COMPREHENSIVE RISK EVALUATION OF OPERATING INDUSTRIES IN NIGERIA

CASE STUDY:

HF – ALKYLATION UNIT OF KADUNA REFINING AND PETROCHEMICAL COMPANY (KRPC)

BY

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DEDICATION

This work is dedicated to the Almighty God, the creator of the whole Universe from whom, the life, inspiration and enablement to accomplish this feat came from, and to the entire Yusuffs' Family for being there for me through out the duration of my study.

CERTIFICATION

This project has been read and certified as meeting the requirements of the department of Chemical Engineering, in the School of Engineering and Engineering Technology, Federal University of Technology Minna for the award of Bachelor of Engineering Degree in Chemical Engineering.

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DECALRATION

I declare that this project work and the report are entirely my effort and to the best of my knowledge, have never been submitted wholly or partly somewhere else before.

____________________ ____________________

RESEARCHER *DATE*

YUSUFF WALE R.

ACKNOWLEDGEMENT

I wish to appreciate all the staffs of the chemical engineering department, worthy of note, I my indefatigable supervisor and HOD, Chemical Engineering Department, Dr. J. O Odigure, I pray that God will continue to increase his greatness.

I also wish to appreciate the family of Mr. Lawal for the love and kindness when I came to Minna as a Total stranger, they despise me not, but accepted me into their home with open arms. I should also not fail to acknowledge my colleagues and friends who have always been there for me in thick and thin in my sojourn in this institution, time, space and ink will not permit me to mention all their names but posterity will also not forgive me if I fail not to mention people like; Olumide Adenaiya, Olayinka Olawuyi, Abiodun Oladunjoye, Adesola Adesanya, Victoria Oyelade, Kayode Obatusin, Thomas Barna Lass, Ahmed Shuaibu and Ajayi S.O. thanks for being my friend, B.Eng. or B.tech is not the end. It is not even the beginning but is perhaps the end of the beginning; we will all meet again at the topmost most.

I refuse to ignore the input of the management and staff of Access Computers to the success of this work, worthy of note, is Comfort Ariyo who worked tirelessly and sacrificially on the Computer to make sure that this work meets the deadline for submission, she's indeed that friend in need, may God reward her.

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To God be the Glory.

YUSUFF WALE R.

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ABSTRACT

The aim of this research work is to present a final tool / model for the evaluation of risk in chemical process industries in Nigeria. The case study is the reaction section of the linear-alkylbenzene plant (LAB) of KRPC. The study covered a period of seven years (1990 – 1997) the method of evaluation employed in this research work was the BETA-FACTOR (B-Factor) method – designed by Flemming in 1985 – based on classification of failures into dependent common – cause failures and independent failures.

The results of the findings showed that 40.97% of failures were as a result of independent causes while 59.03% was as a result of dependent common-cause failures. The respective values of B obtained for the equipment studied coupled with that of the MBTF was used to propose an adequate maintenance program for management.

CHAPTER ONE

INTRODUCTION

1.1.0 BACKGROUND TO STUDY

In the recent past there has been what could be called a recessions in the technological development of the country (Nigeria). This obviously was due to the prevalent aberration in the political climate then. During my three months industrial training it was a Herculean task to secure a place for the training. This was not because the companies/industries were not there, but most of them were down and some have actually folded up.

Apart from, the unfriendly governmental policies and acts –as of then-, some of these breakdowns were actually due to technical reasons, bad maintenance culture, and insensitivity of management and operating personnel to changes in technology in the industrial climate (since most of the heavy industries in the country today were established more than fifteen years ago). In most of the industries, because of lack of good housekeeping practices and improper documentation of equipment breakdown, operating personnel are continuously exposed to hazards as most of these equipment and machines are highly prone to the occurrence of catastrophic "top events" like, fire outbreak, explosion, leakage of poisonous gases, high dust level etc. This work is embarked upon in order to forestall the further occurrence of these events via, the tools of evaluation and prevention of these inherent risks.

The evaluation and prevention of these inherent risk –in process industries –evolved in the 1930s.This was pioneered in the aircraft industry by gathering information and data on failure rate(s) of the aircraft components and proffering solutions so as to guide against future failures. Thus, the weight of this work will lie on the analysis and evaluation of risk in process industries in Nigeria.

