health in U.S.A (2009), ergonomic injuries are the most common cause of workplace illness and injury in the United States. Back injuries and cumulative trauma disorders (CTDs) such as *carpal tunnel syndrome, tendinitis, bursitis and epicondylitis* form the majority of non-fatal occupational injuries and illnesses, costing employers more than 12 billion dollars per year in lost work time, workers compensation payments and medical expenses.

Of the cost implication of ergonomics ailment reported above, how much of it is related to maintenance activities? Is there any relationship between maintenance activities and

ergonomics? In what direction is the relationship –positive or negative? How much is the impact in either direction? If it is negative, how can we mitigate it? Finally, what are the benefits, if any? These are some of the vital questions this dissertation is set to answer in relation to: physical, somatic, medical, overhead cost, production down-time and personnel morale.

To achieve the afore-mentioned, several research instruments were employed which include; case studies, questionnaires, physical observations, interviews, literature reviews, internet resources, journals and other sources (industry experts and professionals).

Relevant keywords and concepts were thoroughly researched in the literature review which serves as a base for the dissertation.

Two hundred technical personnel (maintenance) serve as the population sample and questionnaires were administered to them. Technical personnel with appreciable number of years of experience occupying managerial positions were also interviewed. The outcomes of all the interviews, observations and questionnaires were analysed and interpreted accordingly to verify how ergonomics impact maintenance.

This dissertation based on findings, was able to establish that ergonomics impact the activities of maintenance personnel culminated in proposing an E4M (Ergonomics for Maintenance) assessor. The assessor alongside utilization guidelines and a training matrix will help to effectively mitigate the impact of ergonomics on maintenance activities. There is room for further development of the tool into a computer based package for real-time assessment and mitigation.

The assessor and its instruments cannot work alone without the commitment of stake-holders in the industry. That is why recommendations were included for effective application of the tool.

The dissertation did not overlook the good works the industry has been doing in the area of creating awareness about repetitive stress injuries among its workforce but only complement its efforts in areas they might not look into. That is in a bid to improve the effectiveness of its workforce which will directly increase productivity, profit and stakeholders confidence. On

the other hand, it will reduce their indirect losses through; production down-time, medical cost and over-head costs.

However, the application of the E4M assessor is not limited to the petro-chemical industry only but finds its applicability in other industries like; manufacturing, aviation, automobile and any other field where maintenance activities take place particularly in third world countries.

## **Keywords**

*Adaptation*

*Availability*

*Cost*

*Down-time*

*Effectiveness*

*Ergonomics*

*Improvement*

*Industry*

*Injury*

*Maintenance*

*Medical*

*Mitigation*

*Morale*

*Musculoskeletal*

*Over-head*

*Personnel*

*Petrochemical*

*Plant*

*Production*

*Repetitive*

*Stress*

*Symptoms*

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## List of Acronyms

CAPEX	Capital Expenditure
CBM	Condition Based Maintenance
CMMS	Computerized Maintenance Management System
CTD	Cumulative Trauma Disorder
CTS	Carpal Tunnel Syndrome
DAFW	Day-away-from-work
E4M	Ergonomics for maintenance
FAA	Federal Aviation Administration
HSE	Health, Safety and Environment
IEA	International Ergonomics Association
ILS	Integrated Logistic Support
INCOSE	International Council on Systems Engineering
MSD	Musculoskeletal disorders
MTBF	Mean-Time-Between-Failures
MTTR	Mean-time-to-repair
NAARP	National Aging Aircraft Research Plan
NASA	National Aeronautics and Space Administration
NIOSH	National Institute for Occupational Safety and Health
OEE	Overall Equipment Effectiveness
OPEX	Operating Expenditure
PC	Personal Computer
PM	Preventive maintenance
PVC	Polyvinyl chloride
R&D	Research and development
RCM	Reliability-Centred Maintenance
RMD	Repetitive Motion Disorder
RSI	Repetitive Stress Injuries
ULDs	Upper Limb Disorders
WRMSDs	Work-Related MSDs
WRULD	Work-Related Upper Limb Disorder

## **CHAPTER ONE**

### **INTRODUCTION**

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*Chapter one gives the background to the research study by a way of introduction. Its purpose and intents are explored in form of aims and objectives. The research merits, expectations and constraints are presented.*

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## **1.0 Introduction**

### **1.1 Research background**

In a production environment like the petro-chemical industry, production down-time is of utmost significance because every second lost count (as money and product market share are lost) against production output which is the main focus of the plant (*Galer, 1989*).

Down-time however, may be due to: equipment failure, human error, instrument failure, scheduled maintenance and quality control. In most cases, maintenance is needed when it happens.

More than fifty percent (50%) of down-time in this specific industry is largely due to equipment failure. However, the average time to bring the equipment back on-line may be elongated, which will add to the down-time (*McCormick & Sanders, 1982*). The repair time elongation may be due to several reasons like: equipment complexity or speciality, nature of failure (mechanical, electrical or instrument), maintenance structure or system, tools and machinery requirement for repair, technical support required, lack of skilled maintenance personnel and so on.

There are several factor and parameters that can be worked upon to improve maintenance. Some of the factors are: (*Siemens.com, 2010; Svantesson, 2000*)

- Plant maintenance optimization
- Precision maintenance
- Maintainability improvement
- Equipment improvement
- Logistics improvement
- New equipment selection
- Process optimization
- Equipment optimization
- Supply chain management for effective maintenance.
- Maintenance strategies optimization
- Continuous Improvement Hours

Most of those factors are already been explored by industry specialists, maintenance consultants, academia, independent researchers and research and development (R&D) of

industries. There are successes already recorded in those efforts leading to marketing of products of such areas.

A factor which is not always considered when a piece of equipment breaks down is the ergonomic side factors which may affect maintenance down-time. This research is going to, amongst other things; investigate the effect of ergonomics on maintenance personnel to reduce down-time (improve plant availability) with the ultimate aim of improving maintenance in the petrochemical industry.

## **1.2 Problem statement**

Maintenance is important to continuous and efficient running of a petrochemical plant. Various equipment used in the process sometimes breakdown due to wear and tear, inefficient processes, equipment aging, human error, equipment failure, and so on. Maintenance is required whenever such happens.

Several attempts have been on to improve maintenance because, it is a major factor that determines plant availability in process and other manufacturing industries. That is why organizations adopt suitable maintenance approaches to ensure that their operation is available most of the time.

One of such studies conducted on seventy manufacturing plants revealed that over 50 percent of the maintenance work performed by these organizations was reactive (run-to-failure). 25 percent was preventive (period based), 15 percent was predictive (condition based), and proactive (root-caused based) was 10 percent. The study also found that within a period of five years, there was improved productivity which correlated with a number of variables out of which preventive/predictive maintenance is an important one (a strong correlation exist between production cost reduction and preventive/predictive maintenance). (*Laskiewicz, 2005*)

That led to the following recommendations; maintenance is a key department that needs to be well managed. Maintenance department should be led by a strong-minded individual who is a good motivator, technically competent, experienced and familiar with advanced industry practices and maintenance planning should be given top priority. (*id.*)

A Petro-chemical plant may be shut-down based on routine or planned maintenance. The speed at which the plant is brought back on-line often depends on:

- i) Nature or complexity of the failure
- ii) Tools or machineries required and availability of such
- iii) Parts availability
- iv) Skills or expertise required
- v) Maintenance personnel availability
- vi) Maintenance management system operational in the plant
- vii) Technical support required etc.

A factor not often considered is ergonomics in relation to the speed at which maintenance is carried out. That is because ergonomics is often thought of in relation to perpetual users like operators. The emphasis is mostly on: seating (body position), hands and legs position /movement, lighting, screen monitor resolution and so on.

Sometimes, the design of part of a plant or piece of machinery may not be ergonomically favourable to maintenance personnel, which may extend the down-time of a planned or unplanned maintenance activity.

That may sometimes lead to:

- (i) Ergonomic related injuries to personnel.
- (ii) Increased production or overhead cost.
- (iii) Not meeting production targets (elongation of mean-time-to-repair leading to unexpected production time loss, hence, possible loss of product market share).
- (iv) Modification cost for end – users.

*Those factors, amongst others, directly contribute to this research work being targeted at investigating the impact of ergonomics on the effectiveness of maintenance personnel to reduce down-time (improve plant availability) in the petrochemical industry in a bid to improve maintenance. Whatever has an impact on maintenance personnel activities, directly impact plant availability.*

### **1.3 Research Aims and Objectives**

#### **1.3.1 Aims**

This research work will focus on and has its main aim in:

- A. Identifying the enormity of the impact of ergonomics on technical personnel's performance as it affects plant availability (reduced down-time) in the petrochemical industry using two case studies (Case A and Case B).
- B. Identifying possible solutions and techniques that may be recommended for application in the petrochemical industry to ensure that plant are more available for operation by eliminating ergonomics-related down-time.

#### **1.3.2 Objectives**

Specific objectives of the research will be to:

- A. Inquire about ergonomics issues in maintenance activities in the petrochemical industry in the two case studies.
- B. Investigate if ergonomics have any impact on maintenance and on the performance of maintenance personnel per se.
- C. Investigate the type of impact it may have and quantify the impact in terms of:
  - i) Type of ergonomic related injury or ailment sustained.
  - ii) Man-hour loss or and day-away-from-work (DAFW).
  - iii) Cost (medical and over-head).
  - iv) Production down-time elongation (plant availability).
  - v) Equipment utilisation.
- D. Develop solutions that will mitigate the impact of ergonomics on the performance of maintenance personnel in the petrochemical industry (by eliminate that part of down-time due to ergonomics risk factor).

### **1.4 Merits**

This research work would have achieved its aim if after the research has been carried out and recommendations implemented, it is able to identify the enormity of the negative impact of ergonomics on the effectiveness of maintenance personnel in the petrochemical industry and recommend possible strategies leading to:

- (i) Reduced health hazards on the maintenance personnel due to repetitive stress associated with their activities.
- (ii) Improved effectiveness on the performance of the maintenance personnel.

- (iii) Reduced production down-time.
- (iv) Improved tools and maintenance equipment devised.
- (v) Meeting planned maintenance schedules.
- (vi) Reduced cost, both over-head and medical (treating ergonomic related ailment among maintenance personnel).
- (vii) Other industries might also benefit if the outcome of this research work is applied to their operation to improve maintenance activities.

It is obvious that all the factors mentioned above are inter-linked, if health hazards due to ergonomics are mitigated (overhead cost due to medical aid will be reduced): maintenance personnel will be more available to plan better on maintenance strategies, tools, equipment and attend to maintenance issues promptly. That means everything is working together to increase the plant up-time (reduce plant down-time, increase plant availability)

This research work outcome may benefit maintenance personnel, operators, production planners and maintenance planners in the industry during maintenance shutdowns. If maintenance is done with less or no ergonomic related stress or injuries, production or overhead cost may be reduced as cost of medical aid due to ergonomic related stress/injury (which this project work, in part, seeks to investigate and quantify) may be reduced or eliminated.

Equipment designers and engineers will be informed on the health implication of poor ergonomic design and incorporate it in subsequent designs. Ultimately, every stake holder in the petrochemical industry will benefit as mitigating ergonomics impact on maintenance activities will ensure improved plant availability. That means more profit and incentives to stake-holders.

### **1.5 Limitations**

There are materials on ergonomics/human factor/human engineering in relation to operators, office equipment, personal computers and so on, but very few materials and data available both on the internet and books when it comes to “ergonomics and maintenance”.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

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*Chapter two delves into the necessary background information that substantiates the research topic. It explores proven facts about the various key words and other related concepts.*

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## **2.0 Literature review**

This section deals with in-depth review of sources: books, journals, internet sources, publications (and so on), of relevant topics and keywords that form the basis for the dissertation.

### **2.1 Petrochemical industry**

Products from hydrocarbons (raw materials like oil or gas) are called petrochemicals. There are several petrochemicals and petrochemical end products. Some petrochemical end products serve as raw materials for other industry. Some of the products of the industry can be classified as:

**Primary products** includes: methanol, ethylene, toluene and propylene.

**Intermediate and derivative products** (generally produced by converting the primary products to more complicated form through chemical process) includes: vinyl acetate for paint, vinyl chloride for PVC and styrene for rubber and plastic.

There are various technology (production methods) involved in petrochemical industry based on the required feed stocks and desired end product. Those will determine the configuration of the petrochemical plant. Sizes of petrochemical plants vary but they normally require a large expanse of land because all petrochemical plants use extensive pipeline network, furnaces rotating equipment, columns, vessels and tank.

The technology involved in petrochemical plants requires specialized equipment, sophisticated engineering and high-skilled staff. It is quite evident from the fore-going that the industry is capital intensive as its requirement for productive outputs are expensive. ([www.wisegeek.com](http://www.wisegeek.com)). Figure 2.1 below shows a typical petrochemical plant.

## **Typical Petrochemical Plant**



**Figure 2.1- Typical petrochemical plant**

([www.linde-engineering.com](http://www.linde-engineering.com))

### **2.1.1 Petrochemical plant overview**

A petrochemical plant comprises of an oil refinery and chemical process plants which make use of the products of the refinery in producing other useful products like: raw materials for rubber, paints, paper, Polyvinyl chloride (PVC), resin manufacturing, plastics, textile, fertilizer and so on. (*Chemistry Industry Association of Canada*)

### **2.1.2 Refining**

The oil or petroleum refinery produce petroleum products like: gasoline, diesel fuel, asphalt base, heating oil, kerosene and liquefied petroleum gas from crude oil or coal. The crude oil is usually the product of a production facility. Coal as a raw material for a refinery comes from a coal mine where the coal has been processed to a usable grade.

Oil refineries are generally large industrial complexes with extensive piping carrying streams of fluids (gas and liquid) between chemical processing units. A lot of technological resources are employed. The range of final products from the refinery is usually stored temporarily in oil depot (tank farm) before final shipping or distribution. (*Gary & Handwerk, 1984; Leffler, 1985*)





**Figure 2.2 – A typical oil refinery** (Phillips Petroleum Company)

*Refining is the processing of one complex mixture of hydrocarbons into a number of other complex mixtures of hydrocarbons. The safe and orderly processing of crude oil into flammable gases and liquids at high temperatures and pressures using vessels, equipment, and piping subjected to stress and corrosion requires considerable knowledge, control, and expertise.* ( OSHA technical manual, 2010) Figure 2.2 above shows a typical oil refinery.

It noteworthy however, that various refining processes and technology have evolved over time and are been improved upon continuously. Table 2.1 below gives a summary of some refining technology that has been.

<b>HISTORY OF REFINING</b>			
<b>Year</b>	<b>Process name</b>	<b>Purpose</b>	<b>By-products, etc.</b>
1862	Atmospheric distillation	Produce kerosene	Naphtha, tar, etc.
1870	Vacuum distillation	Lubricants (original) Cracking feedstocks (1930's)	Asphalt, residual coker feedstocks
1913	Thermal cracking	Increase gasoline	Residual, bunker fuel
1916	Sweetening	reduce sulfur & odor	Sulfur
1930	Thermal reforming	Improve octane number	Residual
1932	Hydrogenation	Remove sulfur	Sulfur
1932	Coking	Produce gasoline basestocks	Coke
1933	Solvent extraction	Improve lubricant viscosity index	Aromatics
1935	Solvent dewaxing	Improve pour point	Waxes
1935	Cat. Polymerization	Improve gasoline yield & octane number	Petrochemical feedstocks

1937	Catalytic cracking	Higher octane gasoline	Petrochemical feedstocks
1939	Visbreaking	reduce viscosity	Increased distillate,tar
1940	Alkylation	Increase gasoline octane & yield	High-octane aviation gasoline
1940	Isomerization	Produce alkylation feedstock	Naphtha
1942	Fluid catalytic cracking	Increase gasoline yield & octane	Petrochemical feedstocks
1950	Deasphalting	Increase cracking feedstock	Asphalt
1952	Catalytic reforming	Convert low-quality naphtha	Aromatics
1954	Hydrodesulfurization	Remove sulfur	Sulfur
1956	Inhibitor sweetening	Remove mercaptan	Disulfides
1957	Catalytic isomerization	Convert to molecules with high octane number	Alkylation feedstocks
1960	Hydrocracking	Improve quality and reduce sulfur	Alkylation feedstocks
1974	Catalytic dewaxing	Improve pour point	Wax
1975	Residual hydrocracking	Increase gasoline yield from residual	Heavy residuals

**Table 2.1 - History of refining**

*OSHA technical manual, 2010*

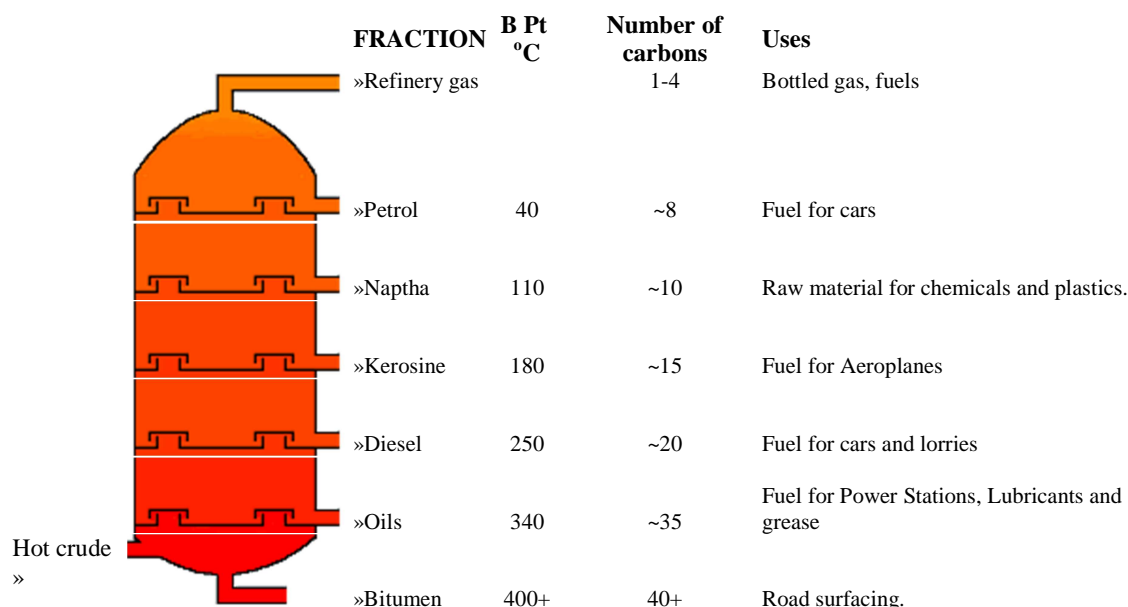
### **2.1.3 General refining processes.**

A refinery breaks down a raw material like crude oil into various components (petro and other related products) which are later changed into new products. The process of refining takes place inside a piping network and vessels. The process is normally controlled from a highly automated control room. Refineries perform three main functions which are:

- Separation (fractional distillation)
- Conversion (cracking and re-arranging the molecules)
- Treatment and blending

#### **Fractional distillation process and products**

Figure 2.3 below shows a fractional distillation system where crude oil is fed into a furnace and the resulting liquids and vapours passes through a distillation column tower. The figure shows the different product coming out of the tower at different temperature.



**Figure 2.3 Fractional distillation process and products**

([www.moorlandschool.co.uk](http://www.moorlandschool.co.uk))

### **Conversion (cracking and re-arranging the molecules)**

This process changes one fraction into another using one of the following methods:

**Cracking** – this is breaking of large hydrocarbons into smaller pieces. There are several methods of doing that which includes: thermal, steam, coking, catalytic cracking, fluid catalytic cracking and hydro-cracking.

**Unification** – this combines smaller pieces of hydrocarbons into larger ones.

**Alteration** – this is re-arrangement of various pieces of hydrocarbon to make desired hydrocarbons (alkylation).

### **Treatment and blending**

Distillates and chemically processed fractions often contain impurities like: organic compounds (containing sulphur, nitrogen, oxygen) water, dissolved metals and inorganic salts. Treatment and blending also ensures that a product meets specific requirement. For instance, refineries produce petrol with more volatile hydrocarbons (short carbon chains) during winter while they add less volatile hydrocarbons during summer due to higher temperatures.

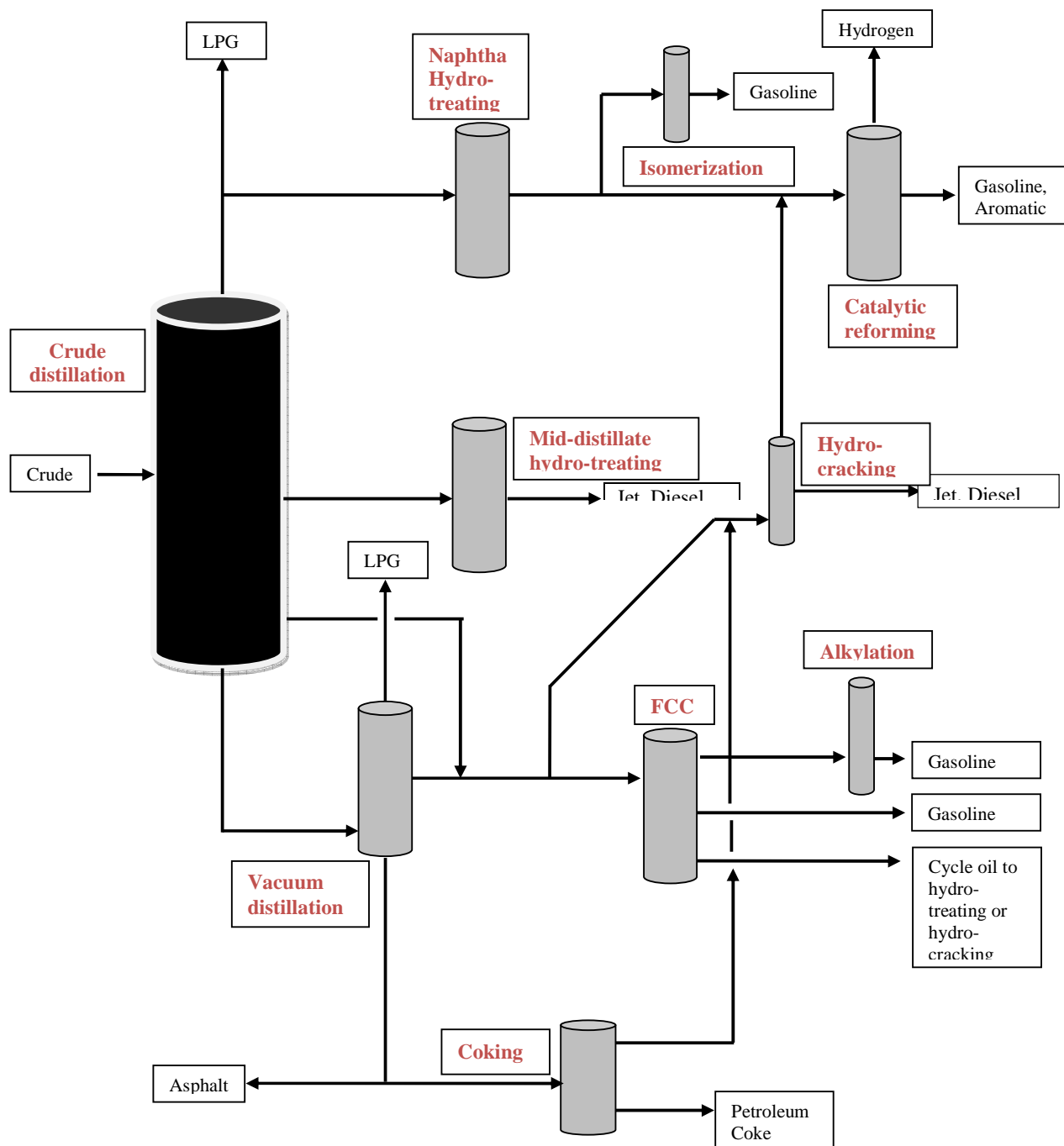
Some examples of treating process are:

Removal of unsaturated hydrocarbons, nitrogen compounds, oxygen compounds and residual solids (tars and asphalt) in a column of sulphuric acid.

Removal of water by passing fractions through an absorption column filled with drying agents.

Removal of sulphur and sulphur compounds in sulphur treatment and hydrogen-sulphide scrubbers. (<http://science.howstuffworks.com>)

### Generic Oil Refinery Process Schematic



**Figure 2.4 Refining Process overview**

(Process Engineer associates)

Figure 2.4 above shows a general refining process based on previous discussion. It is quite obvious that a refinery requires working with process lots of equipment, chemicals, instrumentation and controls.

There are potential physical, mechanical, chemical, and health hazards associated with the operations. Some of those have been identified and provisions are made for safe operating practices and appropriate protective measures. *These measures may include hard hats, safety glasses and goggles, safety shoes, hearing protection, respiratory protection, and protective clothing such as fire resistant clothing where required. In addition, procedures should be established to assure compliance with applicable regulations and standards such as hazard communications, confined space entry, and process safety management. (id)*

As a result of the increasing complexity of a refinery or petro-chemical plant structure and equipment, ergonomics risk increases particularly for technical personnel. Technology required in a process largely determines the layout of the plant. Technology choice however, depends on process feed (crude oil, coal or gas). Technological improvement also often requires modification of existing plants/facilities which sometimes may not put the ergonomics impact on technical personnel into consideration.

Some industry players have standards which put human factor into consideration in their operation but experience has shown that contractors sometimes neglect the standard (referred to as “Safety-in-design”) and build based on the most convenient design they deem fit. That is one major reason for having “as built drawing” during construction phase which supersedes the original design drawing as it becomes the working document for the facility. *(Chevron, 2010)*

## **2.2 Maintenance improvement**

According to encyclopaedia of business, *Maintenance is the combination of all technical and associated administrative actions intended to retain equipment, machinery or plant in, or restore it to, a state in which it can perform its required function. Many companies are seeking to gain competitive advantage with respect to cost, quality, service and on-time deliveries. The effect of maintenance on these variables has prompted increased attention to the maintenance area as an integral part of productivity improvement.*

Improvement has been defined as, “making a thing or its services better and readily available”. Maintenance improvement is a system of restoring the services of a plant or piece of equipment and ensures that it is readily available. It is very essential to have a maintenance improvement strategy in place in a petro-chemical plant. (*Dumn, 1998*)

Some of the methodologies make use of up-to-date record or history of the process operation and maintenance.

The data so collected from the history will identify:

- Nature of failures or breakdown with time
- Down-time duration
- Maintenance efforts in use but not needed.
- Maintenance strategy actually needed.
- Areas where maintenance can be made easier and cheaper
- Training required.
- Logistics changes required.
- Equipment re-designing or modifications required.

Reviewing operations and maintenance history should not be limited to major failures or breakdowns only. Minor failures should be addressed as a cluster of them can cost even more than a major failure. (*Taylor, 2000*)

### **2.2.1 Maintenance improvement strategies**

There are several approaches and methodologies adopted in improving maintenance. Some of the methodologies are (the list in-exhaustive):

- Bench-marking
- Trend analysis (operations and maintenance history analysis)
- Plant maintenance optimization
- Precision maintenance
- Maintainability improvement
- Equipment improvement
- Logistics improvement
- New equipment selection
- Process optimization
- Equipment optimization
- Supply chain management for effective maintenance.

- Maintenance strategies optimization
- Continuous Improvement Hours (the percentage of internal maintenance labor hours that is used to improve the current performance to an increased level. Continuous Improvement Hours are used to improve the performance for, but not limited to safety, quality, and environment, availability, output and cost). (*Svantesson, 2007; Dumn, 1998*)

### **2.2.2 Maintenance improvement efforts**

Numerous attempts have been made to improve maintenance by organizations (equipment manufacturers, industry and consultants), individuals and academia. That has led to development and advances in:

- Maintenance technology
- Information and decision technology in maintenance
- Maintenance methods
- Linking maintenance to quality improvement strategies
- The use of maintenance as a competitive strategy

Those trends of development and advances have brought about:

1. The use of artificial intelligence techniques (like expert systems and neural networks) in formation of maintenance knowledge in industrial organizations. Several of these abound today from vendors and maintenance consultants (like: CHARLEY, XCON, CATS, INNATE, FSM, RLA, GEMS, TOPAS and so on).
2. The need to integrate maintenance management into corporate strategies to remain competitive through equipment availability, quality products, on-time deliveries and competitive pricing. (*Laskiewicz, 2005*)

### **2.2.3 Why ergonomics?**

From the foregoing, it is obvious that maintenance improvement efforts abound in various shades and colour. Delving into it without a focus will be a futile effort. Delving into areas that are already been explored is to re-invent the wheel.

From the discussion so far, the focus of most of the maintenance improvement effort is directed at equipment, machinery, process and operators. Inherent factors like ergonomics is not often considered a necessary metric for improvement. Ergonomics in this sense is not in

relation to operator as that has been over-flogged. Ergonomics is an indirect factor affecting human activities. Most of the time, ergonomic factor is overlooked and treated as work stress.

But, research has shown that ergonomics-related ailment affect people over-time as discussed later on. The cumulative effect could be hazardous if not addressed on time. Most industries and establishment have realized that and are making efforts in creating awareness and putting measures in place to checkmate it.

#### **2.2.4 Ergonomics in trend analysis**

As earlier mentioned, some maintenance improvement efforts make use of plant operational trend (graphical representation of operations over time). This life historical data from the process captures up-time and down-time. However, how much of this down-time has to do with ergonomics impact on maintenance activities is not captured or reflected (*Galer, 1989*).

### **2.3 Ergonomics**

Before the evolvement of technological advancement (traditional times) leading to mass production of tools and machineries, tools were made by users to suit their exact purposes (*Galer, 1989*). Thus, tools fit directly the requirements of the users. Two assumptions on the part of the traditional times tools and machineries makers have been itemised thus (*Woodson & Conover, 1964*):

Assumption one, though the tool and machineries makers in the traditional times are human beings but they are not perfect model of people as a whole both in mental and physical characteristics, likes and dislikes.

Assumption two, things are designed for the use of man and not vice-versa. Hence, things should be made suited to the use of man.

For those and other reasons contrasted below it became necessary to develop a fit between user and machine or tool which has led to the evolvement of an area of study and application devoted to the problem of fit tagged '**ergonomics**'. (Terms like: **human factor**, **biomechanics**, **bio-technology**, **bio-engineering** or **human engineering** is used instead of 'ergonomics'). ([www.thefreedictionary.com/ergonomics](http://www.thefreedictionary.com/ergonomics))



	Traditional tools and machines.	Mass production using technology.
1.	Relatively simple	Increasingly complex.
2.	Made by the user	Made by a manufacturer
3.	Small number made	Large number made
4.	Trivial consequences of design error	Profound consequences of design error
5.	Product competitiveness unimportant	Marketing competitiveness vital
6.	Characteristics of the user population fairly restricted	Wide variation in user population.

*Table 2.2 Traditional versus present day (mass production) production of tools and machineries [Galer: 1989']*

*The design of a tool or equipment may have ergonomics consequence which in effect impacts the way work is done.*

### **2.3.1 Ergonomics defined**

The term 'ergonomics' was derived from two Greek words, '**ergon**' meaning 'work and effort' and '**nomos**' meaning 'natural law or usage' which together mean '**the laws of work**'. The term was first used in modern lexicon when Wojciech Jastrzębowski, a polish biologist, used it in his 1857 article "The Outline of Ergonomics, i.e. Science of Work, Based on the Truths Taken from the Natural Science. ([www.ergoweb.com/resources/reference/history.cfm](http://www.ergoweb.com/resources/reference/history.cfm))

From the International Council on Systems Engineering (INCOSE) stand point, *Ergonomics is the name of the engineering discipline concerned with the elimination of aspects of a system design that could cause temporary or permanent injury to people who operate, maintain, or otherwise use the system. This may include identification of steps people can take to reduce the risk of injury when operating, maintaining, or otherwise using the system after it is deployed.*

Further discussion of the definition continues in the next section.

#### **2.3.1.1 Ergonomics definition from the web**

Considering definitions of ergonomics on the web (internet), it is important to note that, the consideration for occasional users like the maintenance personnel is less than for operators. A list of the definitions is contained in appendix D.

That could perhaps be because:

- i) Few people have venture into relating ergonomics to maintenance (it seems insignificant).
- ii) There has not been a notable event that points in that direction particularly from the maintenance personnel themselves.

However, few industries and agencies in the United States of America like: aviation, manufacturing, Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) have realized that there is a relationship between maintenance and ergonomics (human factor). They have initiated some programs like National Aging Aircraft Research Plan (NAARP), the “safer skies” initiative (etc) geared towards improving maintenance using human factor approach. That has led to the growing effort in research and development in the aviation industry resulting in the establishment of human factor programs by most airlines and third-party repair stations. (*International Journal of Industrial ergonomics*, 2000)

According to McCormick and Sanders (1982), no short catch phrase can adequately characterize the scope of the burgeoning field of human factors, such expressions as *designing for human use and optimizing working and living conditions* may at least lend a partial impression of what human factors is about. However, they approach the definition of ergonomics (human factors) in three stages, as follows:

The central *focus* of human factors relates to the consideration of human beings in carrying out such functions as:

- i) The design and creation of man-made objects, products, equipment, facilities and environments that people use.
- ii) The development of procedures for performing work and other human activities.
- iii) The provision of services to people.
- iv) *The evaluation of the things people use in terms of their suitability for people.*

The *objectives* of human factors in these functions are twofold, which are:

- i) To enhance the effectiveness and efficiency with which work and other human activities are carried out.
- ii) *To maintain or enhance certain desirable human values (like health, safety, satisfaction). This has to do more with human welfare and well-being.*

The central **approach** of human factors is the systematic application of relevant information about human abilities, characteristics, behaviour and motivation in the execution of such functions.

According to Kroemer et al. (2001), Ergonomics is the application of scientific principles, methods and data drawn from a variety of disciplines to the development of engineering systems in which people play a significant role.

Ergonomists should be involved in the system design process. The ergonomist needs to have a thorough understanding of the user's role in overall system performance and that systems exist to serve their users. In this case, it is not just in relation to only operators but even the maintenance personnel.

*Summarily, it can be concluded that ergonomics seeks to enhance the use of science and engineering products (which the petro-chemical industry benefit immensely from) in the most efficient manner that will guaranty the safety and health of end-users and protect the environment.*

#### **2.3.1.2 Ergonomics domains**

The International Ergonomics Association – IEA ([www.iea.cc/](http://www.iea.cc/)) divides ergonomics into three domains which are:

- i) **Physical ergonomics:** this is concerned with human body in relation to physical activities using anatomical, anthropometric, physiological and biomechanical characteristics. (Relevant considerations include: *working postures, materials handling, repetitive movements, lifting, work related musculoskeletal disorders, workplace layout, safety and health*). This domain has much relevance to maintenance activities in the petro-chemical industry.
- ii) **Cognitive ergonomics:** this deals with mental processes (perception, memory, reasoning, and motor response) and how they affect interactions among humans and other elements of a system. (Considerations include: *mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training*). Those are much related to human-system and Human-Computer Interaction design.

iii) **Organizational ergonomics:** this has to do with the optimization of socio- technical systems, including their organizational structures, policies, and processes. (Considerations here include: *communication, crew resource management, work design, design of working times, teamwork, participatory design, community ergonomics, co-operative work, new work programs, virtual organizations, and quality management*).

## **2.4 Development of ergonomics.**

Ergonomics have come a long way in history. That is, men have recognized the need for fitting task to man and not vice-versa. It will suffice to see through some of the work done in that regard so far.

The need to march the way work is done to suit the worker was identified and used during the early Egyptian civilization. Archaeological records show that the early Egyptians Dynasties made tools, household equipment, among other things that illustrated ergonomic principles. ([www.techrecto.com/whatiswhat/what-is-ergonomics](http://www.techrecto.com/whatiswhat/what-is-ergonomics))

Although, that is in contention with some school of thought that attribute the early development of the concept to the Hellenic civilization (Ancient Greece). A good deal of evidence indicates that Hellenic civilization in the 5th century BCE used ergonomic principles in the design of their tools, jobs, and workplaces.

One outstanding example of this can be found in the description Hippocrates gave of how a surgeon's workplace should be designed and how the tools he uses should be arranged. (*Marmaras et al, 1999*)

However, the association between occupations and musculoskeletal injuries was recognized and documented by Bernardino Ramazzini (1633-1714). He wrote about work-related complaints (he was practically involved in studying work-related sicknesses during his medical practice) in the 1713 edition (second) of his 1700 publication titled, "De Morbis Artificum (Diseases of Workers)." (*Franco & Franco, 2001*)

In the early 1900's, the output of industry was still largely dependent on human power/motion. That led to the development of ergonomic concepts to improve workers productivity. A

strategy geared at improving worker efficiency by improving the job process called “Scientific Management”, became popular.

Frederick W. Taylor was the pioneer of this approach and he actively evaluated jobs to determine the "One Best Way" they could be performed. He studied craft jobs like: soldering (steel industry) pig iron lifting and bricklaying. At Bethlehem Steel for instance, Taylor dramatically increased worker production and wages in a shovelling task by matching the shovel with the type of material that was being moved (ashes, coal or ore). He found that 21 pound weight is the optimal for any material been shovelled. (*NetMBA.com, 2010*)

Frank and Lillian Gilbreth succeeded in making jobs more efficient and less fatiguing through: time motion analysis, standardizing tools, materials and the job process. By applying that approach, the number of motions in bricklaying was reduced from 18 to 4.5 which helped bricklayers to increase their pace of laying bricks from 120 to 350 bricks per hour. (*www.accel-team.com/scientific/scientific\_03.html*)

The concept of ergonomics gained more ground during the World War II. There was greater interest in human-machine interaction as the efficiency of sophisticated military equipment (airplanes) could be compromised by bad or confusing design. The consequence of which was very great. That brought about the design concepts of fitting the machine to the size of the soldier and logical/understandable control buttons.

The focus of ergonomics was expanded to include worker safety as well as productivity after World War II. Research began in areas such as:

- i) Muscle force required to perform manual tasks
  - ii) Compressive low back disk force when lifting
  - iii) Cardiovascular response when performing heavy labour
  - iv) Perceived maximum load that can be carried, pushed or pulled
- (*www.ergoweb.com/resources/reference/history.cfm*)

In the recent time however, ergonomics have found its relevance in several applications and industries including aviation (aerospace), information technology (IT), office equipment, health care, product design, transportation, aging, control room design and layout etc.

## 2.5 Ergonomics related disciplines

Ergonomics is not a brand new science. It is a combination of the applications of some aspects of disciplines like: human science, social science and engineering. The involvements of some of the disciplines are: (*American Occupational Therapy Association*)

- i) **Anthropometry:** - the measuring and description of the physical dimensions of the human body.
- ii) **Biomechanics:** - describing the physical behaviour of the body in mechanical terms.
- iii) **Industrial hygiene:** - concerned with the control of occupational health hazards that arise as a result of doing work.
- iv) **Industrial psychology:** - dealing with people's attitude and behaviour in relation to their work and work environment.
- v) **Work physiology:** - applying physiological knowledge and measuring techniques to the body at work.
- vi) **Engineering Psychology:** - studies the relationship of people to machines, with the intent of improving such relationships.

Numerical and data analysis in ergonomics require the application of mathematics and statistics. Apart from normal management functions, management also has the role of co-ordinating the efforts of the other disciplines. Professionals such as: Labour and industrial relations, safety engineers, industrial hygienists, designers, human resources managers, occupational medicine physicians and therapists, and chiropractor also have roles to play when the efforts of the several disciplines are been integrated.

It should not be forgotten however, that all the afore-mentioned disciplines work based on the product of core engineering disciplines like mechanical engineering, chemical engineering, civil engineering and so on who should be involved in implementing good fit between machines and users.

Some application disciplines use ergonomics as components of their knowledge base and work procedures. Some of which are:

- i) **Industrial engineering:** - which deals with interactions among people, machinery, and energies.
- ii) **Bioengineering:** - which works to replace worn or damaged human body parts.
- iii) **Systems engineering:** - which considers human as an important component of the overall work unit.

iv) **Safety engineering and industrial hygiene:** - which focus on the well-being of humans.

v) **Military engineering:** - which relies on the human being as a soldier or an operator.

*(Kroemer, et al, 2001)*

## **2.6                    Adaptation**

A very important factor in ergonomics is adaptation. Adaptation here means, fitting a job to the worker and not the other way round. That is why some writers use the terms ‘good fit’ and ‘poor fit’.

Most emphasis in ergonomics centre around control room size and layout, equipment layout, operator convenience, lighting requirement of work environment, work space characteristics like colour, flooring, roofing, ceilings, walls, fittings layout and so on.

**Good fit** is when the job (tools, machineries and equipment) is made to suit the condition of the worker. That is, tools and machineries are designed in such a way that the worker can use them comfortably. Achieving good fit in a job or task reduces stress on workers. That aids them to do things (perform work) more easily, faster, better with less or no mistakes.

**Poor fit** is when the worker is made to suit the job. In this case, the worker is expected to (or as a matter of necessity) adjusts to the work environment and conditions. That does not go without consequences as outlined in the next section. (<http://www.humanics-es.com/def-erg.htm>)

## **2.7                    Indicators of poor fit between task and user**

Galer: 1989, presented signs of poor fit between task and user at two main levels.

The first and most obvious indication is the output from the user-machine system: lower output than expected, unacceptable quality of output and insufficient output per unit time are possible indications that poor fit exists somewhere in the workplace. An ergonomics investigation is required to confirm that.

At the second level, however, deficiencies in the quality and quantity of the output is sometimes complemented and supplemented by information about the human element in the user-machine system. Poor fit in some occasions is due to the physical relationship between user and machine.

That is summarized in the table 2.3 below.

<b>Level 1</b>	Quality and quantity of output. Quantity of output per unit time
<b>Level 2</b>	Periods of absence because of illness or dissatisfaction. Under use of products or equipment Accidents or critical incidents Complaints and criticism of products and environment

*Table 2.3 Indicators of poor fit between task and user. (Galer: 1989)*

## **2.8 Consequences of poor fit.**

The significance of poor fit is easily understood by anyone who has tried to do a job using the wrong tools. The risk of sustaining injury and increased difficulty in using the tool causes the job to take longer (down-time elongation). That will lead to frustration and loss of temper (morale dampening/psychological impact). This in turn leads to use of excessive force and increases the risk of a slip of the hand and injury (somatic/medical impact). (HSE Books, 2007)

In the industry, such problems arising from poor design of jobs, machines or workplaces sometimes lead to:

- i) Large-scale inefficiencies,
- ii) Risk taking,
- iii) Increase in accidents and 'near-misses', and
- iv) Increase in absenteeism related to dissatisfaction with the job.

Knowledge of ergonomics is very important in preventing ill-health and injury from work and in rehabilitating personnel when injured from ergonomics related system (e.g. someone with back pain).

For example, employees will not like to use personal protective equipment where it does not fit comfortably and interferes unduly with the task for which it is needed. That has defeated the purpose of the personal protective equipment (PPE), though it is not to provide comfort but protection. Protection that hurts is equally undesirable. ([www.agius.com/hew/resource/ergo.htm](http://www.agius.com/hew/resource/ergo.htm))



The following have been itemised as possible signs of ergonomic problem relating to poor fit in a work environment: ([www.hse.gov.uk](http://www.hse.gov.uk))

- i) Tingling
- ii) Continual muscle fatigue
- iii) Sore muscles
- iv) Numbness
- v) Change in the skin colour of your hands or fingertips.
- vi) Swelling in the joints
- vii) Decreased ability to move
- viii) Decreased grip strength
- ix) Pain from movement, pressure, or exposure to cold or vibration.

Laceration, tear and wounds are the extreme manifestation of ergonomics problems.

Sometimes, the signs may not appear immediately because they develop over weeks, months or years. By then, the damage may be serious. That is why it is important to take cognisance of the ergonomic related hazards at work place.

Those signs have been grouped by occupational health practitioners as ergonomics related ailments identified and discussed below.

## **2.9 Ergonomic related ailments.**

According to National Institute for Occupational Safety and Health in U.S.A, ergonomic injuries are the most common cause of workplace illness and injury in the United States. Back injuries and cumulative trauma disorders (CTDs) such as *carpal tunnel syndrome*, *tendinitis*, *bursitis* and *epicondylitis* form the majority of non-fatal occupational injuries and illnesses, costing employers more than 12 billion dollars per year in lost work time, workers compensation payments and medical expenses. (*Lyncht M. Richard, 2002*)

Records in the United States show that over 332,000 cases of work-related CTDs were reported in 1994 alone. Back injuries constitute about 27 percent of the non-fatal occupational injuries annually, meaning that, the back is the part of the body most commonly injured during work. (*id*)

In 1999 alone, repetitive stress injuries (RSI) accounted for 40 percent of all workers' Compensation insurance claims. That led to the proposition of regulations that makes it

mandatory for employers to provide equipment designed to prevent repetitive RSI. (*Kafalas, 1999*)

It has also been noted that, CTDs dramatically increased from 18 percent of occupational illnesses in 1980 to 65 percent in the late 1990s. Within the last two decades, countries like Australia, Japan etc. experienced dramatic increase in ergonomics problem.