1.1.1 NEED FOR STUDY

Due to the complexity of systems of all kinds and the increased potential for disasters on a worldwide scale, people have become more concerned about risks to health and the environment and are requiring answers, nit only for the present generation but for generations to come. There are also many questions regarding the safe and efficient use of resources in addition to environmental concerns generally.

These fall within the province of risk assessment and management. Thus, this research work is necessitated so as to proffer solution to the questions raised above by presenting a simple and comprehensive model of estimating the value of risk in the industries; at the conceptual, design, and operational stages.

From these answers, cost of compensation to workers due to impairments, Death, litigation, cost of replacing damaged machnies e.t.c that arises from these risks will be brought to the barest minimum.

1.1.2 SCOPE OF STUDY

This study will cover process industries (in Nigeria) in general and in particular the reaction section of the linear alklybenzene (LAB) plant of the Kaduna refinery and Petrochemical Company. The method of analysis of the risks will be the cause tree method and the evaluation tool employed in this particular research, will be the Beta-factor (β-factor) approach. The period of investigation will be from 1990-1997, while the type of risk being evaluated will be those caused by dependent and common- cause failure of equipment and operating personnel's. Emphasis will also be laid on the identification of causes and failure modes of various equipment.

1.1.3 AIMS AND OBJECTIVES OF STUDY

The aim of this research work is basically to present a model of evaluating the attendant risks in process industries in Nigeria with a view of achieving a safe working condition in the concerned industries and reducing cost of production due to accidents, litigation, and to also prolong the life of equipment. The objectives with which these aims would be achieved are presented below:

a) To examine and identify areas of possible hazards in the reaction section of the plant by, following all likely or possible top events to their most likely root cause.

b) Evaluating the magnitude or severity of the earlier identified hazards or top events should they occur.

c) Estimating the probability that these top events might occur using the cause tree method.

d) Estimating the value of β for various equipment so as to present an appropriate maintenance schedule.

e) Obtaining quantified expression of risk, which is the combination of event probabilities with the severity of consequence by probabilistic method.

f) Recommendation of ways of evaluating, reducing and eliminating the root causes of these top events.

g) Writing a computer program to facilitate easy and orderly documentation of equipment failure history and how to calculate annual failure cost.

1.1.4 LIMITATION OF STUDY

Some of the factors that actually did not allow this research work achieve much in fulfilling some of the objectives of this work are;

a). Event failure reports do not always have the level of details necessary to allow dependent failures to be analyzed and categorized easily. Thus, one is constrained to actually to actually choose between 'actual' and potential common-cause failures.

b). Unavailability of individual equipment downtime data during failure this hindered the evaluation of repair time calculations.

c). Unavailability of dependability data for some years due to inadequate documentation of equipment failure history.

CHAPTER TWO

LITERATURE REVIEW

2.1.0 INTRODUCTION

In the previous chapter a number of principles and concepts underlying this study was stated. It was clearly pointed out, that this research aims at proffering a simple and comprehensive model of estimating the value of risks in process industries basically, at the conceptual, design, and operating stages. In this chapter, an attempt will be made to further explain the concepts introduced in chapter one.

Since, according to Auguste Comte (1798-1857), that, no thorough knowledge of a science can be attained as long as its history is not known the discussion in this chapter will focus on the following.

- The concept of risk.
- Risks threatening operations in process industries.
- Types of risks.
- Failure rate concept
- Classification of common-cause and dependent failures.

2.1.1 THE CONCEPT OF RISK

Risk as a concept has many meanings attached to it in everyday and technical usage. People often, do not make a clear distinction between this concept and the concept of probability. There are various definitions but according to Starr (1988) these definitions are often in a vague and uncertain way try to associate two aspects of the same event i.e. its probability of occurrence and its effects or dictionary consequences.

To the mathematician, a layman on the street, an insurance broker, and even an engineer, the idea of what the definition of risk is differs. The new Webster's of English language (international edition) defined risk as, the possibility of danger, injury, loss, and e.t.c. For this research work, a definition, which is deliberately as broad as possible-proposed by Starr (1980), will be adopted. Thus, risk is defined as a measure of a hazard combining a measure of its effects or consequences.

2.1.2 RISKS THREATENING OPERATIONS IN PROCESS INDUSTRIES

The process industry worldwide is faced with many risks at the various stages of operation. According to Aderoju (1999) some of these risks fall within the range of those that are common to business in general while others very unique to the nature and processes of production. He pointed out the common –basic-ones as fire, explosion, accident (both *industrial and* transportation), criminal perils (including both robbery and burglary), environmental pollution, and flood.9

Odigure (1988) classified these risks into four classes viz. chemical, electrical, mechanical and static electricity.

2.1.3 CHEMICALS

The risk in industrial handling and processing of chemical materials comes from the possibility of these materials undergoing chemical transformations, with the liberation of large amount of heat. This heat most often, results into explosion or burn to the personnel involved. A measure of the potential violence of most oxidation process reaction can be determined from the oxygen balance;

$$C_xH_yO_Z + (x+Y/4-Z/2)\ O_2 = XCO_2 + Y/2 + H_2O$$

$\Rightarrow O_2$ balance = -1600(2*X+Y/2-Z)/molecular mass.

This particular risk, could be curtail by maintaing the temperature stability of the process, making correct kinetic assumptions, correct assumption on heat balance.

2.1.4 ELECTRICAL CAUSES

Just like the air around us, electricity is an invisible entity whose effect is felt everywhere; in homes and industrial environments. The risk from electricity comes from the possibility of electrical shock. This is a situation that arises when accidental contact is made between a live current carrying material- electrical conductor and exposed metal or humid work. According to Dhogal (1980) the threshold value of a current that makes an electrical shock dangerous [and makes the shock felt by a tightening sensation] is 0.003A.

He further proposed values of; 10-15 Milliamperes, for some tightening of the muscles experienced. This is occasioned by difficulty in releasing any object gripped at that moment.

25-30 Milliamperes for muscle tightening extended to the thoracic muscle and finally at about 50 milliamperes, fibrillation [stiffening] of the heart occurs. This may lead to death if, immediate attention is not given to the victim. This class of risk, can be curtailed by; making sure that plug point on an energized equipment or installation is not being disconnected by pulling the cable, taking necessary precautions such as, use of rubber shoes, mat, gloves e.t.a. When working on an energized circuit, allowing only authorized to touch or handle electrical apparatus, earthling all electrical installations e.t.c.

In case of accidents, due to electrical shock, where the victim is injured, the correct procedure prescribed by the Health and safety executive (HSE) should be followed. The procedure is as outlined below:

i. Switch off the electric current immediately.

ii. If the switch can not be found, the contact, or injured person must be removed from the electrical contact. Do not touch his/her hands or body. Pull the clothing or use a dry wooden stick to free him/her.

iii. If the casualty is not breathing, he must be given artificial respiration. I.e. the victim must be resuciated.

iv. Medical help (a doctor or a nurse) should be brought. The casualty should be kept warm and still. If to moved should be on a stretcher.

2.1.5 MECHANICAL

Mechanical devices in any industrial establishment can constitute risk to life when the operating regulations and procedures are not observed. Investigations by Odigure and Adgidzi (1998) revealed that, most of the hazards encountered in workshops are from the lathe machines, drilling machines, shaping machines. Others come from welding, hoisting, and lifting machines, fuels, and electrical installation e.t.c. To curtail this risk, workers should be adequately instructed on safety regulations in industrial premises and workshops. Preventive and fire fighting techniques in industries should be made mandatory for workers.

2.1.6 STATIC ELECTRICITY

One of the silent but dangerous risks threatening the safety of workers in chemical process industries is electrostatic discharge. This occurs when two objects at different potentials or polarities come close to generate a charge transfer.

Cross (1987), identified four charge accumulation processes that can cause electrostatic discharge dangerous in chemical process industrial plants. These accumulation processes according to cross (1987) are;

i. Contact and frictional charging.

ii. Double layer charging on microscopic scale in any interference.

iii. Induction charging.

iv. Charging by transport.

Investigations by Glor and Maurer (1993) and Glor (1998) revealed that flammable gases and vapor can be ignited by sparks, brush, conical pile and propagating brush discharges. Their investigations further revealed that, flammable dust could be ignited by sparks, propagating brush and conical pile discharges. The potential hazard of a discharge is estimated by comparing the minimum ignition energy of fuel and air mixture to the equivalent energy of discharge. Two other major risks that threatens process industries that can not be overlooked are;

explosions thus, to forestall further lost due to fire and explosion in the process industries, it is expedient to take prompt and appropriate preventive and remedial actions.