### **2.9.1 Musculoskeletal disorders (MSDs)**

Musculoskeletal disorders occur (although causes not limited to this) whenever a mismatch or “poor fit” exist between the physical requirement of a job and the physical capacity of a worker. MSDs affect muscles, joints, tendons, ligaments, and nerves. Most work-related MSDs (WRMSDs) develop over time and are caused by work itself or work environment. MSDs constitute the largest category of self reported ill-health caused or aggravated by work in Britain. ([www.agius.com/hew/resource/muskel.htm](http://www.agius.com/hew/resource/muskel.htm))

Information from a paper presented to a group of newly appointed Magistrates in Nigeria by a consulting physiotherapist on Work-Related MSDs in October, 2008 shows the impact of WRMSDs on Nigerian workers as illustrated below:

The magnitude, cost and burden of work related musculoskeletal disorders (WMSDs) are enormous. Close to 1 million people each year report taking day-away from work to treat and recover from: musculoskeletal pain, loss of function due to overexertion or repetitive motion (either in the low back or upper extremities).

Low back pain constitute about 50% of physiotherapy outpatient cases with a high recurrence rate of 50%- 82% within a year.

Although, there is a risk of long-term disability in both types of disorders, the majority of individuals return to work within 31 days. For workers in their 50s and 60s, musculoskeletal disorder represents the most common cause of disability and current projections suggest that these figures are on the rise.

Musculoskeletal disorder (MSDs) of the low back and upper extremities are crucial and costly national health problem. They are very common among workforce in many countries with

substantial costs and impact on quality of life. Although not only caused by work, they constitute a major proportion of all registered work – related diseases in many countries.

In Nigeria, it is difficult to get accurate data on the incidence and prevalence of musculoskeletal disorders, because only few people report these disorders. Most victims use conservative therapy to treat themselves. Nevertheless, they are the single largest category of work-related illness, representing a third or more of all registered occupational diseases in the United States. (*Uzoamaka, 2008*)

Risk factors causing MSDs are present virtually in every workplace: automobile, textile, mines, commerce, petro-chemical, agriculture, health services, pharmaceutical and construction. An estimated 11.6 million working days a year are lost to work-related MSDs. ([www.hse.gov.uk/msd](http://www.hse.gov.uk/msd))

#### **2.9.1.1 Facts about MSDs (from United Kingdom)**

The health and safety Executive in Great Britain has come up with the following facts about MSDs.

- i) There are things that can be done to prevent or minimize MSDs.
- ii) **MSDs affect large numbers of people across most industries and occupations.**
- iii) MSDs have the potential to ruin people's lives.
- iv) **MSDs impose heavy costs on employers and on society.**
- v) The prevention measures are cost effective.
- vi) Not all MSDs can be prevented, so early reporting of symptoms, proper treatment and suitable rehabilitation is essential. ([www.hse.gov.uk/msd/hsemsd.htm](http://www.hse.gov.uk/msd/hsemsd.htm))

According to Bernard (1997), the European Union included a strategy in ‘Lisbon Objective’ having recognized the impact of MSDs particularly on the work force to reduce MSDs in its community by creating quality jobs. The strategies are to:

- i) Enable workers to stay in employment
- ii) Ensure that work and workplaces are suitable for a diverse population.

#### **2.9.1.2 Causes of Musculoskeletal disorders**

Factors that can cause musculoskeletal disorders have been grouped under two major headings called risk factors which are: physical risk factors and psychosocial risk factors.

### **2.9.1.3 Physical Risk Factors**

- i) Poor or bad Posture (of back, neck, arms etc) - uncomfortable working position.
- ii) Range of movements needed to undertake task.
- iii) Repetitive nature of task.
- iv) Absence of adequate breaks.
- v) Weight of load (heavy lifting).
- vi) Awkwardness of load.
- vii) Bending and twisting (repeating an action too frequently)
- viii) Adverse working environment (e.g. hot, cold)
- ix) Exerting too much force
- x) Working too long without breaks. (*Vogt, 2010*)

### **2.9.1.4 Psychosocial Risk factors**

Psychosocial risk factors are things that may affect workers' psychological response to their work and workplace conditions (including working relationships with superiors and colleagues). Psychosocial risk factors may lead to stress and MSDs when (workers or work):

- i) Have little control over work and work methods (including shift patterns).
- ii) Are unable to make full use of their skills.
- iii) Are not involved in making decisions that affect them.
- iv) Are expected to only carry out repetitive and monotonous tasks.
- v) Is machine or system paced (and may be monitored inappropriately).
- vi) Demands are perceived as excessive.
- vii) Payment systems encourage working too quickly or without breaks.
- viii) Systems limit opportunities for social interaction.
- ix) High levels of effort are not balanced by sufficient reward (resources, remuneration, self-esteem, status).
- x) Not receiving and acting upon reports of symptoms quick enough  
([www.hse.gov.uk/msd/mac/psychosocial.htm](http://www.hse.gov.uk/msd/mac/psychosocial.htm))

### **2.9.1.5 Symptoms of Musculoskeletal disorders**

Musculoskeletal disorders may begin as: (<http://www.merck.com>)

- i) Pain
- ii) Numbness or stiffness in joints
- iii) Weakness
- iv) Joint noises

- v) Decreased range of motion
- vi) Tingling, or aching sensation in muscles.

*That may be accompanied by:*

- i) Burning sensation,
- ii) Swelling,
- iii) Warmth,
- iv) Tenderness,
- v) Impaired function,
- vi) Redness (sometimes).

MSDs symptoms often start and progress gradually. They become more severe with continuous exposure to the condition causing them. That may result in: damage to nerves, tendons, joints, or soft tissue. (*id.*)

## **2.9.2 Upper Limb disorders (ULDs):**

Upper limb disorders (ULDs) are aches, pains, tension and disorders felt in any part of the arm from fingers to shoulder, or the neck. That may include problems with soft tissues, muscles, tendons and ligaments, along with the circulatory and nerve supply to the limb. Upper limb disorders (ULDs) are often caused or made worse by work. ([www.iom-world.org/sicknessabsence/uld.htm](http://www.iom-world.org/sicknessabsence/uld.htm))

Some recognized conditions of ULDs are: *Carpal tunnel syndrome* and *tenosynovitis*. In some cases, we have conditions where there is pain but no recognized condition.

**Repetitive strain injury (RSI)** (also called: repetitive stress injury, repetitive motion injuries, repetitive motion disorder “RMD”), **cumulative trauma disorders (CTDs)**, **regional musculoskeletal disorder or occupational overuse syndrome** are also used to describe ULDs. ([en.wikipedia.org/wiki/Repetitive\\_strain\\_injury](http://en.wikipedia.org/wiki/Repetitive_strain_injury)) Some schools of thought, however, prefer to use ULDs because several factors contribute to the onset of ULDS which will make narrowing it down to any of those terms or conditions by the victim or patient misleading. However, it will be necessary to look into each of those terms for the purpose of this research.

### **2.9.2.1 Symptoms of ULDs**

The following are typical symptoms of ULDs ([www.healthyworkmatters.or.uk](http://www.healthyworkmatters.or.uk))

- i) Tenderness
- ii) Aches and pain

- iii) Stiffness
- iv) Weakness
- v) Tingling
- vi) Numbness
- vii) Cramp
- viii) Swelling

#### **2.9.2.2 Causes of ULDs** (*health.independent.co.uk*)

- i) Repetitive work
- ii) Uncomfortable working postures
- iii) Sustained or excessive force
- iv) Carrying out a task for a long period of time
- v) Poor working environment and organization (e.g. temperature, lighting and work pressure, job demands, work breaks or lack of them)
- vi) Individual differences and susceptibility (some workers are more affected by certain risks)
- vii) The way the work is organized and managed can make a significant contribution to the risk of ULDs as well as make them worse.
- viii) Workers may be more likely to suffer an upper limb problem if exposed to more than one risk factor.

#### **2.9.3 Repetitive Strain injury (RSI)**

Repetitive strain injury (RSI) is a general term used to describe the pain caused to muscles, nerves and tendons by repetitive movement and overuse. The condition mostly affects parts of the upper body, such as the forearm, elbow, wrist, hands, neck and shoulders.

RSI is usually associated with doing a particular activity repeatedly or for a long period of time. It occurs often in people who work with computers or carry out repetitive manual work. That is why 'RSI' is also called 'work-related upper limb disorder' (WRULD).

In the UK, one out of every 50 workers has reported an RSI condition. In 2006 only, nearly half a million people in the UK suffered from some form of RSI. The problem is increasing principally through the intensive use of computers and other technology that involves large amount of typing on keyboard. Posture related health problems are also growing due to the sedentary nature of many jobs. (*www.rsi.org.uk*)

### 2.9.3.1 Types of RSI

There are two types of RSI:

**Type 1 RSI:** RSI is classified as type 1 when a doctor can diagnose a recognized medical condition, such as carpal tunnel syndrome. Symptoms of type 1 RSI usually include swelling and inflammation of the muscles or tendons.

**Type 2 RSI:** RSI is classified as type 2 (otherwise known as, non-specific arm pain) when a doctor cannot diagnose a medical condition from the symptoms. This is usually because there are no obvious symptoms, just a feeling of pain. It is also referred to as non-specific pain syndrome. ([www.repetitivestraininjury.org.uk/types-of-rsi.html](http://www.repetitivestraininjury.org.uk/types-of-rsi.html))

### 2.9.3.2 RSI conditions

Medical conditions and injuries that can be classified as type 1 RSI includes:

- i) **Bursitis:** inflammation and swelling of the fluid-filled sac near a joint at the knee, elbow or shoulder.
- ii) **Carpal tunnel syndrome:** pressure on the median nerve passing through the wrist.
- iii) **Dupuytren's contracture:** a thickening of deep tissue in the palm of the hand and into the fingers.
- iv) **Epicondylitis:** inflammation of an area where bone and tendon join. An example of epicondylitis is tennis elbow.
- v) **Rotator cuff syndrome:** inflammation of muscles and tendons in the shoulder.
- vi) **Tendonitis:** inflammation of a tendon.
- vii) **Tenosynovitis:** inflammation of the inner lining of the tendon sheath that houses tendons. Tenosynovitis most commonly occurs in the hand, wrist or forearms.
- viii) **Ganglion cyst:** a sac of fluid that forms around a joint or tendon, usually on the wrist or fingers.
- ix) **Raynaud's phenomenon:** a condition where the blood supply to body extremities, such as the fingers, is interrupted.
- x) **Thoracic outlet syndrome:** compression of the nerves or blood vessels that run between the base of the neck and the armpit.
- xi) **Writer's cramp:** part of a family of disorders known as dystonia that cause muscle spasms in the affected part of the body. Writer's cramp occurs from overuse of the hands and arms. ([www.nhs.uk/conditions/repetitive-strain-injury](http://www.nhs.uk/conditions/repetitive-strain-injury))

#### **2.9.4 Carpal Tunnel Syndrome (CTS)**

Carpal tunnel syndrome is a painful disorder of the wrist and hand. A band of fibrous tissues surround the wrist which normally support the joint. The narrow tunnel between the fibrous band and the wrist bone is called the carpal tunnel. (*U.S. National Institutes of Health*)

The carpal tunnel protects the median nerve which helps to move the thumb, index and the two middle fingers of each hand. Any condition that causes swelling or a change in position of the tissue within the carpal tunnel can squeeze and irritate the median nerve. Irritation of the median nerve in that manner causes: tingling and numbness of the thumb, index and the middle fingers, a condition known as "carpal tunnel syndrome."

Carpal tunnel syndrome occurs when other tissues in the carpal tunnel (such as ligaments and tendons) get swollen or inflamed and press against the median nerve. That pressure can make part of the hand hurt or feel numb. ([www.ninds.nih.gov/disorders/carpal\\_tunnel/detail\\_carpal\\_tunnel.htm](http://www.ninds.nih.gov/disorders/carpal_tunnel/detail_carpal_tunnel.htm))

There are controversies on work-related CTS in some areas but researchers are still working on. Some professionals believe that some cases of CTS are work-related due to facts emerging from nations around the world. Some writers however, prefer to refer to work-related CTS as RSI.

In USA, Carpal tunnel surgery is between 400,000 and 500,000 annually with economic costs in excess of two billion dollars per annum. Cost of compensating workers relative to other cases is about three times. (*Palmer & Hanrahan: 1995*) Research in Norway shows that at least 1 out of 10 patients drop-out of work after CTS treatment which implies a substantial socio-economical burden on the society. (*Bekkelund et al: 2001*)

##### **2.9.4.1 Causes of Carpal Tunnel Syndrome.**

- i) Repetitive movement of the hand (Doing the same hand movements over and over).
- ii) Working with hand in awkward position. (It's most common in people whose jobs require pinching or gripping with the wrist held bent. People at risk include people



who use computers, carpenters, grocery checkers, assembly-line workers, meat packers, musicians and mechanics. Hobbies such as gardening, needlework, golfing and canoeing can sometimes initiate CTS symptoms). More common among women than men.

- iii) Heredity (which means it runs in families).
- iv) Injury to the wrist, such as a fracture.
- v) Disease (such as diabetes, rheumatoid arthritis or thyroid disease.)
- vi) Carpal tunnel syndrome is also common during the last few months of pregnancy.  
. (*Familydoctor.org/online, medicinenet.com*)

#### **2.9.4.2 Symptoms of carpal tunnel syndrome**

- i) Numbness or tingling in hand and fingers, especially the thumb, index and middle fingers.
- ii) Pain in wrist, palm or forearm.
- iii) More numbness or pain at night than during the day.
- iv) Increasing pain when using hand or wrist.
- v) Difficulties in gripping objects, such as hand tools, doorknob etc.
- vi) Weakness in thumb. (*id.*)

#### **2.9.5 Cumulative Trauma Disorders “CTD”**

Cumulative Trauma Disorders (CTD) is a condition where a part of the body is injured by repeatedly overusing or causing trauma to that body part.

Trauma occurs when the body part is called on to work harder, stretch farther, impact more directly or otherwise function at a greater level than it is prepared for. *The immediate impact may be minute, but when it occurs repeatedly the constant trauma cause damage. It is the build up of the trauma that causes the disorder.* (*ergonomics.about.com*)

CTD is a collective term for syndromes characterised by discomfort, impairment, disability or persistent pain in joints, muscles, tendons and other soft tissues, with or without physical manifestations. *It is caused or aggravated by repetitive motions including vibrations, sustained or constrained postures, and forceful movements at work or leisure.*

CTD describes a large group of conditions that result from traumatizing the body in either a minute or major way over a period of time. Some of the conditions so called are: over-use

injury, cervicobrachial disorder, cumulative trauma injury, repetition strain injury, repetitive motion injury, rheumatic disease and osteoarthritis. (*Putz-Anderson, 1988*)

Repetitive strains may be caused by different occupational activities, such as in assembly plant, manufacturing, meat processing, sewing, packing and other manipulations. Other manipulations include maintenance personnel using hand tools. Cashiers in supermarkets and keyboard operators also experience CTD. (*th.mt.com*)

#### **2.9.5.1 Causes and Symptoms of CTDs**

From the fore-going, it is obvious that the causes and symptoms of CTDs are the same as that of RSI and CTS earlier discussed. CTD is a collective name for the ergonomic related ailments earlier discussed apart from back injury or back pain.

#### **2.9.6 Back Injury or pain:**

Back injury (or pain) is a hurtful sensation usually felt at low back. Back injury is not associated with any serious disease known but mostly due to damage, wear, or trauma to the bone, muscles, or other tissues of the back. Back injuries affect mainly the lower part of the back (the lumbar). That area is susceptible because of its flexibility and amount of body weight it bears. (*Shiel, 2008*)

Low back pain is common and can be extremely painful. Speculation has it that about 50 to 70 percent of the total population in the United States suffers back pain. It should improve within days or weeks if not as a result of slipped disc or trapped nerve which normally get better on their own too. If a back pain should get worse within weeks, then medical attention is required. (*Putz-Anderson et al, 1994*)

##### **2.9.6.1 Causes of back pain**

Back pain is more common in tasks that involve:

- i) Incorrect lifting methods and posture (lifting heavy or bulky loads):
- ii) Carrying loads awkwardly, possibly one handed.
- iii) Repetitive tasks, packing of products.
- iv) Long distance driving or driving over rough ground, particularly if the seat is not, or cannot be properly adjusted.
- v) Stooping, bending or crouching, including work at PCs (poor posture).
- vi) Pushing, pulling or dragging heavy loads.

- vii) Working beyond normal abilities and limits.
- viii) Working when physically tired.
- ix) Stretching, twisting and reaching (lifting, bending, and twisting motions of the torso affect both the degree of severity and frequency of low-back pain).
- x) Sedentary lifestyles (Prolonged periods in one position).  
([www.hse.gov.uk/msd/backpain/workers/work.htm](http://www.hse.gov.uk/msd/backpain/workers/work.htm))

## 2.10 Ergonomics and Systems Engineering

Systems Engineering handbook, (INCOSE, 2006) defines Systems Engineering as an interdisciplinary approach and means to enable the realization of successful systems.

It emphasized Systems engineering application throughout a systems life cycle. It also models Systems life cycle into six stages which are: Concept, Development, Production, Utilization, Support and Retirement.

Four process groups were identified that support systems engineering which are:

**Technical Processes:** this deals with technical requirements of a system which include: stakeholder requirements definition, requirements analysis, architectural design, implementation, integration, verification, transition, validation, operation, maintenance and disposal.

**Project Processes:** this deals with soft aspect of a system development which includes: planning, assessment, control, decision-making, risk management, configuration management and information management.

**Enterprise Processes:** the management aspect of a project is addressed here which comprises of: enterprise management, investment management, system life cycle processes management, resource management and quality management. This process is very important in systems engineering as the outputs of the system life cycle management process directs the tailoring of the Technical and Project processes.

**Agreement Processes:** this process deals with systems acquisition and supply.

The technical process addresses operation and maintenance phases of a system's life cycle. Essentially, those are the phases where ergonomics comes in.

Operation phase has the main purpose of making the system deliver its intended services. The operation phase more often runs concurrently with maintenance phase.

The Operation phase: brings in personnel to operate the systems, monitors operator-system performance and monitors the system performance. If the system is replacing an existing system, the transition between the systems needs to be well managed such that persistent stakeholders do not experience a breakdown in services or experience unexpected operational conditions.

The technical process monitors operator-system performance as mentioned above. Although, ergonomics comes in here under the technical process but Speciality engineering activities takes much cognisance of it. The approach of speciality engineering in relation to ergonomics is as expressed below.

Systems engineering recognise that ergonomics (Human Engineering or Human Systems engineering) affects every areas of a system that has a human-machine interface. That is why it recommends that human system factors should be integrated into the design of systems.

The objective of speciality engineering is to achieve a balance between system performance and cost. To achieve that is to ensure that the system design is compatible with the capabilities and limitations of the diverse people, who will operate, maintain, transport, supply, and control the system. Systems engineering takes it as both ethical and obligatory that a concern for human operators, maintainers, and administrators is reflected in the design of systems.

It also recognises the fact that it is not possible to eliminate all ergonomics risks by design. But, it recommends that remediation steps be identified and taught to people so as to reduce the risk of temporary or permanent injuries.

### **Ergonomics specialist/engineer roles in system engineering**

Systems engineering addresses ergonomics issues early enough in system development, that is, during “requirements analysis”. At this stage requirements from different sources and disciplines are analyzed to resolve conflicts. The human factors engineer is primarily responsible for two types of requirements:

1. Human performance requirements
2. Human engineering design requirements.

The first requirement, human performance requirements put into considerations times and accuracies for tasks assigned to humans. The ergonomics engineer must ensure that the proposed requirements are in fact achievable by the intended operators and users (including maintainers).

Systems engineering has a robust consideration for ergonomics not only in relation to operators but other users including maintenance personnel.

*As earlier mentioned, systems engineering takes it as a matter of ethics that systems do not present undue risks to the people who will use them. That is why ergonomics engineering process begins during the Concept Stage of the system life cycle and continues throughout the life of the system.*

Systems engineering identifies a three-step process to reduce the risk that a system will require costly rework due to ergonomics issues before it is deployed for use or may not be deployed at all. The three-step process is to:

1. Identify the key design considerations during development of the system and address them in step 3.
2. Build the right team.
3. Manage the human factors engineering process. (*id.*)

From the fore-going, the consideration given to ergonomics in systems development by systems engineering is quite big but the reality is that some systems do not conform. That implies that the application of systems engineering in process equipment development needs to be taken more seriously by all stake-holders.

## **2.11 Maintenance**

Maintenance can be applied to several things and situations in human endeavours, however, it would be considered in the context of this research work as it relates to petro-chemical industry.

Maintenance is the act of keeping a machinery, plant, equipment and system in good working condition using routine (care) operations, servicing, overhauling, repairs, part replacement and so on to ensure plant availability and optimum production. (*Prof. Wichers, 2007*)

There are several other definitions available but they all tend towards that same end. Some of the definitions are contained in appendix E.

## **2.12 Maintenance strategies.**

Several strategies are there to adopt in maintaining process equipment. The complexity and size of petro-chemical plant requires that a maintenance structure be on ground. Individual company (organization) within the industry has to adopt the most suitable maintenance strategy for its operation. Some of the strategies are discussed below.

### **2.12.1 Pro-active Maintenance**

This is a maintenance strategy that uses a variety of technologies to extend the operating lives of machines and to virtually eliminate reactive maintenance. It is the latest innovation in the field of predictive maintenance. This strategy employs root cause failure analysis-the determination of the mechanisms and causes of machine faults. It is aimed at correcting fundamental causes of machine failures and systematically eliminates the failure mechanisms from each machinery installation.

For instance, imbalance and misalignment have been identified as the root causes of the majority of machine fault for a long time. Those conditions shortening the service life of bearings by placing undue forces on them. Instead of replacing worn bearings in a machine continually, a better approach will be to perform precision balance and alignment on the machine and verify the results by careful vibration signature analysis. ([www.dliengineering.com](http://www.dliengineering.com))

### **2.12.2 Preventive Maintenance**

Preventive Maintenance are actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level. Simply put, preventive maintenance is performed in order to avoid a failure. This includes simple actions

of greasing and oiling of machine parts.  
([www.weibull.com/SystemRelWeb/preventive\\_maintenance.htm](http://www.weibull.com/SystemRelWeb/preventive_maintenance.htm))

### **2.12.3 Run-to-Failure**

Run-to-Failure, also known as, Corrective/Reactive Maintenance is based on the fact that a piece of equipment is not maintained until it fails. This approach is appropriate when the cost of failure is not significant and production is not affected. The disadvantage is that the maintenance department operates a 'crisis management' maintenance system which is an inefficient way of running a plant. ([www.maintenanceworld.com](http://www.maintenanceworld.com))

### **2.12.4 Condition-Based Maintenance**

Condition Based Maintenance (CBM) also refers to as Predictive maintenance has been defined as "Maintenance actions based on actual condition (objective evidence of need) obtained from in-situ through non-invasive tests, operating and condition measurement." (*Mitchell, 1998*)

Butcher defines this maintenance technology thus "CBM is a set of maintenance actions based on real-time or near-real time assessment of equipment condition which is obtained from embedded sensors and/or external tests & measurements taken by portable equipment." (*Butcher, 2000*)

### **2.12.5 Reliability-Centred Maintenance**

Reliability-Centred Maintenance (RCM) is a maintenance approach used to determine the maintenance requirements of any physical asset in its operating context. Its emphasis is mainly on inherent reliability. In other words, it is a scheduled maintenance program designed to realize the inherent reliability potential of equipment. This is based upon the premise that maintenance cannot improve upon the safety or reliability inherent in the design of the hardware. Good maintenance can only preserve those characteristics. (*Moubray, 1999*)

### **2.13 Maintainability**

According to Jardine (1992), the maintainability of equipment can be defined as the probability that the equipment will be restored to specified conditions within a given period of time ' $T$ ' when the maintenance action is performed in accordance with prescribed procedures and resources. Maintainability is related to the design standard of the equipment.

INCOSE (2006) also looks at maintainability in the light of the design of equipment and how it should be executed. It is presented as follows:

“Maintainability uses analytic methods to determine the proper approach to maintain each element, considering: locations, levels of repair, types of scheduled maintenance, repair or replacement to meet mission objectives in a cost/effective manner. It gives priority to the design process monitoring to ensure that adequate maintenance considerations are included in the system been engineered. It also takes into cognisance: handling and support equipment, test and checkout equipment, facilities, and logistical plans”.

Emphasis is placed on:

- 1. Determining requirements based on the user's-system readiness, mission performance, requirements, physical environments and resources available to support the mission.*
- 2. Managing the contributions to system reliability made by system elements. Some measures include: Failure Rate, Mean-Time-Between-Failures (MTBF), Mean-Time-To-Repair (MTTR), and Mean Error Isolation Time.*
- 3. Ability to find and isolate errors after failures and repair them.*
- 4. Preventing design deficiencies (including single point failures), precluding the selection of unsuitable parts and materials, and minimizing the effects of variability in the manufacturing process.*
- 5. Developing robust systems, acceptable under specified adverse environments experienced throughout the system's life cycle, repairable or restorable under adverse conditions and supportable under conditions consistent with the ILS (Integrated Logistic Support) plan.*
- 6. Requirements for parts, software, materials, and processes should be developed that ensures that the reliability standards for the program can be obtained. Standards and Specifications should be incorporated into program specifications, where appropriate.*
- 7. Monitoring and managing the contributions to system availability from: system reliability, maintainability, supportability, and the overall ILS plan standpoint. (id. Ebeling, 1996)*

From the above definitions and discuss, it is clear that the design of equipment greatly affects the maintenance of the equipment. How ergonomic factors associated with the equipment affect maintenance and maintainability is embedded but not specified.



## **2.14 Ergonomics and Maintenance**

As earlier mentioned, there has not been much consideration for a relationship between ergonomics and maintenance both in literature and internet. It was however found that some industries like, aviation and mining have recognized the relationship and have been working on it. That may be due to:

1. The sensitive nature of their product, services and operations
2. Rate of incidents and accidents occurrence
3. Severity of accidents when they occur

The aviation industry in the United States of America initiated human factors studies in maintenance-related issues through agencies like: Federal Aviation Authority (FAA) and National Aeronautics and Space Administration (NASA), manufacturers, and the aircraft maintenance industry. Examples are: the National Aging Aircraft Research Plan (NAARP), the “Safer Skies” initiatives, the white House Panel on Aviation Safety, and NASA’s aircraft maintenance program. The support of the government in this regard cannot be underscored.

The objective of all those efforts is to identify research issues, to promote and conduct both basic and applied research related to human factors in aircraft maintenance. That approach in maintenance research considers the human as the centre of the system.

([www.vitrom.com/Articles/mso4A8.pdf](http://www.vitrom.com/Articles/mso4A8.pdf))

The importance of ergonomics or human factor to maintenance activities in the mining industry was recognised in the early 1990s and one of such concerns is best put in the words of Mason Steve (1995) below.

*Maintenance has a major relevance to the business performance of industry. Whenever a machine stops due to a breakdown, or for essential routine maintenance, it incurs a cost. The cost may simply be the costs of labour and the cost of any materials, or it may be much higher if the stoppage disrupts production.*

*A maintenance technician who is motivated, well trained, under no time pressure, given the correct information, and working with equipment which has been designed to be maintenance friendly, will likely complete all specified maintenance work to a high standard.*

If those requirements are not met, it is more likely that the maintenance work will receive less than the desired attention and the probability of using short cuts in work methods become very high. That means, the equipment is poorly maintained leading to reduced reliability/availability or direct damage to the plant. On the other hand, the safety of the maintenance technician, other employees and the environment is highly at risk.

The scope for human error in maintenance activities is wide just like in most types of work. These range from: becoming distracted, forgetting important checks and short cut (intentional deviation from a permit to work or standard operating procedure in order to save time or to get the job done in unauthorized circumstances).

Due to unchecked and continual use of some types of human error, they tend to almost become the accepted custom (norm) and practice.

For example, fitters may have got into the habit of omitting final checks during a routine maintenance procedure. Other forms of human error may only occur rarely during exceptional circumstances. For example, crews may mis-diagnose the cause of a novel failure.

Factors which influence the behaviour of maintenance crews and the likelihood of human error should be considered in terms of its effect on, safety of people, damage to plant or equipment, reduced reliability and subsequent breakdown. (*id.*)

The Human Factor Reliability Group in the mining industry presented an observed relationship between ergonomics and maintenance of some equipment and steps taken to correct the impacts.

After observing that machineries entering the mining industry in the recent times have features that make them maintenance unfriendly (result of a research project), a set of design guidelines were developed to correct flaws in both the contents and presentation of available ergonomic guidelines for equipment manufacturing.

The former guidelines contained human factor specifications presented in the extreme conditions in the form of 'Maximum - Minimum' or 'Optimum' format. Designers could not meet such ideal human factors requirement due to some other factors; hence, they chose their perceived best approach (compromise among the factors). A major problem was therefore

apparent in that the designer would then have no idea whether his/her compromise had minimal or severe impact on the performance of the maintainer.

That was why the set of guidelines were reviewed to provide the designer with performance information that will aid him to identify the nature of changes that could be made or acceptable. For instance, if the ideal access to certain fasteners was not provided, better trade-off decisions could therefore be made.

## **2.15 Process Equipment Design**

Equipment, tools, machineries and plants are generally designed today by engineers who may never operate them as earlier mentioned. There are various steps associated with machineries, plants and tools production or construction. Most equipment in the petro-chemical industry are mechanical with electrical and instrumentation controls.

The stages of the design and construction of the equipment and machines varies from process to process based on number of factors like,

- i) Process function
- ii) Technology required (Patented or not, available or to be developed)
- iii) Subject matter experts' availability and proximity (in-house engineers, R&D academia, consulting engineers or firms)
- iv) Cost implication
- v) Material requirement (Construction)

Mechanical design which involves: conception, modelling and design of mechanical systems or modules. From concept to detailed design, drawings production, fabrication and testing. Instrumentation and other support (utilities) will be on going and coupled as construction continues. As construction goes on, series of tests may take place. It is after testing that functional errors are detected and corrected. (<http://sdm.mit.edu>)

## **2.16 Ergonomics and Process Equipment Design**

Developing a new chemical process plant requires the service of industry, academia and technology developers or entrepreneurs. It normally starts with a known need requiring technical solution - for example, removal of heavy metal pollutants from wastewater. In the development stage, the focus is to find a solution to technical need in the most cost effective manner.

The enterprise evaluates whether the technology will accomplish its intended purpose at several stages of the development (bench, pilot and full scale) in a cost effective manner. Once, it is clear that the technology will accomplish its purpose at cost effective manner, it is launched into the market. Detail consideration for end user requirement at this stage has been forgotten. (*McDevitt, 2002*)

That explains while ergonomic error in the mechanical designs is not detected early because the functionality of the equipment is considered more paramount. Nowadays, many functional errors are avoidable because of knowledge gained and lessons learned from existing facilities which are functioning. (*Grossmith, 1998*)

Although, not generally well recognized, the role of ergonomics in improving productivity and quality is well documented. In most cases, ergonomics interventions have been reactive, that is, ergonomics interventions are often initiated only after an injury has occurred and after organization(s) and the worker(s) have incurred losses.

The prospect and opportunities for profitability that present themselves at the commencement of a process plant operation becomes less apparent. The proactive evaluation of a new process plant at the design stage, before losses occur, is of paramount importance. Ideally, such evaluation activities should occur with a fundamental need to support the productivity and profitability goals of the organization.

Ergonomic upgrades often done after a production line has been in operation for some time and after employees have incurred CTDs cannot make for already lost profit. Such losses include costs incurred due to, workers compensation, lost work days, restricted work days, productivity losses in replacing temporarily absent employees, re-work, scrap, employee turnover and other penalties associated with lowered employee morale.

Most often, management wants such upgrades to be simple, fast and of a relatively low cost. Unfortunately, this is not always practicable hence, the rationale for a proactive ergonomics designs review.

Introducing retrofits to an existing process plant comes with enormous problems. Changing a component position, for example, to better suit the employee population, often require changing other work stations and process equipment. This equipment modification is

generally too costly, especially when there may be a need to shut the line down for an appreciable period.

More crucial is the fact that, organizations do not have budget for modifying existing plant and engineering resource are not readily available. Resources would have been logically allocated to new products. The outcome of an ergonomics intervention at this stage is to a great extent, a compromise solution. Certainly where simple, cost effective solutions can be implemented, appreciable successes are often recorded but that is more common at individual work stations and not to a process plant as a whole.

Some ergonomic impacting factors are important and fundamental system parameters that cannot be retroactively resolved easily. Some of such factors are; the improper allocation of space, poor process flow, incorrect working heights, lack of consideration of seated versus standing modes, incorrect equipment design and so on. Consequently productivity and quality penalties associated with these concerns must continue throughout the life of the process plant with a concurrent reduction of profits. Unfortunately, new production lines seem to replicate these same problems.

A proactive approach is required to reduce the ergonomics risk factors. A motto frequently used is: "Design it Right the First Time". To do this, any design team must have a clear understanding of the productivity and profitability goals for the project.

As earlier mentioned, one key solution is to hold process design meetings (where an ergonomics specialist well versed in the technology will be present) for any new process facility. The ergonomist can objectively track design process performance to the organizational productivity and profitability goals from ergonomic stand point. More so, there may be no one in the design team who is more aware of the stressors present in the work place and the resultant cost penalties they represent than him.

As a pre-requisite activity for compiling a project scope of work and budget, ergonomist should be incorporated as he is in position to evaluate task design and workplace stressors. Involving an ergonomist after a project is identified and the project budget is set invariably gives the ergonomist some difficulties in justifying additional monies for improved process designs.

Above all, ergonomics can be the conscience of a project during the design process. It lends support to the project manager in ensuring that the overall system goals remain focused and weak links in independent disciplines are eliminated, or at least minimized. (*Edward, 1998*)

### **Barriers to integration of ergonomics into process design**

Some barriers to integration of ergonomics into process design have been itemised as shown below. (*Steiner & Vaught: 2002*)

**Barrier 1:** people are expected to adapt, hence, there is no demand for use parameters in design. Users are forced to adapt to designs that “make sense” to the designer most. Understanding that ergonomics is not just a “common sense” issue leaves the interface problem unrecognized like working posture, work space constraints and so on.

**Barrier 2:** Organizations often put forth alternatives or perceived solution to a complicated user problem. Many a times, the alternative or perceived solution is arrived at without thorough consideration for all critical parameters like equipment design, work space constraints, working posture/position and so on .

**Barrier 3:** Organizations many a times do not welcome outcomes of independent carefully controlled studies on issues that affect them, leading to repeated designs that are ineffectual and its consequences. Organizations often consider independent researchers’ claims on their activities as indictment rather than improvement synergy.

**Barrier 4:** On recognising machine/human interface problem, organizations often use work force training as a solution which is not. Training is no remedy for process inadequacies.

**Barrier 5:** Quick fix solutions due to time pressure and regulatory or other constraints may work for a while, but they are inappropriate and ineffective.

**Barrier 6:** Design claims are often not put to real-world tests first. Organization perception of an ergonomic problem remains the same until an end user confirms it.

**Barrier 7:** The afore-mentioned training and usability instructions developed when ergonomics problems are encountered are not good enough substitute for anticipation of design problems prior to implementation.

**Barrier 8:** If a process is working and giving out expected outputs according to specifications, any subsequent failures are likely to be blamed on the human user rather than ergonomics.

**Barrier 9:** A process may be meeting physiological requirements, yet fail to meet psychological ones. This must be recognized, identified and attended to, or the device may not be successful. (*id.*)

At present, effort is been directed towards incorporating ergonomics into design of equipment and machineries in some quarters in the United Kingdom as mentioned below.

There are growing concerns for human factors (ergonomics) integration into plant and system design. The aim is to 'design-in' the humans into plant and systems, taking into consideration their capabilities and limitations. This can lead to significant savings in both capital expenditure (CAPEX) and operational expenditure (OPEX) through appropriate manning levels, maintainable plant, reduced re-work and user-friendly facilities and systems.

([www.hu-tech.co.uk](http://www.hu-tech.co.uk))

## **2.17 Maintenance Personnel's effectiveness**

The effectiveness of a maintenance workforce directly impacts the industry as it determines production and other parameters. Assessing the effectiveness of a maintenance workforce or personnel requires using metrics set by the organization. Various organizations have different metrics often referred to as KPI (Key Performance Indicators) for measuring. That depends on what the organization considers paramount.

The concept of Key Performance Indicators and its component varies in its application from one organization to the other but some of them have common ground. Some of the KPI used in relation to maintenance personnel effectiveness in various industries are discussed below.

A survey conducted by Røstad et al (1999) revealed that the most commonly used KPIs in the Norwegian food processing industry are;

- ❖ *Maintenance costs / Produced units*
- ❖ *Budgeted maintenance costs / Real costs*
- ❖ *% Preventive maintenance of total maintenance*
- ❖ *Produced units / Time*
- ❖ *Maintenance costs / Production costs*
- ❖ *Maintenance costs / downtime*
- ❖ *Number of rush- jobs*

- ❖ *Downtime*
- ❖ *Maintenance hours / Produced unit*
- ❖ *Failure rate*
- ❖ *Workload for maintenance personnel*

*The most commonly used indicators are: Budgeted maintenance costs / Real costs, Maintenance costs / Produced units, Maintenance costs / Production costs, and Produced units / Time.*

The research revealed that KPIs are more widely applied in production than in maintenance. However, companies seem to be focusing mainly on economical figures when considering key performance indicators for maintenance personnel. A fraction of the companies use technical-related maintenance KPIs (e.g. downtime, failure rates etc).

The following have been identified as key performance indicators used for maintenance in the manufacturing sector in Canada ([www.ivara.com](http://www.ivara.com))

- ❖ Maintenance Cost
- ❖ Maintenance Cost / Replacement
- ❖ Asset Value of Plant and Equipment
- ❖ Maintenance Cost / Manufacturing
- ❖ Maintenance Cost / Unit Output
- ❖ Maintenance Cost / Total Sales
- ❖ Mean Time Between Failure (MTBF)
- ❖ Failure Frequency
- ❖ Unscheduled Maintenance Related Downtime (hours)
- ❖ Scheduled Maintenance Related Downtime (hours)
- ❖ Maintenance Related Shutdown Overrun (hours)

The following have been identified as KPI for a production process environment;

- ❖ PM schedule compliance
- ❖ Overtime worked against plan
- ❖ Time taken to answer maintenance calls
- ❖ Budget compliance
- ❖ PM Backlog man-hours
- ❖ Critical Equipment availability (Don't worry about non-critical equipment)



- ❖ Number of breakdowns (Unplanned maintenance)
- ❖ Production equipment performance (By output volume levels)
- ❖ Equipment performance (with respect to quality)
- ❖ MTBF ([http://www.pemms.co.uk/maintenance\\_KPI.htm](http://www.pemms.co.uk/maintenance_KPI.htm))

Some industry players base their KPI on SMART (Specific, Measurable, Attainable, Realistic and Time-specific) goals. (<http://www.vorne.com/learning-center/kpi.htm>)

Variants of KPI abound depending on the industry and applications. Common ground for them all centre around; production (equipment availability), down-time, production quality and cost. None of those metrics put down-time due to ergonomics into consideration as it affects maintenance down-time. It is obvious that ergonomics impact maintenance from the discussion so far. It is also clear that many stake-holders including the personnel themselves rarely recognise this.

## **2.18 Summary**

This chapter delved into the review of relevant literature sources to establish concrete facts upon which subsequent works in the dissertation will be based. From the discourse, it can be deduced that robust consideration for ergonomics as it relates to human-machine interface exist, particularly for operators. Apart from aviation and mining industry where ergonomics has been entrenched in their maintenance activities, some other industries are yet to take full advantage of that. Although, the petro-chemical industry has good ergonomics awareness programmes most of which centre round operators and office workers (computer users). Hence, the need to relate ergonomics to maintenance particularly in the petro-chemical industry to ensure plant availability.

The next chapter concentrates on discussion of: the research topic, research instruments and their application.

## **CHAPTER THREE**

### **EMPIRICAL INVESTIGATION**

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*Chapter three presents the analysis of the research topic and a discussion of the research instruments employed. The application of the research instruments is also discussed.*

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### **3.0 Empirical Investigation**

Having gone through the relevant literatures for a clear understanding of concepts behind the research, the pace is set for the actual research field work. Before then, the dissertation topic has to be looked into for clarity.

#### **3.1 Research Design**

Research has several definitions based on individual view but it all boils down to the fact that 'it is *a carefully planned and performed investigation, searching for previously unknown facts in order to solve a problem or add to human knowledge.* ([www.spaceday.org/index.php/Glossary-of-Aeronautics-Terms.html](http://www.spaceday.org/index.php/Glossary-of-Aeronautics-Terms.html))

This research seeks to improve maintenance personnel's performance or effectiveness with respect to ergonomics design of process equipment in the petrochemical industry.

To achieve that, a research design that will deliver the aims and objectives outlined at on-set need to be selected. Bearing in mind that, "*The research design is the structure of any scientific work that gives direction and systematizes the research. The research method chosen however, will affect results and how to conclude the findings.* ([www.experiment-resources.com/research-designs.html](http://www.experiment-resources.com/research-designs.html))

The research solely depends upon case studies as subsets of the petrochemical industry employing a number of research approaches starting with the descriptive research approach on a broader view. Descriptive research approach has been defined as a scientific method of observing and describing the behaviour of a subject matter without influencing it in any way. (*Shuttleworth, 2008*)

This approach investigates the problem statement based on established facts. That however, will lead to a much narrower investigative work adopting scientific methods like; physical observations, interviews and questionnaires to acquire primary data in both case studies. Experiment will not be involved but simulation of real live situation may come up if need be, in the process of personal interviews.

The purpose of this research work would have been achieved if it has worked towards improving maintenance personnel's effectiveness by reducing or eliminating impediments due to ergonomics impact.

To achieve that, some basic questions need to be answered, which are;

1. Is there ergonomic related impact on maintenance activities in the process industry?
2. Are there poor ergonomically designed equipment impacting the performance of the maintenance personnel?
3. What other ergonomic factors impact the performance of the maintenance personnel?
4. What is the nature of impact?
5. How much are these impacts?
6. What can be done to reduce or eliminate the impact?
7. How do the impacts affect plant availability?

Those questions will serve as bedrock for the research work been embarked upon with the various approaches employed to under study maintenance activities in both Case A and Case B.

To validate my research outcomes, proven theories and established facts on effects of ergonomics related ailments will be employed. Firsthand experience, gained over long term work experience of personnel in the maintenance field and experts' inputs in the field will be used.

### **3.2 Data Collection Methods**

This research work was carried out within two industry players (as case studies) in the petrochemical field referred to as Case A and Case B.

#### **3.2.1 Identification of Case Studies**

According to the notable researcher, Yin (2003), Case study research continues to be an essential form of inquiry for knowledge acquisition. The method is very much applicable when researchers desire or are compelled by circumstances to;

- (a) Define research topics broadly and not narrowly,*
- (b) Cover contextual or complex multivariate conditions and not just isolated variables,*
- (c) Rely on multiple and not singular sources of evidence.*

He also identified at least six kinds of case studies based on a 2x3 matrix.

Firstly, he categorised case study research based on **single-or multiple**-case studies;  
Secondly, he categorised case study research on their nature. That is, the case study can be **exploratory, descriptive or explanatory** (causal). It does not matter if the case study is single or multiple.

The combination of both categories gives what he called 2x3 matrix. He defined the component of each category as follows;

#### **Category one**

**Single-case study**- *focuses on a single case only.*

**Multiple-case studies**- *include two or more cases within the same study.*

#### **Category two**

**Exploratory case study** (*whether based on single or multiple cases*) – *can be used to define the questions and hypotheses of a subsequent study (not necessarily a case study) or to determine the feasibility of the desired research procedures.*

**Descriptive case study** – *is used to present a complete description of a phenomenon within its context.*

**Explanatory case study** - *is used to present data bearing on cause-effect relationships-explaining how events happened. (id.)*

This research employs a multiple combination of the categories.

### **3.2.2 Observations**

Observing maintenance activities during shutdowns was very helpful as there were more than enough opportunities to gather information. Observations were carried out during maintenance work coupled with interviews in the case study where annual turn-around maintenance is not observed. Observation without necessary input from the personnel observed may be frustrating particularly when they do not understand the concept of ergonomics. However, people with higher educational background helped in throwing light to the issue and giving reliable feedback.

### **3.2.3 Questionnaires**

This is a research tool used to gather information on the ergonomic impact as perceived or experienced by the maintenance personnel themselves. The information therein gathered is used in conjunction with observatory evidences so as to come to a logical conclusion.

It is important to state that 30 initial questionnaires were administered in each case study with update based on response from each version (giving a total of sixty for each version of the three successive versions).

The final questionnaire was administered in both case studies among a population sample of 240 maintenance personnel in both organizations.

The questionnaire is intended to investigate and get feedback from maintenance personnel as to how ergonomics affects their performance and possible suggestions on what can be done to ameliorate the impact if not eliminated.

The questionnaire along with a covering letter for this research administered physically to respondents are attached in Appendices A and B.

To ensure a quality work, the questionnaire was designed with the contribution of experts in the field of ergonomics who are also in the petro-chemical industry.

### **3.2.4 Interviews**

Interview was conducted both in case A and B among maintenance personnel of rank and files using an abridged version of the questionnaire presented in appendix C. It is noteworthy however that, some personnel needs to be enlightened on the subject of ergonomics before they could give the right view and avoid biased responses.

## **3.3 Summary**

In this chapter, the dissertation topic and its components have been discussed along with methodology adopted in gathering data for this dissertation. The next chapter will look into the research instruments employed and the outcomes.