2.2.0 TYPES OF RISKS IN PROCESS INDUSTRIES.

Most losses in the chemical process industries could be traced to two major factors. According to studies carried out by Aderoju (1997) these factors are:

i **Physical Hazards;** these are risks associated with the nature, location, construction, and use of the property or plant.

ii **Moral hazards;** this brings into consideration the human element as opposed to the physical characteristics of the plant or facility at risk. It relates to the character, outlook, laxity, carelessness and state of mind, low-morale, discontent and frustration. Thus, based on these two major factors, risks may be classified into four categories as;

2.2.1 PARTICULAR RISK.

These are individual originated risk. The consequence and impact of the effect of this type of risk, is of a localized nature. An example of this kind of risk, is an explosion or accident in the plant due to an operator's (human) failure.

2.2.2 SPECULATIVE RISK.

This type of risk is also known as commercial risks. The investor (entrepreneur) attached a lot of responsibilities to this type of risk, because it could either make or mar their investment. This risk emanates from sudden change in the economic yield (productivity) of a given plant, facility or investment. This could be as a result of the interplay of market forces, management decisions and the political climate at a given time. The evaluation of this risk is based on speculation thus, it could either result to a profit, break-even or loss.

2.2.3 PURE RISK.

This type of risk is also referred to as insurable risk. Though, no one will deny the fact that insurance is the most popular tool of risk management, but insurance is not risk management in itself. It is just a means of transferring or lessening the impact \burden of the risk on investment. Pure risk arises from; loss or damage to physical asset, loss of possession of asset by fraud or criminal violence, loss of ownership by adverse judgement of law, loss of income resulting from damage to properties of others and loss of income owing to debt or disability of key employees. Pure risk may result in loss or no loss.

2.2.4 FUNDAMENTAL RISK

Fundamental risks do not have a direct bearing –in origin and impact/consequence – on individuals. I.e. they are impersonal. The effect of this type of risk is usually propagated to the immediate and larger environment. These risks are usually not easily controllable by human actions or efforts. Examples of such risks are; inflation, war, natural disaster, earthquakes, and unemployment in the society e.t.c.

2.3.0 THE CONCEPT OF A SYSTEM.

A system is an entity consisting of several units with specified interaction between them. The definition of units is arbitrary and remains context independent. For example a refinery complex can be a system while the distillation column, utilities plant, and the petrochemical plants can be a system on its own while the other parts that makes it up, becomes its unit.

2.3.1 REDUNDANT SYSTEM.

According to N. Ravichandran (1992), a system is said to be redundant if it has more than the necessary units for its proper functioning. In an earlier work J.A Baxter (1981), described a redundant system by specifying the; number of units in the system, the conditions under which the system is operating, the status of the system corresponding to the failure of the system, the repairable/ non-repairable nature of the units, the life time duration (if they are repairable), interactions of spares with the operating units, the repair policy in terms of priority, the number of repair channels, and maintenance schedules if any.

Ravichandran (1979) in his earlier description of what a system is, presented it in a general context as that which;

i. If it consists of n (>=1) units, then the system would require k (<=n) units for a successful operation.

ii. Initially K units are operative and (n-k) units are kept as standbys.

iii. When the number of operable units is less than K, the system is said to be non-operable or in the degraded state of operation with reduced output.

2.3.2 CHARACTERISTICS OF A SYSTEM.

The international organization for standardization (1987) ISO 9001 stated that, every system is generally defined by one or several functions (goals) it must fulfill with given components under given conditions and in a given environment. Thus, the characteristics that should be mentioned before a system is analyzed are as follows.

iii Operational stresses e.g. temperature, voltage, e.t.c

iv Environmental stresses e.g. vibration, shock, and humidity

v Stresses during assembly into the equipment e.g. electrostatic damage of semiconductor components, thermal and mechanical abuse.

2.4.3 ASSUMPTION OF CONSTANT-FAILURE RATE

The constant failure assumption is often used in fields where failure analysis, prediction and prevention is carried out – reliability engineering -. Some of the practical advantages of this assumption are listed below.

i Failure data collection is simpler: only the total accumulated time and total number of failures need to be recorded.

ii Analysis of failure data is much simpler.

iii Mathematics e.g. of reliability prediction is very much simpler.

iv Contribution of components to system failure intensity is simple to calculate; in the absence of redundancy, it is merely the sum of the component failure rates.

v No need, to know past history when making prediction about future reliability.