## **CHAPTER FOUR**

### **Results and findings**

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*Chapter four gives the analysis of results and findings emanating from the application of the research instruments. The results were presented in tabular and graphical forms that give the information in an easy to understand manner. Extrapolations were made where information was not accessible and the resulted outcomes are presented.*

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## 4.0 Results and Findings

The previous chapter presented the discussion of the components of the dissertation topic and all the necessary instruments employed in achieving the aims and objectives of this research work. The outcomes of the research are discussed in this chapter alongside graphical and tabular representation of data generated from the survey instruments used.

### 4.1 Results

At the onset, the research was structured to investigate each case study independently and finally compare the outcomes. But, it was discovered that the reasons for the independent investigation would not yield any positive result. The purpose of the separation at the beginning was to find the impact on each case study individually and compare them using cost implication (medical and over-head).

The initial pilot survey (30 initial questionnaire were administered in each case study) revealed that respondents were not ready to give information regarding wages. Information regarding medical cost was not within the reach of respondents as both case studies have structured medical aid. That specific area posed challenges that alternatives have to be sought to meet the expectation of the research. As there is no ground for comparison, the results were analysed together.

One of the major constraints faced by the questionnaire is that, none of the electronic copies sent out was completed and returned out of the thirty sent out in each case study. Three different versions in succession were sent out to different personnel at different time interval but no response from anyone.

A former maintenance supervisor in Case study B gave this reply (*I have been on some sort of vacation, and just resuming. You have very good questionnaire here, but I tell you what, you cannot get the answer just in a jiffy. Give me some time. Good luck.*).

He also sent it to his colleagues who could be of help but not one of them replied.

That necessitated a physical distribution and monitoring (the assistance of some personnel in both case studies helped in getting their subordinates, peers and colleagues to complete them on time and return immediately) which yielded a positive result. Respondents (including those



who got the electronic copies before) freely completed it and expressed their views, more so, there is no name attached and no specific industry information is sort.

The original aim was to administer one hundred in each case study but as it turned out that the response to initial electronic survey yielded nothing, the ground was shifted to one hundred and twenty in each case study hoping to get at least eighty back. Because of the assistance received (mentioned earlier), and as soon as one hundred completed questionnaires were received from each case study, analysis began. A total of two hundred respondent feedbacks were analysed.

#### **4.1.1 Outcome of questionnaire survey.**

The questionnaire addressed five areas presented in five sections below;

##### **i) Respondents profile.**

This section was aimed at gathering relevant information from reliable sources; maintenance personnel from relevant fields (mechanical, electrical or instrument), with appreciable number of years already put into the profession (to truly appreciate the intent of the questions and avoid bias or inexperience) and finally the level of education as that will also influence perception by individuals.

A total of two hundred and forty questionnaires were administered physically to maintenance personnel but only two hundred were analyzed. Fifty-one percent of the respondents are graduates and masters degree holders. Fifty-two percent of respondents have between five and fifteen years of experience in their relevant field (mechanical, electrical and instrument) as maintenance personnel. Summary of the profile is presented in table 4.1 below.

<b>1.2</b>	<b>Fields</b>	<b>Respondents</b>		<b>Respondents</b>
	<b>Mechanical</b>	80	<b>Instruments</b>	70
	<b>Electrical</b>	50		
<b>1.3</b>	<b>Year of experience on the job.</b>			
	<b>0-5 yrs</b>	69	<b>5-10 yrs</b>	57
	<b>10-15 yrs</b>	48	<b>&gt;15 yrs.</b>	26
<b>1.4</b>	<b>Level of education</b>			
	< O/Level	0	Diploma	56
	O/Level	18	B. Tech / B. Sc	89
	Trade test /C&G	23	M. Tech / M. Sc	14

**Table 4.1 – Respondents Profile**

## **ii) Ergonomic issues indices**

This section deals with indices that probe the presence of ergonomic related issues in maintenance activities.

The indices probe the areas of: equipment design, workspace and tools.

Section 2.7 however, probes the frequency of task that pose ergonomic issues while section 2.8 probes the level of awareness created having experienced the situation that poses ergonomic risk.

## **iii) Impact indices**

This section actually deals with impact evaluation. The indices used here seek to evaluate the impact of ergonomic related issues among maintenance personnel based on;

- a) Man-hour loss in terms of Day-Away From-Work (DAFW) addressed by section 2.9 of the questionnaire.
- b) Health implication (medical cost) addressed in section 3.1-3.4 of the questionnaire.
- c) Personnel morale addressed in section 4.1-4.2 of the questionnaire.
- d) Over-head cost addressed in section 5.1-5.3 of the questionnaire.
- e) Down-time elongation as it affects production addressed in section 5.4-5.5 of the questionnaire.

## **iv) Respondents' suggestion for mitigation**

Respondents were given opportunities to express their views with regards to possible mitigation factors that can be adopted to minimize the impact of the ergonomic risk associated with their job. Those were addressed in section 6.1-6.3 of the questionnaire.

## **v) Implementation constraints.**

Realising that mitigation efforts may not succeed if there is no good ground to aid it, section 6.4 of the questionnaire seeks to probe possible constraints to implementing mitigation efforts like; Cost, management issues, company policy, maintenance strategies, awareness creation and personnel morale.

### **4.1.2 Interviews**

Six maintenance personnel were interviewed particularly those in supervisory/managerial positions using a combination of formal and informal method. A set of questions (an extract

from the questionnaire) presented in appendix C and their responses revealed some things not previously anticipated. Details of the findings are presented below.

Four medical personnel were also interviewed to estimate how much as a baseline, the medical cost of ergonomics-related ailments inflicted on personnel (*such information could not be gathered from within the industry for reasons afore mentioned*). The outcome of that is also presented below.

#### **4.1.3 Observation**

Physical observation of maintenance activities were carried out during normal operation and shut down periods in Case A. Case B does not operate a routine shut down programme but maintenance activities present themselves in scheduled maintenance, condition based, time based and equipment failure. Those opportunities were explored to investigate the aims and objectives of the research works.

### **4.2 Presentation of Results**

The outcome from each of the research instruments used are presented in this section.

#### **4.2.1 Survey questionnaire outcomes**

Outcomes of the administered questionnaire are presented under the various indices employed as shown below.

##### **4.2.1.1 Ergonomics issues in maintenance.**

All two hundred respondents admitted that ergonomic issues exist in their profession. From the indices employed; 94.5% agreed that they work under uncomfortable posture, 84.5% admit that they use tools in uncomfortable manner that causes pains or stress while 86% profess that they use tools under such circumstances that can lead to repetitive stress injuries. Supporting indices addressing equipment design, that is, question 2.1 and 2.5 have 89% and 73.5% positive responses respectively (See Table 4.2 below). That position was also confirmed from interviews.

			Yes	No
	Yes	No	%	%
2.1 The part is not accessible	178	22	89	11
2.2 There is high risk of sustaining injury	151	49	75.5	24.5
2.3 Work is done under an uncomfortable posture.	189	11	94.5	5.5
2.4 The job requires using tools in uncomfortable manner that causes pains or stress.	169	31	84.5	15.5
2.5 The mechanical design of the equipment is not good.	147	53	73.5	26.5
2.6 Tool is used repetitively that can lead to repetitive stress injuries.	172	28	86	14

**Table 4.2 - Ergonomics issues indices.**

#### **4.2.1.2 Frequency of ergonomic impacted task.**

The frequency of occurrence of ergonomic impacted maintenance task was investigated using question 2.7 - *How often does the work re-occur?*

Responses show that 73% of ergonomic impacted tasks come up once a year at least. Only 1.5% re-occurs weekly. That in a way helps to re-establish the fact that the ergonomics impacting tasks do exist. Table 4.3 below shows the rate of re-occurrence.

Frequency	Once a week	Once a month	Once in 3 months	Once a year at least	More frequent
Responses	3	16	35	146	0
%	1.5	8	17.5	73	0

**Table 4.3 - Task re-occurrence index**

#### **4.2.1.3 Awareness creation.**

If the ergonomics impacting tasks do exist, how much awareness have been created about them and to what level, was the next thing looked into by question 2.8? Data acquired revealed that only 18.5% of respondent actually complain to their superiors as shown in table 4.4 below. The data is not conclusive as 70.5% of respondents did not respond to this question. That is further discussed in chapter five.

	Yes	No	No response
Responses	37	22	141
%	18.5	11	70.5

**Table 4.4 - Awareness creation index**

#### **4.2.1.4 Impact Evaluation**

A number of indices were adopted here and the results are as follows.

##### **4.2.1.4.1 Man-hour loss**

Man-hour loss as a result of ergonomics related issues affecting maintenance personnel in terms of Day-Away From-Work (DAFW) addressed by section 2.9 of the questionnaire. Table 4.5 below shows that only 13% take days away from work when the ailment surface.

*Question 2.9 - How often do you take day-away from work because of it?*

Frequency	Often	Sometimes	Never
Responses	0	26	174
%	0	13	87

**Table 4.5 – Man hour loss index**

##### **4.2.1.4.2 Medical implication/cost**

Question 3.1 to 3.4 probes the medical implication of the ergonomics related ailment experienced during maintenance activities and the outcomes are as shown below.

The responses to *Question 3.1 - On which part of the body is discomfort normally felt after working on the equipment?* - is displayed in table 4.6 below.

<i>S/no.</i>	<b>Body Parts</b>	<b>Responses</b>		<i>S/no.</i>	<b>Body Parts</b>	<b>Responses</b>	
		<b>Yes</b>	<b>%</b>			<b>Yes</b>	<b>%</b>
<b>1.</b>	Bones	11	5.5	<b>7.</b>	Head	8	4
<b>2.</b>	Neck	131	65.5	<b>8.</b>	Spines	144	72
<b>3.</b>	Waist	92	46	<b>9.</b>	Joints	153	76.5
<b>4.</b>	Muscles	87	43.5	<b>10.</b>	Wrists	184	92
<b>5.</b>	Back	107	53.5	<b>11.</b>	Others	4	2
<b>6.</b>	Hands	47	23.5				

**Table 4.6 – Diagnostic**

Leading indicators confirming the fact that ergonomic related ailment do exist are; waist (46%), muscles (43.5%), back (53.5%), spines (72%), joints (76.5%), and wrists (92%). It is important to note that, some of the respondents ticked more than one indicator.

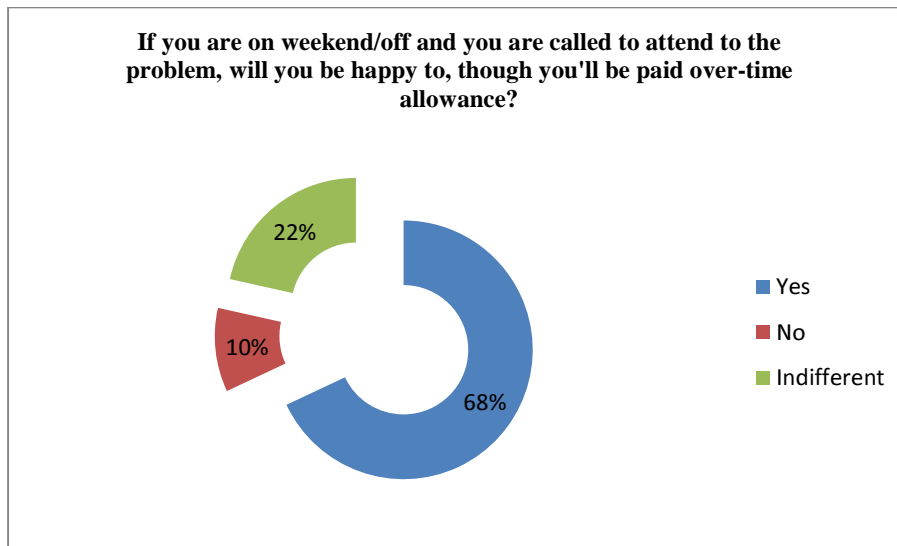
		Symptoms		Yes	%	Symptoms	Yes	%	
3.2	What type of pain is normally experienced?	Tingling		141	70.5	Numbness	107	53.5	
		Continual muscle fatigue		91	45.5	Decreased ability to move	103	51.5	
		Change in the skin colour of hands or fingertips		22	11	Decreased grip strength	78	39	
		Swelling in the joints		40	20	Pain from movement	95	47.5	
3.3	Does the pain normally require medical assistance or first Aid?			Yes	123	61.5%	No	77	38.5%
3.4	How long does it normally take for the pain to go?	Less than a week	35	17%		2-3 weeks		122	61%
		A month	30	15%		More than a month		13	6.5%

**Table 4.7 – Symptomatic**

From question 3.2, leading symptoms of ergonomics ailment that were most prominent are; tingling (70.5%), numbness (53.5%), decreased ability to move (51.5%), pain from movement (47.5%) and continual muscle fatigue (45.5%). See table 4.7 above. They correlate with results from section 3.1.

#### 4.2.1.4.3 Personnel morale

Figure 4.1 below shows the attitude of the respondents in response to the ergonomics related ailment. 68% of the respondents would still attend to the problem anytime. Other findings in this regard will be discussed later.



*Figure 4.1 – Personnel morale.*

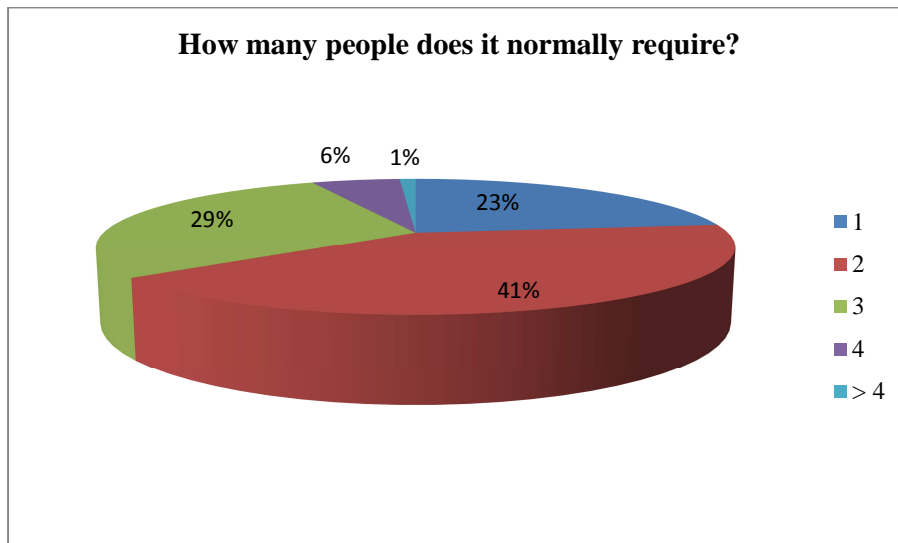
#### 4.2.1.4.4 Over-head cost

All the respondents agreed that tasks having ergonomics related impact always require using extra number of maintenance personnel. The response to question 5.2 – (*How often does it require using extra number of maintenance personnel?*) returned a response shown on table 4.8 below. 72% agrees that they **always** require more hands while 28% agrees that they **sometimes** do need more hands.

Always	Sometimes	Never
144	56	0
72%	28%	0

*Table 4.8– Frequency of using extra hands*

The extra number of people required varies and that is what figure 4.2 presents. Most of the time (83%) between 1 and 3 extra maintenance personnel is required.



**Figure 4.2 – Number of extra hands used**

Question 5.4 returned a response far from the response for 5.2 as 81.5% said that the impacting task though required extra number of personnel but not extra working hours most times. Detail in table 4.9 below.

	Yes	No
Does it normally require working longer hours or over-time every time?	37	163
%	18.5	81.5

**Table 4.9 – Over-time**

#### **4.2.1.4.5 Plant availability (Production Down-time)**

According to respondents, the impacting task always require more working hours than necessary if the equipment had been more comfortable. The extra hours differ based on task and equipment involved but the average is 6-12 hours. See table 4.10 below.

	0 - 3	3 - 6	6 - 12	12 - 18	18 - 24	> 24
How much extra time on the average is spent working on the equipment compare to working on it if it is more comfortable?	38	61	69	21	8	3
%	19	30.5	34.5	10.5	4	1.5

**Table 4.10- Plant availability (Production down-time.)**



#### 4.2.1.5 Mitigation

Questions in this section were not exhaustive but as a result of response from pilot survey, it was necessary to limit the questions and allow respondents to add their views. 91.5% of respondents agree that modification of equipment will mitigate the impact of ergonomics on maintenance personnel effectiveness.

All the respondents agree that replacing equipment with one of better design will improve their performance as maintenance personnel. That actually confirms one of the assumptions these research held at the beginning.

71% of the respondents think that adjusting maintenance strategy/approach employed by their organization will improve the situation. Table below summarizes those outcomes.

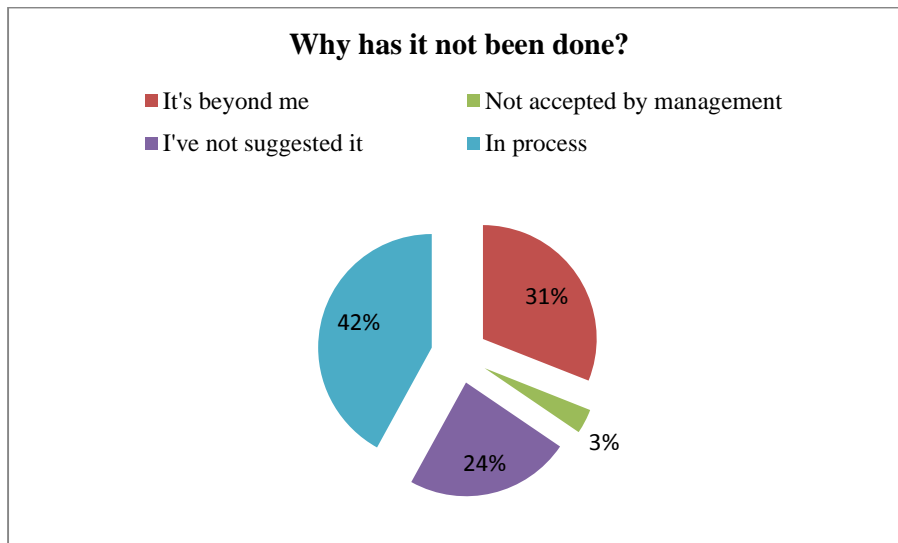
		Yes	No	Yes	No
		Yes	No	%	%
6.1	Will a modification of a part of the equipment make things better?	183	17	91.5	8.5
6.2	Will a replacement of the equipment with another of better design make things better?	200	0	100	0
6.3	Is there any adjustment that can be made to the maintenance strategy/approach been used to make things better?	142	58	71	29

**Table 4.11 – Mitigation indices**

#### 4.2.1.6 Implementation constraints.

The last question looks into why mitigation effort has not been in place. So far, it has been established by the respondents that they have ergonomically impacting task in their maintenance activities but what have they done to mitigate those problems?

42% have taken proactive step but still in process while 36% said, “it is beyond them” (See Figure 4.3 below). 24% prefer to be silent and endure it while only 3% have met with deadlock with management but not without reasons. That will be further discussed in chapter five.



*Figure 4.3 – Implementation index.*

## 4.2.2 Interviews

Interviews are discussed under two sub headings: technical and medical. Responses of people from each field are presented below.

### 4.2.2.1 Technical

Six maintenance personnel were interviewed using a set of questions adapted from the main questionnaire (attached in appendix C). The outcomes are;

Person 1: (*Maintenance manager of 15years experience in the field from Case A*) confirms that ergonomics impact maintenance activities from his experience. He had worked under several uncomfortable postures which required using tools repetitively resulting in RSI on several occasions. According to him, why he did not worry is that most of such tasks only come up once in a year while a few come up more frequently.

He buttressed his points by referring to a colleague of his who deserted maintenance and moved to operations because he could no longer endure the pains. He referred me to Person 2 for confirmation.

Person 2, *Operations Supervisor in Case A*, had put in ten years in as a mechanical technician (maintenance) in the same Case A before he switched over to operations. He also confirmed that such activities come up mostly once a year, which is during shutdown. He also noted that he has sustained injuries many times and got them treated at company's expense.

They both agreed that in such situations, little work get done in long hours.

Person 3, *maintenance Supervisor* in Case A reiterated the fact that ergonomics impacting task present itself in several forms where his subordinates work under uncomfortable posture and use tools repetitively leading to discomfort and leading to elongation of down-time.

A discussion with Person 4 (*Case B, Maintenance manger*) who has put in more than 25years as *maintenance personnel* in various organizations yielded the following; he has worked under ergonomic impacting task several times during his career. He still witnesses ergonomics impacting maintenance tasks sometimes. He makes efforts to mitigate the impacts where possible. He has initiated mitigation plans on occasions.

Person 5, (*Case B, maintenance Supervisor*) who has put in more than 30 years as a maintenance person within the organization confirmed the presence of ergonomics impacting maintenance activities in the industry. On several occasions manufacturers ignore company specifications as regards safety and ergonomics in equipment design, he reiterated.

Person 6, (*Case B, maintenance technician*) who has put in five years into the profession re-affirms that ergonomics impacting task seems to be part of their life on the job. It is of no use talking about it because several constraints also come with the tasks. Most of the time, he and his colleagues have to get jobs done in order to reduce down-time in an environment where all alternatives that would have ease the job cannot be provided. That is because several logistics have to be put in place which is not convenient.

#### **4.2.2.2 Medical**

It is impossible to evaluate every ergonomic ailments associated with maintenance activities in the petro-chemical industry (but a selected few were addressed by the questionnaire which serves as indicators only) as that will amount to a project work on its own.

The questionnaire was initially designed to gather data on every indices including medical and over-head cost. But, on pilot survey, it was discovered that both Case A and Case B have structured medical aids and services for their staffers which makes such records inaccessible as they are classified information.

The organizations also use medical personnel (specialist and consultants) who may be invited to address special issues. Hence, the area of medical cost was handled using average of sampled private specialist hospital and government own (public clinic/health centre) rates in treating such ailments in Nigeria.

The following medical personnel of repute and long standing were interviewed on an average cost of treating ergonomics related ailment;

- 1) Dr. Abiodun (Ore-Ofe Specialist Hospital and clinics, Lagos, Nigeria), been practising for over 30 years. The first ten years of his career were in Ogun State Specialist hospital which exposed him to treating personnel of organization like; breweries, rubber processing company, wood processing factory and so on.
- 2) Dr. Iredia (Edo state Specialist hospital, Nigeria) been practising for about 15years in public (government owned hospital).
- 3) Dr. Olunuga has been practising for more than 35years as a general medicine practitioner and surgeon.
- 4) An Occupational health practitioner of University College Hospital, Ibadan, Nigeria, who would not like to be mentioned, also contributed.

The cost estimate from each source include; consultation, diagnosis, therapy (where necessary), and medications. *The estimates are baseline (very minimum) only as the actual cost will vary depending on; severity, location, nature of treatment (in-patient or out-patient), treatment period (long or short) and surgery, where required.* The outcome is presented in the table below.

(Dr. Abiodun is represented as “A”, Dr. Iredia is represented as “B”, Dr. Olunuga is represented as “C”, while Occupational health practitioner of University College Hospital is represented as “D”)

		Treatment cost in						
		N						
	Symptom	Dr. A	Dr. B	Dr. C	Dr. D	Average in N	Average in \$	Average in Rand
1	Tingling	3,500	2,500	5,000	2,000	3250	21.66667	162.5
2	Numbness	5,000	5,500	8,000	3,500	5500	36.66667	275
3	Continual (Chronic) muscle fatigue – fibromyalgia.	3,000	2,000	3,000	1,500	2375	15.83333	118.75
4	Change in the skin colour of hands or fingertips	1,000	1,000	1,000	500	875	5.833333	43.75
5	Swelling in the joints	3,000	2,500	3,500	2,500	2875	19.16667	143.75
6	Decreased grip strength	3,000	3,500	3,000	2,000	2875	19.16667	143.75
7	Pain from movement.	4,500	5,000	7,000	3,500	5000	33.33333	250
8	Decreased ability to move.	15,000	13,000	20,000	10,000	14500	96.66667	725

**Table 4.12 – Medical cost index.**

It should be noted that conservative management exists for treating some of those ailments which can be carried out in-house and know by some of the personnel as gathered during observation and interview. Those include; cold treatment, hot treatment, stretching, and time to heal couple with exercises. Those are only applicable at the early stage beyond which doctors/specialists may have to come in.

#### **4.2.3 Observations**

Physical observations of maintenance activities alongside discussion with some personnel in both case studies during shutdown and other maintenance activities in Case study A and Case study B revealed the following;

- i) Work done under uncomfortable posture for hours (1-3 hours).
- ii) Some tasks involve using tools repetitively that can lead to RSI.
- iii) Some maintenance activities were done under situations that pose high risk of sustaining injuries.
- iv) Some of the tasks would have been easier if the equipment design is different.
- v) Most of the injuries sustained are seen as work stress and personnel treat them unofficially using over-the-counter drugs or exercises. Some ergonomics related ailments normally heal up after sometimes without any other intervention.

vi) Some maintenance personnel are just busy developing themselves waiting the time they will have an opportunity to change to a more comfortable profession.

### **4.3 Extrapolations**

As earlier mentioned that information regarding wages and production were not accessible for their classified nature. For the purpose of this dissertation, it is needful to extrapolate the possible cost to the baseline (minimum) so as to ascertain how much ergonomics impact on company's expenditure and production.

#### **4.3.1 Over-head cost**

Information about wages and salaries are not easily accessible as more than 90% of respondents in the pilot survey declined giving any response to the questions. However, an estimate based on possible minimum wage was used to compute the possible overhead cost incurred due to ergonomics related ailments among maintenance personnel.

Proven figures on financial implication of ergonomics related ailments (but not specific to maintenance personnel in the petro-chemical industry) from countries around the world particularly; USA, UK and EU abounds as previously stated. Hence, the estimated cost should be seen as a minimum or baseline only.

From the outcome of the survey, two extra hands take the lead and average according to 41.5% of respondents (See table 4.13 below). If an average of two technicians are required. It then follows that, an organization employs an average of two maintenance personnel extra due to ergonomics related issues on their job.

Using a minimum wage of R5, 000 per month for a maintenance technician, it then follows that R10, 000 per month (R120, 000 per annum) is expended as extra over-head cost. That translates to ~~N~~2,400,000 (two million four hundred thousand naira) or \$17,142.86 (Seventeen thousand one hundred and forty-two dollars and eighty-six cents) per annum in Nigeria and the U.S. respectively.

	1	2	3	4	> 4
How many people does it normally require?	46	83	58	11	2
Percentage	23	41.5	29	5.5	1

**Table 4.13 – Over head cost index**

#### **4.3.2 Plant availability (Production loss)**

94.5% of the respondents indicated that between zero and 18 hours is spent as average extra time working on the equipment having ergonomics issues (See Table 4.14 below).

Taking an average of nine hours as extra down time for a production facility producing products at the rate of ten thousand dollars per hour on the minimum, that means ninety thousand dollars of product and market share is lost due to ergonomic impact on maintenance activities as extra production down-time.

<b>Hours</b>	0 - 3	3 - 6	6 - 12	12 – 18	18 - 24	> 24
How much extra time on the average is spent working on the equipment compare to working on it if it is more comfortable?	39	62	67	21	8	3
Percentage	19.5	31	33.5	10.5	4	1.5

**Table 4.14 – Production down-time index**

#### **4.4 Summary**

This chapter presented the outcome and analysis of the research instruments employed; questionnaire, interviews and observations. It also included an extrapolation of outcomes where it was impossible to gather data based on the nature of the data required. The next chapter presents a discussion of the research outcomes, solutions and necessary recommendations.

## **CHAPTER FIVE**

### **Discussion and Interpretation**

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*Chapter five discusses the outcome results and findings presented in chapter four. A proposed tool geared at assessing and evaluating the impact of ergonomics on maintenance activities in the petro-chemical industry is also presented alongside the necessary tools to facilitate effective application. The tool, E4M (Ergonomics for maintenance assessor), E4M training matrix and the effective application guidelines form a complete framework.*

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## **5.0 Discussion and Interpretation**

In the previous chapter, outcomes of the research based on the various research instruments employed and extrapolation made were presented. This chapter discusses the outcomes presented in chapter four for logical conclusions.

### **5.1 Ergonomics issues in maintenance activities**

The findings from the research instruments used are discussed below in relation to ergonomics as it affects maintenance activities. The outcomes are discussed under each instrument used.

#### **5.1.1 Interviews and observation**

As mentioned in the previous chapter, all personnel interviewed and observed agreed to the fact that there are ergonomics related issues impacting their activities. If such are mitigated, their effectiveness will be enhanced, as they will be able to do more with no stress or injury in a given time. It would be recalled that in the cause of the interview, reference was made to someone who left the maintenance profession for operations and an interaction with him one-on-one confirmed the claim (people change job from maintenance to other fields where there are less ergonomics related stress) by the interviewees.

#### **5.1.2 Survey questionnaire outcome**

##### **Existence**

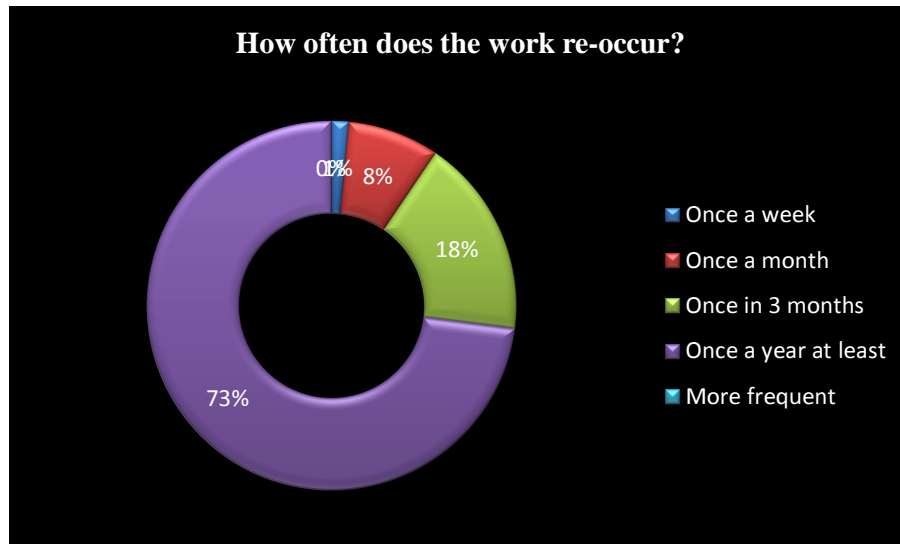
The two hundred respondents agreed that they encounter ergonomics related issues on their activities irrespective of the year of experience on the job. 51.5% (103 personnel) of the respondents were graduates and second degree holders who should know better coupled with their years of experience on the job. Of the indices employed;

- i) “Working under uncomfortable posture” had the highest percentage (94.5%)
- ii) Inaccessible parts that pose risk of injury (89%)
- iii) Using tools repetitively that can lead to repetitive stress injuries (86%)
- iv) Using tools in uncomfortable manner that causes pain or stress is (84.5%)

The outcomes confirm that equipment design, work space and tools are the main factors posing ergonomic risks to maintenance personnel.

### Re-occurrence

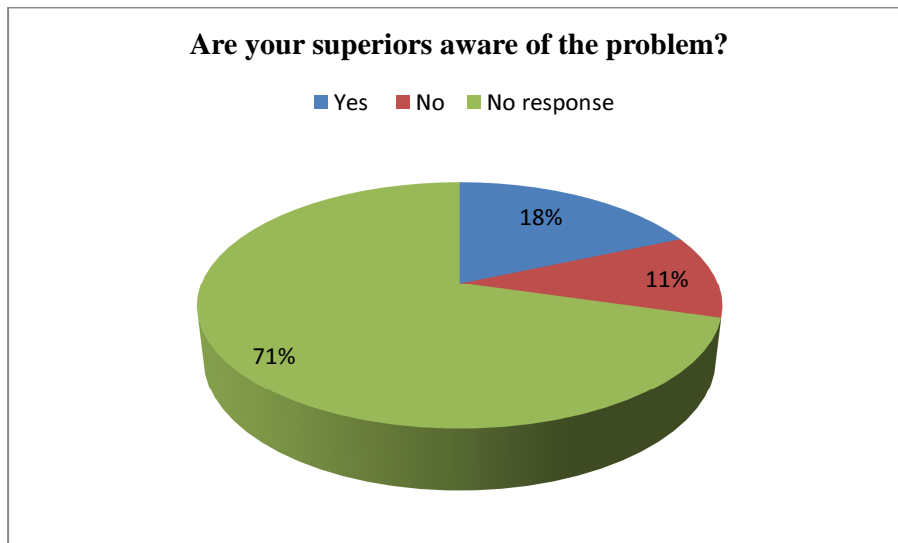
To further confirm the claims by all the instruments employed, the next query sought to know how often the ergonomic impacted task re-occur if they really exist. 73% confirmed that such tasks re-occur at least once in a year. That may be the reason for the silence on ergonomics impact on maintenance as they are not common. If only 1.5% re-occur once a week it would not draw much attention but only reiterate the fact that ergonomic impacted tasks among maintenance personnel do exist.



*Figure 5.1 – Task re-occurrence index*

### Awareness creation

The next index probed the level of awareness generated since the ergonomics impacted task had been identified. The responses to this question show that only 18.5% actually reported to their superiors while a majority (70.5%) gave no response. The reason for that according to observed and interviewed personnel is that they will not be seen as lazy, disgruntled or complainant, thereby risk retrenchment. Many pretend and endure till such a time they can find a more comfortable job just like the examples in the interview section.



*Figure 5.2 – Awareness creation index*

## 5.2 Impact evaluation (Key Performance Indicators)

This section assesses the level of impact of ergonomics on maintenance personnel using the following Key Performance Indicators – Man-hour loss, medical implication/medical cost, personnel morale, overhead cost and plant availability.

### 5.2.1 Man-hour loss

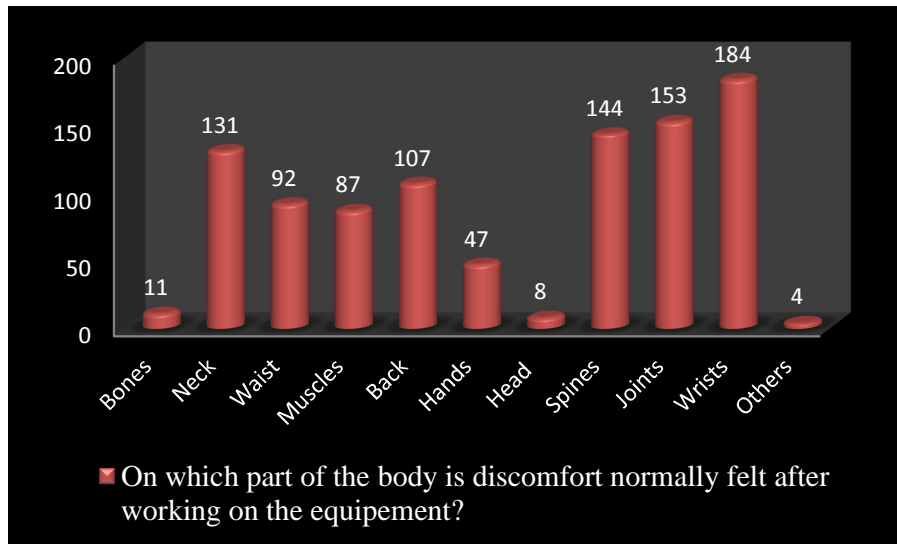
The outcome of this research shows that only 13% of the 200 respondents to the questionnaire take day-away-from-work as a result of the ergonomic related ailment on their job. That is rather unexpected but understandable for responsible personnel. This is very important because personnel availability directly impacts plant availability.



*Figure 5.3 – Man hour loss index.*

### 5.2.2 Medical implication/cost

Diagnostic indices for this purpose were carefully selected to ensure that what the respondent is describing is actually ergonomic related based on proven facts already delved into in the literature review. Indices that confirm ergonomic related ailments are; wrists (92%), joints (76.5%), spines (72%), back (53.5%), waist (46%) and muscles (43.5%).



*Figure 5.4 – Diagnostic (somatic)*

Symptoms of ergonomic ailments used and the outcome are as displayed on the table 5.1 below.

		Symptoms	Yes	%	Symptoms	Yes	%
3.2	What type of pain is normally experienced?	Tingling	141	70.5	Numbness	107	53.5
		Continual muscle fatigue	91	45.5	Decreased ability to move	103	51.5
		Change in the skin colour of hands or fingertips	22	11	Decreased grip strength	78	39
		Swelling in the joints	40	20	Pain from movement	95	47.5

*Table 5.1 – Symptomatic*

### 5.2.2.1 Index matching / correlation.

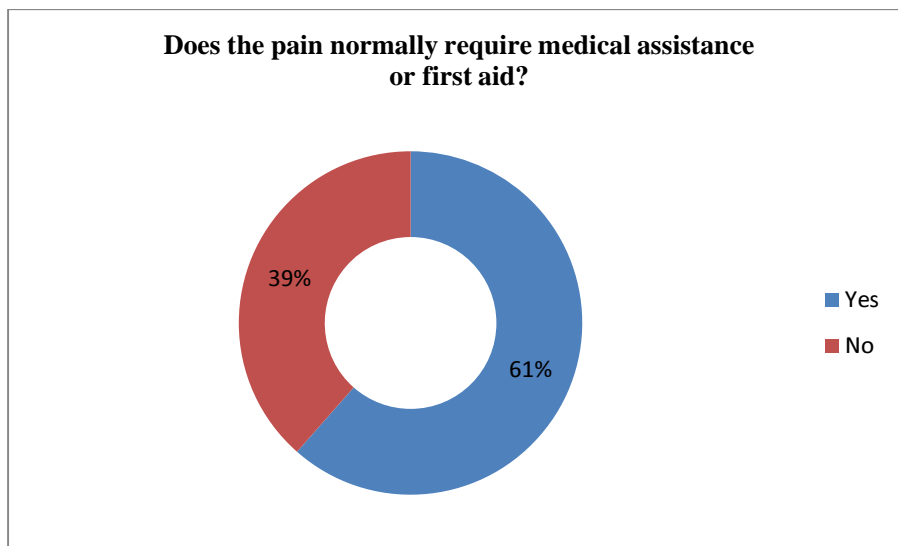
From the diagnostic (somatic) indices, ailments can be related to symptoms to verify if the two indices actually match respondent's claims. The outcome of that is then compared with experts' description for ergonomics ailment symptoms and affected parts.

It was discovered that correlation exists in some areas which can justify the respondents' claims that they experience ergonomics related ailments on their profession as follows;

- Tingling may relate to waist, muscles, spine, wrist, hands, joints, back and so on.
- Numbness sometimes has to do with RSI in hands and muscles.
- Decreased ability to move, pain from movement and continual muscle fatigue are related to abuse of body parts like; joints, wrists, muscles, hands, spine and back.

Tingling and numbness are purely symptoms of RSI conditions which can culminate in Carpal tunnel syndrome (if not addressed early may result in condition that will require surgery).

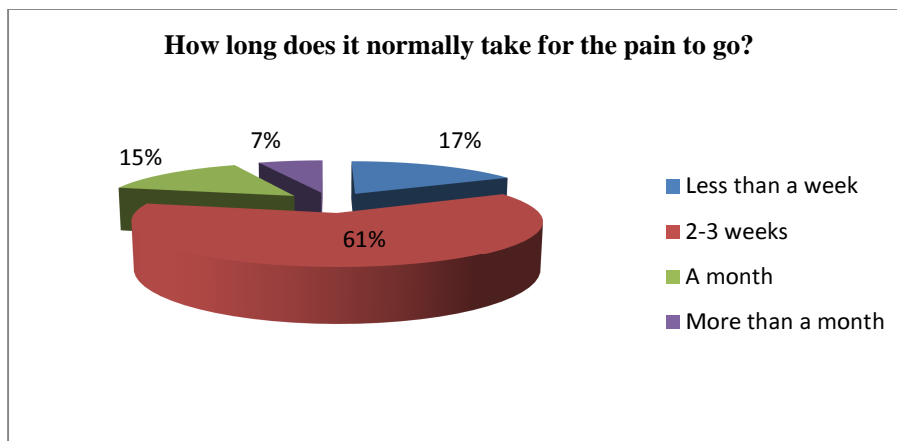
It is also important to note that, respondents ticked more than one symptom in 3.2.



*Figure 5.5 – Symptomatic-I*

Responses to question 3.3 show (See figure 5.5 above) that 61% of occurrence of those ailments requires medical attention. Others allow the pain to go on its own after a while or use

conservative therapy or exercises to heal affected parts as revealed in interviews and observations.



**Figure 5.6 – Symptomatic-II**

From figure 5.6, majority (61%) of the ailment takes about 2-3 weeks to heal completely while 17% takes about a week to heal. Medical practitioners interviewed agreed that within a week and maximum of four weeks with proper treatment ergonomics related ailments should be cured provided there is no complication. That means a personnel suffering from ergonomics ailment is unavailable for a week or more though he may be physically present but not functionally. That directly impact plant availability as impacted personnel cannot help to restore plant in record time. That definitely increases plant down-time.

#### **5.2.2.2 Extrapolated medical cost.**

Having established from the research so far, that ergonomic impacting task exist in maintenance activities. And, the impacting activities do not leave the personnel without ailments or levels of injury requiring medical assistance or first aid.

The challenges of getting information regarding the medical cost have been reiterated earlier on. The need to get a baseline cost that can be used for the purpose of this research work has brought about the figure in table 5.2 below based on the average of values gotten from the interviewed medical personnel earlier mentioned.

	Symptom	Average in ₦	Average in \$	Average in Rand	Respon dents	Total cost (#)	Total cost (\$)	Total cost (R)
1	Tingling	3250	21.67	162.5	141	458,250	3,055	22,912.50
2	Numbness	5500	36.67	275	107	588,500	3,923.33	29,425.00
3	Continual muscle fatigue	2375	15.83	118.75	91	216,125	1,440.83	10,806.25
4	Change in the skin colour of hands or fingertips	875	5.83	43.75	22	19,250	128.33	962.50
5	Swelling in the joints	2875	19.17	143.75	40	115,000	766.67	5,750.00
6	Decreased grip strength	2875	19.17	143.75	78	224,250	1,495	11,212.50
7	Pain from movement.	5000	33.33	250	95	475,000	3,166.67	23,750.00
8	Decreased ability to move.	14500	96.67	725	103	1,493,500	9,956.67	74,675.00
						3,589,875	23,932.5	179,493.8

**Table 5.2 – Medical cost**

The baseline medical cost above is just the minimum that can be incurred by an industry player. It shows that, ergonomic related ailment among maintenance personnel cost three million five hundred and eighty-nine thousand, eight hundred and seventy-five naira per annum. Actual cost can only be determined by the organizations based on their records. It only confirms that maintenance personnel encounter ergonomic related problems on their job.

### **5.2.3 Personnel morale**

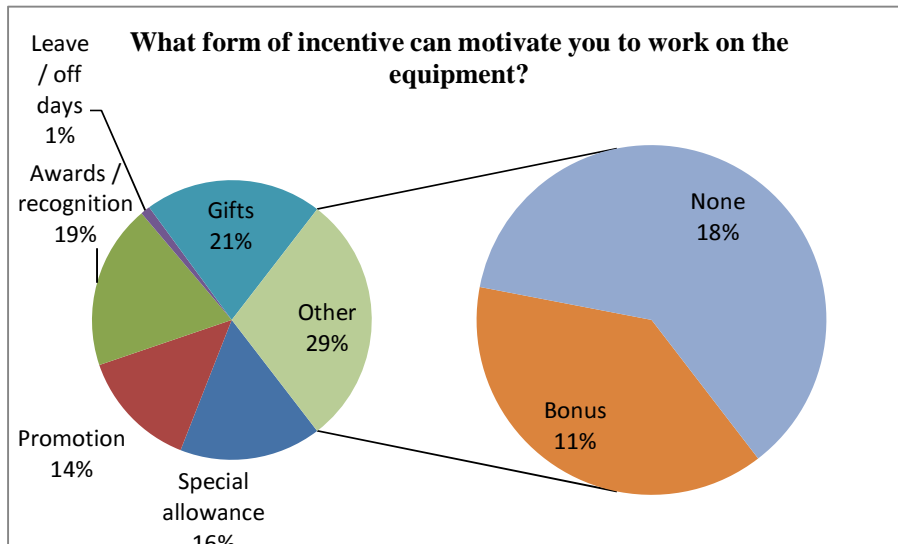
The state of a man's mind affects his activities to a great extent. Is there any impact on the morale of the personnel due to the ergonomic related discomfort associated with the job? The response to the question shows that 68% of the respondents are positive in their reaction. They will still do the job happily anytime any day.

Some factors were observed as motivating factor for the majority that are positive in their response, like;

- Sense of responsibility among personnel.
- The need to secure their job rather than been discouraged.
- As earlier mentioned, some are just holding fort till they will get something better as detailed in the interview section.

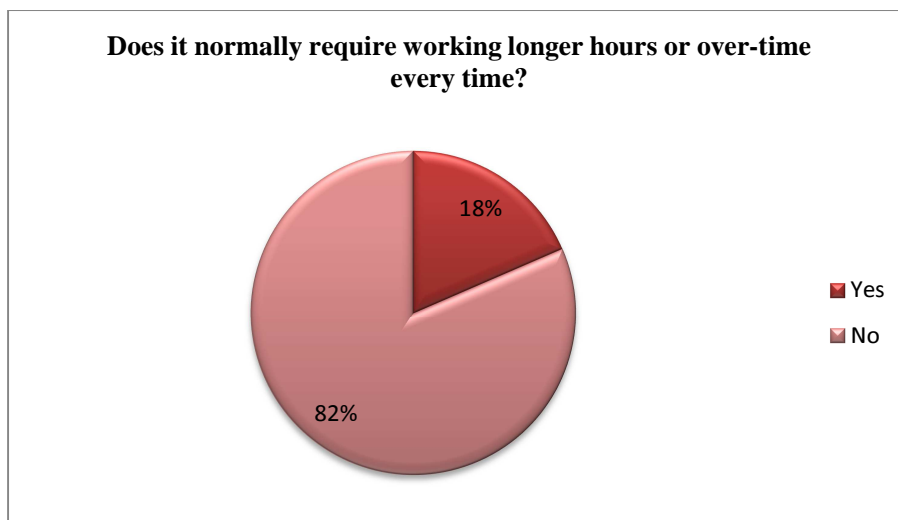
It is important to note that 10% would not want to attend to the job even with over-time allowance. The rest 22% are indifferent.

Responses to question 4.2 shows that (Figure 5.7 below) there is no particular form of motivation that cuts across a wide population that can enhance personnel generally. Individual preferences in any given organization will over-shadow any morale boosting effort. **The best will be to mitigate the cause or eliminate where possible else, the job becomes boring and a drudgery leading to increased down-time (reduce plant availability).**



*Figure 5.7 – Morale booster.*

#### 5.2.4 Over-head cost



*Figure 5.8 – Overhead cost index*



From figure 5.8 above, most of the respondents agreed that the ergonomically impacting task does not require their working longer hours but the task often requires more hands (72% always, 28% sometimes but 0% never), see table 5.3 below.

Which is cheaper, to work extra hour and be pay over-time or have two extra personnel?

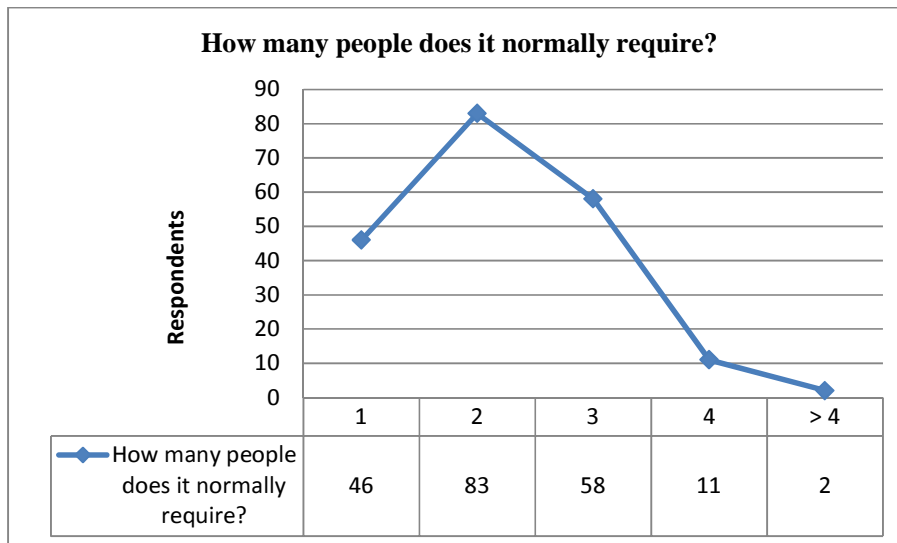
Based on the respondents information, the extrapolation results shows that organizations lost some income to over-head due to ergonomics related issues. One alternative may be cheaper than the other or more humane and law abiding. The fact that it costs something which can be eliminated or reduced is an issue that should be addressed.

	Always	Sometimes	Never
How often does it require using extra number of maintenance personnel?	144	56	0
%	72	28	0

***Table 5.3 – Overhead cost index***

To the credibility of the organization, their maintenance personnel work within normal regulated and agreed working hour. But, unknown to them, the organization employs at least two extra maintenance personnel on the average (figure 5.9 below) for ergonomics reasons. Perhaps, adduced to man-power shortage rather than ergonomic impact on maintenance activities where it is known.

According to the result of the extrapolation carried out in chapter four, if it costs a single organization in an industry about R120, 000 per annum {~~N~~2,400,000 (two million four hundred thousand naira) or \$17,142.86 (Seventeen thousand one hundred and forty-two dollars and eighty-six cents) per annum in Nigeria and the U.S. respectively}, the total cost for the industry can be estimated for a particular area or demography.



*Figure 5.9 - Over head cost index*

### 5.2.5 Plant availability (Production loss)

Stake holders of a production facility will wish that the facility runs un-interrupted from inception. That has been impossible anyway. Production facilities experience interruptions in their operations due to various reasons.

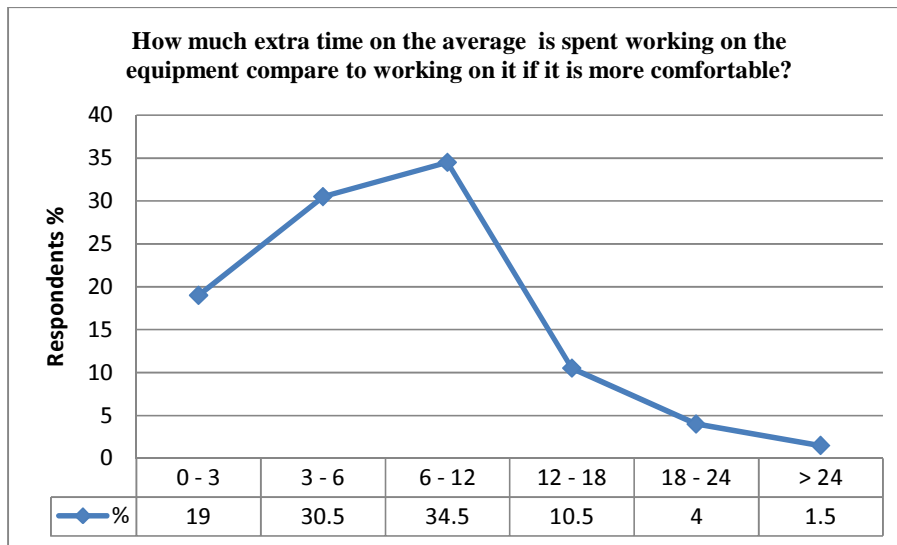
Does ergonomics have anything to do with down-time? 81.5% of respondents agreed that they do not work longer hours than necessary but ergonomically impacting tasks take longer hours than if the task had been without the impact.

Reference to figure 5.10, 19% said such tasks takes 0-3 hours extra, 30.5% (3-6hours), 34.5% (6-12 hours), 10.5% (12-18 hours), 4% (18-24 hours) while 1.5% (>24 hours).

The statistical mode of the distribution is 6-12hours. Taking statical mean of the modal distribution gives 9hours. Working with that mean implies that a production facility may be down on an average of 9hours longer than necessary due to ergonomics impact of maintenance activities on it whenever such equipment breaks down. If other factors like dampened morale or medical condition should be involved the plant will be unavailable much longer.

If the value of the facility production per hour is known, we can calculate how much is actually lost. But, for the purpose of this research an extrapolation has been done in chapter four putting the value on the baseline at about ninety thousand U.S. dollars (13.5million

naira or R675, 000) per annum if it is basically annual or per the equipment breakdown. Depending on the frequency of the equipment breakdown, the value may be more.



**Figure 5.10 - Production down-time.**

### **5.3 Mitigation**

To reduce ergonomic impacts on maintenance personnel effectiveness some suggestions emanated from the respondents that can be of help which are discussed below.

#### **5.3.1 Equipment modification**

Modification of process equipment design or parts will help to minimise the ergonomic impact on maintenance personnel but observations and interviews revealed that some factors had been identified as bottle necks to a prompt action in such instances which are;

- Company policy regarding changes
- Cost
- Down-time involved
- Existence of alternatives to equipment modification
- Lack of awareness (by management)

#### **5.3.2 Equipment replacement**

All the respondents agree to a replacement of the equipment or its part but that is a last option a facility owner will want to consider except when it becomes extremely un-avoidable because of reasons like:

- Cost
- Company policy

- Profitability
- Technology / design (proven or not)
- Compatibility with existing facility
- Nature of substitute (long / short term)

### 5.3.3 Maintenance strategy

71% of the respondents agreed that an adjustment to maintenance strategy been used by the company will make things better in carrying out their tasks with minimal ergonomic impact but that is also not easy to carry out as it would mean:

- Change in company operational and maintenance policy
- Total review of maintenance strategy

That will inevitable require: capital cost, personnel training /re-orientation, tools, maintenance planning, production planning, time, transition management, probability of success and so on.

### 5.3.4 Mitigation Implementation Constraints

Only 42% of respondents have taken pro-active steps to mitigate ergonomic impact on their tasks, but they also claimed that it is in process (See table 5.3).

24% have neither suggested any solution nor complained at all while, 31% felt it's beyond them to initiate. Going by that last finding, it is obvious that solution is not insight as 55% of those directly impacted have done nothing about it. Those who think it is beyond them have superiors who they expect to initiate it.

Why has it not been done?	Respondents	%
<i>It's beyond me</i>	62	31
<i>Not accepted by management</i>	6	3
<i>I've not suggested it</i>	48	24
<i>In process</i>	84	42
<b>Total respondents</b>	200	100%

**Table 5.4 Implementation constraints**

## **Findings summary**

The dissertation outcomes discussed herein sufficiently point at the following:

- Ergonomics impacting tasks exists among maintenance personnel.
- The impacting tasks mostly come up annually.
- Personnel are not comfortable with the impacting tasks as they sustain various injuries from them.
- Treatment of ergonomic-related ailment among maintenance personnel costs the industry (Case A, exact figure not known) about three million five hundred thousand naira (one hundred and eighty thousand rand or twenty-four thousand US dollars) on the minimum per annum (though day-away-from-work is minimal).
- There is no morale booster that can sufficiently please personnel in an organization as a compensation for carrying out such tasks. Ergonomic impacting tasks dampen the morale of personnel.
- Mitigating efforts are in place but in very few cases. Most cases are left unattended to. Workers manage them their own way.
- Maintenance activities are prolonged as a result of the impacting task leading to elongated production down-time (reduced plant availability leading to loss of income for organization). The major aim of the research is to enhance plant availability (reduced down-time).
- Organizations employ more maintenance personnel unknown to them because of the ergonomics impact on their tasks.
- Some maintenance personnel are just waiting for opportunity to move to a more comfortable job (while some have already left).

Mitigating the ergonomics impacts on maintenance activities will: improve the personnel productivity, reduce medical cost on organizations, reduce production down-time (increasing production and profit), reduce over-head cost and encourage some maintenance personnel to be more productive rather than planning to leave the profession. Above all, the more available the maintenance personnel are, the more available the plant will be. The ultimate achievement of this research will be reduced down-time due to ergonomics impact on personnel.

#### **5.4 Ergonomics for Maintenance Assessor**

To mitigate ergonomics impact on maintenance personnel effectiveness, an assessor to capture and mitigate impact per task is proposed and presented in figure 5.11 below.

Understanding of ergonomics, its impacts, ailments/injuries, mitigation efforts already in place and applications form bedrock of the development of the assessor. It was validated by existing works on ergonomics thoroughly delved into earlier and by industrial ergonomics specialists within the industry who attest to its workability from their years of working with personnel in the industry.

Though, they lend credence to its applicability as they admitted the facts generated from the research findings but would not like to be quoted due to company policies. That is not different from the same experience the questionnaire suffered (soft copy) earlier mentioned. Comparing it with existing job safety instruments like; work permit and JHA (job hazards analysis) also validated its applicability and functionality.

The assessor comprises of nine sections which are; job profile, ergonomics query, diagnostics, symptomatic, mitigations, remedial actions, post job feedback and status. The status section indicates what is been done to the information contained on the completed E4M.

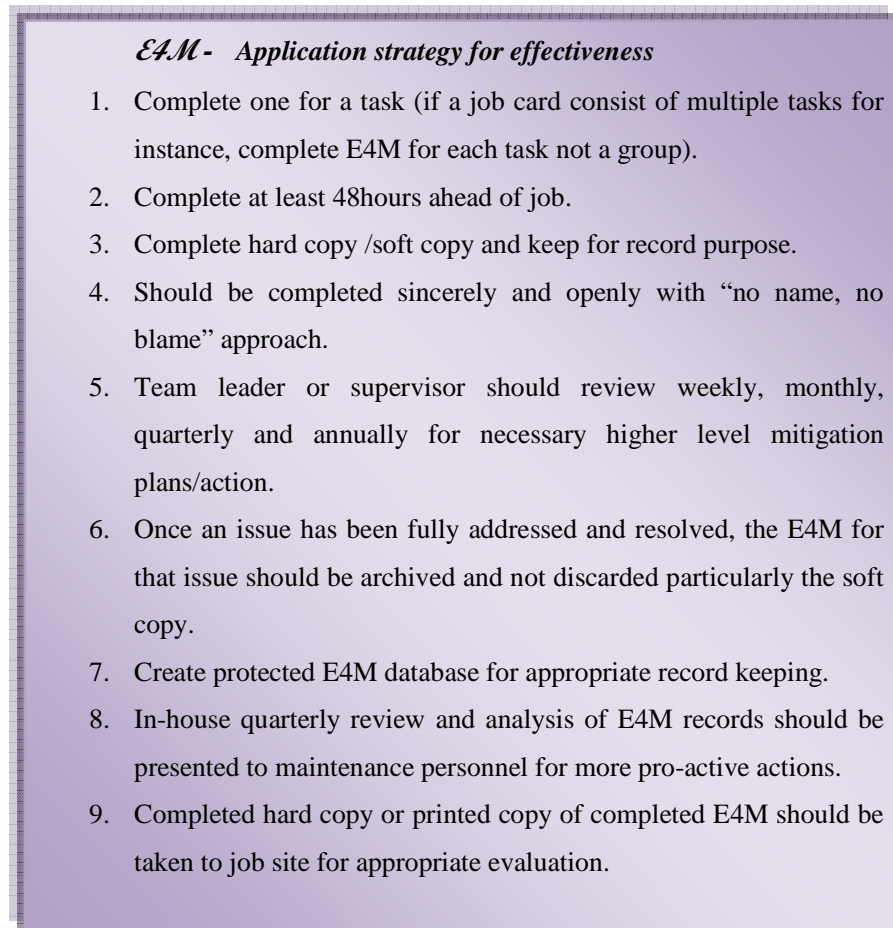
<b>Ergonomics for maintenance job analysis assessor – E4M</b> (complete 48hours before task)																	
E4M	Field	Mech.	<input type="checkbox"/>	Elect.	<input type="checkbox"/>	Instrument.	<input type="checkbox"/>	Date		Time							
<b>Task</b>																	
Task										Job card No.							
Location																	
Equipment involved																	
Ergonomics impact present? Yes <input type="checkbox"/> No <input type="checkbox"/>																	
Working position/posture involved																	
Ergonomics risk factors (tick as applicable)																	
Not easily accessible part						<input type="checkbox"/>	Equipment design is not favourable to task.				<input type="checkbox"/>						
Uncomfortable posture						<input type="checkbox"/>	High repetitive motion/movement.				<input type="checkbox"/>						
Using tools in manner that can cause pain, stress or injury?						<input type="checkbox"/>	Others (specify).				<input type="checkbox"/>						
Body parts that could be impacted (tick as applicable)																	
Neck		<input type="checkbox"/>	Spines		<input type="checkbox"/>	Back		<input type="checkbox"/>	Hands		<input type="checkbox"/>	Head		<input type="checkbox"/>	Wrists		<input type="checkbox"/>
Fingers		<input type="checkbox"/>	shoulders		<input type="checkbox"/>	Bones		<input type="checkbox"/>	Joints		<input type="checkbox"/>	Muscles		<input type="checkbox"/>	Ankle		<input type="checkbox"/>
Ergonomics ailments (symptoms) risk																	
Tingling				<input type="checkbox"/>	Back pain				<input type="checkbox"/>	Decreased grip strength				<input type="checkbox"/>			
Numbness				<input type="checkbox"/>	Swollen joints				<input type="checkbox"/>	Body aches.				<input type="checkbox"/>			
Muscle fatigue				<input type="checkbox"/>	Decreased ability to move				<input type="checkbox"/>	Tear or laceration.				<input type="checkbox"/>			
Change in skin colour				<input type="checkbox"/>	Neck pain				<input type="checkbox"/>	Weakness				<input type="checkbox"/>			
Joint pain				<input type="checkbox"/>	Pain from movement				<input type="checkbox"/>	Sore muscle				<input type="checkbox"/>			
Mitigation																	
Pre-task disassembling				<input type="checkbox"/>	Customized tools				<input type="checkbox"/>	Tools improvising				<input type="checkbox"/>			
Work platform (step ladder, scaffolding,				<input type="checkbox"/>	Task division/assignment (time-based/stress based).				<input type="checkbox"/>	Improved tools/powered tools in place of manual.				<input type="checkbox"/>			
Job sequencing				<input type="checkbox"/>	Task( semi/full) automation				<input type="checkbox"/>	Specialize PPE				<input type="checkbox"/>			
Remedies for ailment																	
Rest breaks				<input type="checkbox"/>	First aid				<input type="checkbox"/>	Medical assistance				<input type="checkbox"/>			
Exercise				<input type="checkbox"/>	Conservative therapy				<input type="checkbox"/>	Over-the counter medication.				<input type="checkbox"/>			
Post job feedback																	
Number of personnel					Job card No.					Date			Time				
First names																	
Ergonomic impacting conditions experienced																	
True working postures																	
Body parts affected																	
Injury sustained																	
Mitigation plan(s) that worked and why.																	
Mitigation plan (s) that did not work.																	
Mitigation plan that could have helped.																	
Recommendations																	
Status																	
In progress				<input type="checkbox"/>	Closed out				<input type="checkbox"/>	Date			Time			Sign	

Figure 5.11 – Ergonomics for Maintenance assessor (E4M)

(Oluwasina Oluremi. I.)

#### 5.4.1 Methodology for usage

For effective application personnel need to follow through the prescribed guidelines presented in figure 5.12 below. The checklist will be on a page attached before the E4M or at the back (hard copy) while it will be on a pop up window (welcome window) or instruction section for soft copy.



***Figure 5.12 – E4M application strategy checklist (Oluwasina Oluremi. I.)***

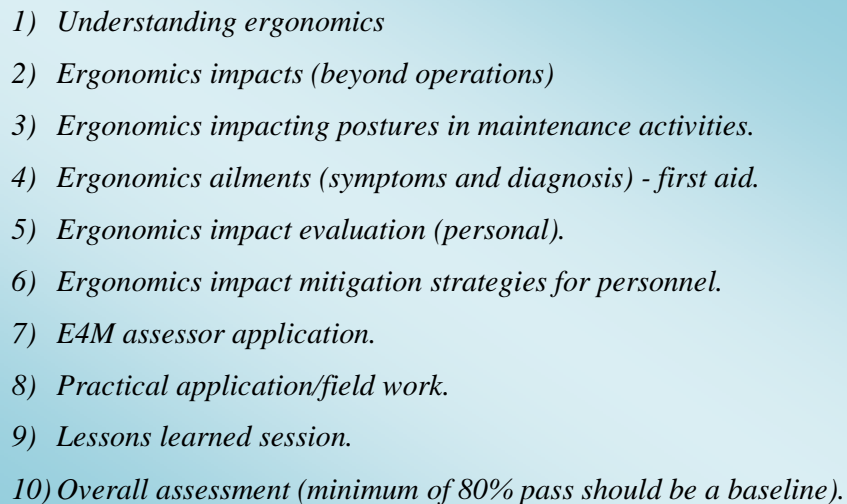


#### **5.4.2 E4M Personnel training.**

Applying the E4M assessor should be precluded with a training session for the personnel for effectiveness. As earlier mentioned, lots of maintenance personnel particularly of low educational background do not understand the concept of ergonomics.

The training will be entitled “**Ergonomics for maintenance training session**”.

It will contain the modules presented in figure 5.13 below;

- 
- 1) *Understanding ergonomics*
  - 2) *Ergonomics impacts (beyond operations)*
  - 3) *Ergonomics impacting postures in maintenance activities.*
  - 4) *Ergonomics ailments (symptoms and diagnosis) - first aid.*
  - 5) *Ergonomics impact evaluation (personal).*
  - 6) *Ergonomics impact mitigation strategies for personnel.*
  - 7) *E4M assessor application.*
  - 8) *Practical application/field work.*
  - 9) *Lessons learned session.*
  - 10) *Overall assessment (minimum of 80% pass should be a baseline).*

**Figure 5.13 – E4M training matrix**

*(Oluwasina Oluremi. I.)*

Content of those modules will have to be developed and tailored towards maintenance personnel needs to avoid information overload.

#### **5.4.3 Applications of the E4M proposed**

The E4M assessor may;

1. Serve as impact indicator or information board for; new maintenance employee, newly deployed employee to unit, HSE personnel, in-house ergonomic specialist, supervisors, project managers, design engineers, production planners/analyst, maintenance planners and management.
2. Be used as decision making tool for individuals mentioned above at their various roles for mitigation action.
3. Be an ergonomics impact assessment aid for specialist where needed.
4. Be source of lessons learned for both new and un-informed maintenance employees.

5. Be used to create a platform for E4M software or programme (which is more corporate than E4M database).
6. Serve as a reference check for improvement on captured ergonomically impacting tasks over time to assess the effectiveness of mitigating steps.

Catching and tracking ergonomics impacts on maintenance activities geared at mitigating the impacts will not only ensure that personnel are healthy and motivated to bring back the plant whenever there is a breakdown within the shortest possible time. It also guarantees the availability of the plant for prompt and effective maintenance intervention whenever there is a breakdown. As earlier mentioned a maintenance friendly plant is most likely to be available most of the time.

This research is more of maintaining the maintainer, the more available the maintainer the more available the plant. That is, reducing ergonomics stressors reduce plant down-time (increases plant availability).

#### **5.4.4 Summary**

This chapter presents the discussion and interpretation of survey outcomes under the impact evaluation indices; man-hour loss, medical cost, personnel morale, over-heads cost and production loss. Possible mitigation approaches and their attendant constraints. The proposed E4M assessor and other aids were also presented.

## **CHAPTER SIX**

### **Conclusion and Recommendations**

---

*Chapter six summarises the dissertation from the on-set based on its outcomes and concludes logically. Vital recommendations are also given in order to achieve a positive result wherever the outcomes of this work finds its application. Possible further research areas also mentioned.*

---

## **6.0 Conclusions and Recommendations**

This chapter put together the essence of the research and the significance of the findings analysis and discussions therein. Recommendations for effective application of the outcomes of the research and possible further research work are also suggested.

### **6.1 Conclusions**

This dissertation started with the purpose of improving maintenance activities (personnel effectiveness) by mitigating ergonomics factors to ensure that petro-chemical plant is available most of the time (reduced down-time). The following indices were employed to investigate whether the ergonomics impacting tasks actually exist or not (else there would not be any need going further):

- ❖ Type of ergonomic related injury or ailment sustained.
- ❖ Man-hour loss or (and) DAFW.
- ❖ Costs (medical and over-head).
- ❖ Production down-time elongation.
- ❖ Equipment utilisation (end-user satisfaction).

The dissertation outcomes or findings presented herein serve as sufficient evidence to the fact that:

- ❖ Ergonomics has impact on maintenance activities.
- ❖ Ergonomics impacting tasks on maintenance mostly come up annually.
- ❖ Maintenance personnel are not comfortable with ergonomics impacting tasks.
- ❖ Industry incur cost both medical and over-head due ergonomics impact on maintenance personnel.
- ❖ Ergonomic impacting tasks dampen the morale of personnel.
- ❖ Maintenance activities are prolonged as a result of ergonomics impacts.
- ❖ Organizations employ more hands because of ergonomics impact on maintenance activities (unknown to them).
- ❖ Some maintenance personnel will readily change their job if given an opportunity to do so to a more comfortable job (while some have already left).

Mitigating the ergonomics impacts on maintenance activities will: improve the personnel productivity, reduce medical cost on organizations, reduce production down-time (increasing production and profit), reduce over-head cost and encourage some maintenance personnel to be more productive rather than planning to leave the profession.

Eliminating ergonomics stressors in maintenance activities ensures that work force are healthy, motivated (high morale by working in a healthy-*ergonomically impacting process or equipment is unhealthy*- and safe environment) and available (does not have cause to take day-away-from-work or temporarily unable to perform his duties). That in essence directly ensures plant availability (reduced down-time).

## **6.2 Recommendations**

For effective use of the E4M assessor presented in section 5.4 alongside the application guidelines and training matrix discussed in sections 5.4.1 and 5.4.2 respectively, the following recommendations are necessary:

### **6.2.1 Organizational commitment**

For a beneficial application, the concept of the E4M assessor should be accepted by management of an organization, who will ensure that its application does not suffer a setback as personnel will be free to express themselves. Commitment to improvement from top management is highly important for the effect of its application on the work force performance to be felt.

### **6.2.2 Sincerity**

Personnel sincerity in using the assessor is important rather than seeing it as a loop hole for mischievous purposes like; excusing themselves from task or undue medical claims. Sincerity on the part of the management to use the information gathered from the assessor to develop and improve maintenance activities is also significant.

### **6.2.3 Personnel training**

The training that was proposed in the previous chapter should be pre-assignment for new maintenance employees as part of induction training. For those who are already in the system, they have to be scheduled in manners that will not paralyse their normal daily activities. The sessions have to be presented clearly with examples to drive home the points. Careful explanation to differentiate ergonomic ailments from other similar ailments should be given as well.

Rate of understanding will depend to an extent on the level of education of personnel and exposure. The length of the training session may vary from three to five days with module assessment at the end of each module.

#### **6.2.4 Management role**

As the instrument proposed cannot be used outside an operating environment, the consent and support of the management must be in place to ensure the following;

- ❖ Preventive maintenance measures for high ergo risk area to reduce down-time where impact has been identified.
- ❖ Predictive maintenance for high ergo risks area to fore-stall frequent incessant breakdown.
- ❖ Equipment reliability assurance to enhance equipment functionality and reduce mean-time – between -failure (MTBF).
- ❖ Ergonomics impact assessment for maintenance activities may be incorporated into company maintenance planning.
- ❖ Improved equipment design should be looked into based on the records from the assessor. The records may be shared with contractors to drive the point home on the issue of designing for safety.
- ❖ Equipment modification may be carried out where possible.
- ❖ Improved or customized tools may be produced for some very special areas depending on outcome of assessment.
- ❖ Pre-planned maintenance strategy (combination of maintenance strategies may have to be adopted) for high ergonomics impacting tasks.
- ❖ Tools may be improvised locally but to acceptable standard to suit work in such areas (tools to fit-length, size and shape).
- ❖ Power tools may have to be provided in some cases.

#### **6.3 Further Research**

As a follow-up to this research work, further research may be carried out on, “Maintenance versus equipment design: optimising process utilisation”, and “Impact assessment of ergonomics due to equipment design on maintenance”.

## **Annexure**

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## **Appendix A: Questionnaire Letter**

### **ACADEMIC RESEARCH PURPOSES ONLY (PRIVATE & CONFIDENTIAL)**

For further information please call +27730747222 or +2348070761600

**OR**

Faculty of Engineering, (Centre for Research & Continued Engineering Development),  
North-West University, South Africa.

Dear Sir/Madam,

### **SUBJECT: Academic Research the Petro-chemical industry: MAINTENANCE IMPROVEMENT.**

I am a student of North-West University, Potchefstroom, South Africa, (degree of Engineering in Engineering Development and Management and intending to complete my studies at the end of year 2010.

I am working on a research project aimed at improving maintenance personnel's effectiveness by mitigating inadequacies due to ergonomics in the petro-chemical industry. I hereby humbly request your co-operation in completing the attached questionnaire.

The research is aimed at identifying if there are poor ergonomically impacting tasks under which maintenance work cannot be favourably carried out or lead to sustenance of ergonomic related injuries like; strain, stress, back pain etc. The end is to recommend a procedure or approach that will enhance the performance of maintenance under such condition that will mitigate or eliminate the ergonomics related stressors or injuries.

It will be highly appreciated if you could kindly complete and return as early as 31<sup>st</sup> of March, 2010. Completed questionnaire may be returned by email to osinapi@yahoo.com before 31<sup>st</sup> March, 2010.

The data herein gathered will be used in very high confidentiality and strictly for academic purpose only. Perhaps, you'll like have the outcome of the research, you may indicate and it would be shared with you as soon as the University approves it.

Your co-operation and support is highly anticipated and will be appreciated.

Thank you very much.

Regards,

Oluwasina O. I.



## Appendix B: Research Questionnaire

This questionnaire is intended to gather data for academic purpose only, hence feel free to express your views. Thanks for your time.

Please, tick ☐ the appropriate box and put comment where necessary.

Section 1							
1.1	Are you a maintenance personnel in the petro-chemical industry?			Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
1.2	What field are you?	Mechanical	<input type="checkbox"/>	Electrical	<input type="checkbox"/>	Instrument	<input type="checkbox"/>
1.3	How long have you been a maintenance personnel in the petro-chemical industry?		0-5yrs	<input type="checkbox"/>	5-10yrs	<input type="checkbox"/>	
			10-15yrs	<input type="checkbox"/>	>15yrs	<input type="checkbox"/>	
1.4	What is your level of education?	< O/Level	<input type="checkbox"/>	Diploma		<input type="checkbox"/>	
		O/Level	<input type="checkbox"/>	B.Tech /B.Sc		<input type="checkbox"/>	
		Trade test/C&G	<input type="checkbox"/>	M. Tech/M.Sc		<input type="checkbox"/>	
Section 2							
<i>Have you had an experience of working on an equipment where;</i>							
2.1	The part is not accessible.			Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
2.2	There is high risk of sustaining injury.			Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
2.3	Work is done under an uncomfortable posture.			Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
2.4	The job requires using tools in uncomfortable manner that causes pains or stress.			Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
2.5	The mechanical design of the equipment is not good.			Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
2.6	Tool is used repetitively that can lead to repetitive stress injuries.			Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
<i>If you answered "Yes" to any question between 2.1 &amp; 2.6, please, proceed to 2.7.</i> <i>If you answered "No" to all the questions between 2.1 &amp; 2.6 proceed to the end of the questionnaire.</i>							
2.7	How often does the work re-occur?	Once a week at least	<input type="checkbox"/>	Once a month at least	<input type="checkbox"/>		
		Once in 3 months at least	<input type="checkbox"/>	Once a year at least	<input type="checkbox"/>		
		More frequent	<input type="checkbox"/>				
<i>If you chose "more frequent" above, please specify how often.</i>							
2.8	Are your superiors aware of the problem?			Yes	<input type="checkbox"/>	No	<input type="checkbox"/>
2.9	How often do you take day away from work because of it?	Often	<input type="checkbox"/>	Some times	<input type="checkbox"/>	Never	<input type="checkbox"/>

Section 3												
3.1	On which part of the body is discomfort normally felt after working on the equipment?	Bones	<input type="checkbox"/>	Neck	<input type="checkbox"/>	Waist	<input type="checkbox"/>					
		Muscles	<input type="checkbox"/>	Back	<input type="checkbox"/>	Hands	<input type="checkbox"/>					
		Head	<input type="checkbox"/>	Spines	<input type="checkbox"/>	Joints	<input type="checkbox"/>					
		Wrists	<input type="checkbox"/>	Others	<input type="checkbox"/>							
If you chose "others" above, please specify,												
3.2	What type of pain is normally experienced?	Tingling	<input type="checkbox"/>	Numbness	<input type="checkbox"/>							
		Continual muscle fatigue	<input type="checkbox"/>	Sore muscles	<input type="checkbox"/>							
		Change in the skin colour of hands or fingertips	<input type="checkbox"/>	Decreased grip strength	<input type="checkbox"/>							
		Swelling in the joints	<input type="checkbox"/>	Pain from movement	<input type="checkbox"/>							
		Decreased ability to move	<input type="checkbox"/>									
3.3	Does the pain normally require medical assistance or first Aid?	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>							
3.4	How long does it normally take for the pain to go?	Less than a week	<input type="checkbox"/>	2-3 weeks	<input type="checkbox"/>							
		A month	<input type="checkbox"/>	More than a month	<input type="checkbox"/>							
Section 4												
4.1	If on weekend/off and you are called to attend to the problem, will you be happy to go, though you'll be paid over-time allowance.	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	Indifferent	<input type="checkbox"/>					
4.2	What form of incentive can motivate you to work on the equipment?	Special allowance	<input type="checkbox"/>	Promotion	<input type="checkbox"/>							
		Awards/recognition	<input type="checkbox"/>	Gift	<input type="checkbox"/>							
		Leave/off days	<input type="checkbox"/>	Bonus	<input type="checkbox"/>							
		None	<input type="checkbox"/>	Others	<input type="checkbox"/>							
Section 5												
5.1	Does it normally require using extra number of maintenance personnel?	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>							
5.2	How often does it require using extra number of maintenance personnel?	Always	<input type="checkbox"/>	Sometimes	<input type="checkbox"/>	Never	<input type="checkbox"/>					
5.3	How many people does it normally require?	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	>4	<input type="checkbox"/>	
If you chose ">4" above, please specify,												
5.4	Does it normally require working longer hours or over-time every time?	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>							
5.5	How much extra time on the average is spent working on the equipment	0-3 hrs	<input type="checkbox"/>	3-6 hrs	<input type="checkbox"/>	6-12 hrs	<input type="checkbox"/>					

	compare to working on it if it is more comfortable?	12-18 hrs	<input type="checkbox"/>	18-24 hrs	<input type="checkbox"/>	>24 hrs	<input type="checkbox"/>
<b>Section 6</b>							
<b>6.1</b>	Will a modification of a part of the equipment make things better?	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>		
<b>If you chose “No” in 6.1 above please specify,</b>							
<b>6.2</b>	Will a replacement of the equipment with another of better design make things better?	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>		
<b>6.3</b>	Is there any adjustment that can be made to the maintenance strategy/approach been used to make things better?	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>		
<b>If you answered “Yes” in 6.3 above, please specify,</b>							
<b>6.4</b>	Why has it not been done?	It's beyond me	<input type="checkbox"/>	Not accepted by management	<input type="checkbox"/>		
		I've not suggested it	<input type="checkbox"/>	In process	<input type="checkbox"/>		

Thank you for your time.

If you have additional information kindly write at the back of this questionnaire.

**ACADEMIC RESEARCH PURPOSES ONLY**  
(PRIVATE & CONFIDENTIAL)

**Research topic: MAINTENANCE IMPROVEMENT IN THE PETRO-CHEMICAL INDUSTRY.**

- 
1. What field are you?  
Mechanical ☐ Electrical ☐ Instrument ☐
- 
2. For how long have you been maintenance personnel in the petro-chemical industry?  
0– 5yrs ☐ 5 – 10yrs ☐ 10 – 15yrs ☐ >15yrs ☐
- 
3. What is your level of education?  
(a) < O'Level ☐ (b) O'Level ☐ (c) Trade test /City & Guild ☐  
(d) Diploma ☐ (e) B. Tech, B. Sc ☐ (f) M. Tech ☐
- 
4. Have you had an experience personally or of other maintenance personnel working on an equipment where (Please tick as many as applicable)  
(a). The part is not easily accessible. ☐  
(b). High risk of sustaining injury. ☐  
(c). Work done under an uncomfortable posture. ☐  
(d). The job requires using tools in uncomfortable manner that leaves you with pains or stress. ☐  
(e). The mechanical design of the equipment is not good? ☐  
(f). Other reasons. Please specify
- 
5. Did it require working under uncomfortable posture? Yes ☐ No ☐
- 
6. Under what kind of posture was the work on the equipment done that was not comfortable?  
Bending ☐ Kneeling ☐ Stooping ☐ Sitting ☐  
Standing ☐ Stretching ☐ others, (please specify)
- 
7. Which part of the body normally feels discomfort after working on it?  
Neck ☐ Back ☐ Spines ☐ Waist ☐ Hands ☐  
Joints ☐ Muscles ☐ Wrists ☐ Head ☐ Bones ☐  
Others, (please specify)
- 
8. How often does it require using extra number of maintenance personnel?  
Always ☐ Sometimes [ $\frac{1}{4}$  ☐  $\frac{1}{2}$  ☐  $\frac{2}{3}$  ☐  $\frac{3}{4}$  ☐] Never ☐
- 
9. Would you prefer a modification of the part of the equipment? Yes ☐ No ☐
- 
10. Would a modification of the equipment ease stress? Yes ☐ No ☐

---

11. How much time on the average do you think you waste working on the equipment compare to working on it, had it been more comfortable?

0 -1hr

1 – 3hrs

3 – 6hrs

6 – 12hrs

12 -18hrs

18 – 24hrs

>24hrs

---

12. Is it possible to modify the equipment design at low cost? Yes  No

---

**Appendix D: Ergonomics definitions from the web.**

- The applied science of equipment design intended to maximize productivity by reducing operator fatigue, safety and discomfort. ...  
[spyderco.com/edge-education/glossary.php](http://spyderco.com/edge-education/glossary.php)
- The science of obtaining a correct match between the human body, work-related tasks, and work tools.  
[www.montefiore.org/healthlibrary/adult/pmr/content.asp](http://www.montefiore.org/healthlibrary/adult/pmr/content.asp)
- The relation of humans with machines, in particular the study of body posture in relation to engineering. Ergonomics includes features of chair design, tool design, positioning of dials, room layout and computer interface which correspond to healthy body form. ...  
[www.eubios.info/biodict.htm](http://www.eubios.info/biodict.htm)
- (er-go-nom-ics) (ərˈgo-nomˈiks) [ergo- + Gr. nomos law] the science relating to humans and their work, embodying the anatomic, physiologic, psychologic, and mechanical principles affecting the efficient use of human energy.  
[www.mercksource.com/pp/us/cns/cns\\_hl\\_dorlands.jspzQzpgzEzzSzppdocszSzuszSzcommonzSzdorlandszSzdorlandzSzdmd\\_e\\_14zPzhtm](http://www.mercksource.com/pp/us/cns/cns_hl_dorlands.jspzQzpgzEzzSzppdocszSzuszSzcommonzSzdorlandszSzdorlandzSzdmd_e_14zPzhtm)
- The study of workplace design and the physical and psychological impact it has on workers. Ergonomics is about the fit between people, their work activities, equipment, work systems, and environment to ensure that workplaces are safe, comfortable, efficient, and that productivity is not compromised.  
[www.powerhomebiz.com/Glossary/glossary-E.htm](http://www.powerhomebiz.com/Glossary/glossary-E.htm)
- [SCOPE NOTE: Field of knowledge of human work; matching of machines and people to increase efficiency; includes concern with design of equipment and the arrangement of physical conditions of work or environment and measurement of energy and muscle output in the performance of work]  
[cirrie.buffalo.edu/thesaurus/these.html](http://cirrie.buffalo.edu/thesaurus/these.html)
- The science of designing equipment to better fit the human body.  
[www.precor.com/cons/tools/glossary/](http://www.precor.com/cons/tools/glossary/)
- The study or science of how people interact with their work.  
[www.tvb.org/multiplatform/Multiplatform\\_Glossary.asp](http://www.tvb.org/multiplatform/Multiplatform_Glossary.asp)
- A discipline that involves fitting the job to the worker and not the worker to the job. It is the science of adapting workstations, tools, equipment and job practices to be compatible with the individual worker and thus reduce the risk of injury due to risk

factors.

[www.workriteergo.com/ergonomics/glossary.asp](http://www.workriteergo.com/ergonomics/glossary.asp)

- The science of designing the job to fit the worker, rather than physically forcing the worker's body to fit the job.

[www.nationalpainfoundation.org/MyTreatment/MayoClinic\\_glossary.asp](http://www.nationalpainfoundation.org/MyTreatment/MayoClinic_glossary.asp)

- Ergonomics is the study of optimizing the interface between human beings, and the designed objects and environments they interact with.

[www.nouky.fr/en.php](http://www.nouky.fr/en.php)

- The science of fitting a job and job-related equipment to individual human physical and psychological characteristics.

[www.ehealthmd.com/library/carpaltunnel/CT\\_glossary.html](http://www.ehealthmd.com/library/carpaltunnel/CT_glossary.html)

- A discipline dealing with the interaction between the worker and the work environment.

[www.whscc.nf.ca/ohs/glossary.htm](http://www.whscc.nf.ca/ohs/glossary.htm)

- The applied science involving the factors and interaction of the workplace environment on its workers. Although it is most often associated with automation in the workplace, this science covers the cause and effect of any workplace environment.

[www.j6insurance.com/index.asp](http://www.j6insurance.com/index.asp)

- The study of workplace design and the physical and psychological impact it has on workers. The science of analyzing human beings and how we function in conjunction with a variety of equipment, products, methods, and work circumstances to improve our health, safety, and welfare. ...

[educators.fidm.edu/educators/information/definitions-by-design/interior-design.html](http://educators.fidm.edu/educators/information/definitions-by-design/interior-design.html)

- The study of work organization, and the human/machine interface in particular. Not to be confused with mere appearance, ergonomic design is a science devoted to helping the machine operator be more productive by allowing him/her to operate more efficiently, comfortably, and safely.

[www.raymondcorp.com/solutions/glossary.cfm](http://www.raymondcorp.com/solutions/glossary.cfm)

- The practice of changing the work environment to meet the physical and other needs of workers.

[www.afscme.org/publications/2819.cfm](http://www.afscme.org/publications/2819.cfm)

- The scientific study of human work. It is derived from the Greek words ergon (work) and nomos (laws). Ergonomics considers the physical and mental capabilities and limits of the worker as he or she interacts with tools, equipment, work methods, tasks

and the working environment.

[www.assemblymag.com/CDA/Articles/Web\\_Exclusive/58e0022c106c9010VgnVCM100000f932a8c0](http://www.assemblymag.com/CDA/Articles/Web_Exclusive/58e0022c106c9010VgnVCM100000f932a8c0)

- The study of the proper and efficient use of the body in work and recreation, including the design and operations of machines and the physical environment.  
[www.backguide.com/glossary.htm](http://www.backguide.com/glossary.htm)
- The term comes from the Greek words ergon (labour, work) and nomos (law, rule). The aim of ergonomics is to make it easier for people to use tools and other objects. The kitchen should adapt to the user – and not the other way round. ...  
[www.nolte-kuechen.de/index.php](http://www.nolte-kuechen.de/index.php)
- An applied science which considers human characteristics in designing machinery and arranging things for effective interaction, comfort, and safety; also called human engineering.  
[www.knowledgebank.irri.org/glossary/Glossary/E.htm](http://www.knowledgebank.irri.org/glossary/Glossary/E.htm)
- Study of the problems of people in adjusting to their environment; science that seeks to adapt work or working conditions to suit the worker. ...  
[www.chml.ubc.ca/safety/appendices/glossary.html](http://www.chml.ubc.ca/safety/appendices/glossary.html)
- The science of designing machines, tools and computers so that people find them easy and comfortable to use.  
[www.infocus.com/Support/Glossary/E.aspx](http://www.infocus.com/Support/Glossary/E.aspx)
- The study of the physical relationship between people and their tools. In the world of computing ergonomics Seeks to help people use computers correctly to avoid physical problems such as fatigue, eyestrain, and repetitive stress injuries.  
[www.techiwarehouse.com/cms/engine.php](http://www.techiwarehouse.com/cms/engine.php)
- The science of designing tools and work processes for the comfort and safety of employees to avoid such hazards as back injuries or muscle, tendon and eye strain.  
[www.yourpowerinside.com/pages/glossary.htm](http://www.yourpowerinside.com/pages/glossary.htm)
- Ergonomics (or human factors) is the application of scientific information concerning humans to the design of objects, systems and environment for human use (definition adopted by the International Ergonomics Association in 2007). ...  
[en.wikipedia.org/wiki/Ergonomics](http://en.wikipedia.org/wiki/Ergonomics)



## **Appendix E: Maintenance definitions.**

Some of the definitions of maintenance on the internet are listed below;

- I. Inspection, overhaul, repair, preservation and the replacement of parts, but excluding preventive maintenance. ([nmshtd.state.nm.us](http://nmshtd.state.nm.us))
- II. Changes made to a system to fix or enhance its functionality. ([www.cbu.edu](http://www.cbu.edu))
- III. Includes preventative maintenance, normal repairs, replacement of parts and structural components, and other activities needed to preserve the asset so that it continues to provide acceptable services and achieves its expected life. ([www.pps.noaa.gov](http://www.pps.noaa.gov))
- IV. This is offered with agreements and includes routine maintenance and servicing (at manufacturer's recommended intervals), mechanical repairs and replacement parts, tyres, batteries and exhausts. ... ([www.lombardvehiclemanagement.co.uk](http://www.lombardvehiclemanagement.co.uk))
- V. Services that provide the physical upkeep of a facility and its systems, including repairs designed to keep a facility in good condition and preserve its asset value. ([www.mw-zander.com](http://www.mw-zander.com))
- VI. The performance of services on fire protection equipment and systems to assure that they will perform as expected in the event of a fire. Maintenance differs from inspection in that maintenance requires the checking of internal fittings, devices and agent supplies. ([edis.ifas.ufl.edu](http://edis.ifas.ufl.edu))

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