However, the constant-failure rate assumption has its own shortcomings too, among which are:

i For non-electronic components, the assumption is often not very true. Thus, it can cause wrong reliability predictions and interpretation of test results.

ii The simplifications permitted by the constant failure rate assumption have encouraged the growth of system reliability modeling to a level that at times have little sconnections with reality.

iii Test and field failure data often result in pessimistic reliability predictions because of the higher failure rate in the infant mortality period, which is often much longer than is believed.

externally generated normal environment, extreme, natural environment, internally generated accident environment or externally generated accident environment.

ii ***Design Errors:-*** These are most difficult failure causes to foresee since they are closely related to our know-how limitations. These errors are as a result of; system component not adapted to its mission, inadequate or damageable periodical tests, system (or component) difficult to operate, system (or component) difficult to maintain and omission or negligence in design studies.

iii ***Manufacturing Errors:-*** These errors usually arises from the non-conformity (of operation/ operator) to manufacturing technical specifications and technology errors [e.g. as in Ajaokuta Steel Company: type of coal/fuel].

iv ***Assembly errors:-*** These errors may be due to;

- Non-compliance with good engineering practice
- Non-compliance with cleaning up rules.
- Non-compliance with technical specification
- Defective welds on several components
- Inadequate or botched pre-operational test.

v ***Operating Errors:-*** These errors are incurred during;

- Normal, incident, accident, operating conditions
- During inspection and test
- During maintenance operation.

Failure generally could be classified as shown in the diagram below:

fig 2.5.1

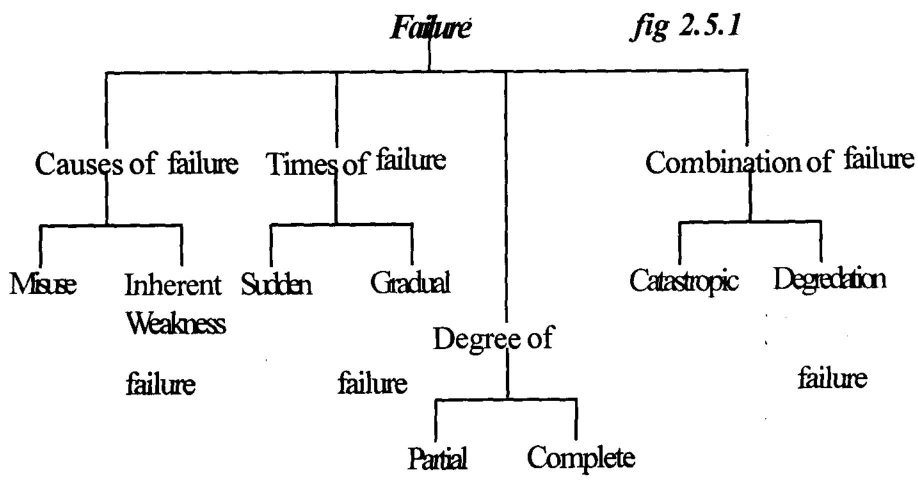


TABLE 2.4B

ITEMS	*MTBF ()HOURS*
P.Cs	16,000
TV sets	20,000
Refrigerator	30,000
Lifts (elevators)	44,000

2.5.4 CONCLUSION OF LITERATURE REVIEW

The review of literature of the subject reveals that a lot of work has been done to identify and classify the sources of risks, with reference to system description and the failure rate concept. But the knowledge of estimating these risks is a growing one. It is in this light, that this research work will be channeled towards estimation of risks in process industries.

CHAPTER THREE

3.1.0 INTRODUCTION

The knowledge of common cause failures are derived from operating experience of industrial systems. During this time, event reports are written to this end so that these failures may be correctly analysed and methodically categorized. The main methods for predicting the dependability of industrial systems revealed interdependencies between failures.

However, since it is extremely difficult to predict all these dependencies, more numerous and specific approaches are used. These main methods are:

- Preliminary Hazard Analysis (PHA)
- Failure Modes and Effect Analysis (FMEA)
- Success Diagram Method (SDM)
- Truth Table Method (TTM)
- Cause Tree Method (CTM)
- Gathered Fault Combination method (GFCM)
- Consequence Tree Method (CQTM)
- Cause – Consequence Diagram Method (CCDM)
- State – Space Method (SSM)

In carrying out this research work, the following steps were followed:

i The case study (HF Alkylation plant of the KRPC) was visited

ii Observation of the various system functions and breakdowns

iii Questions were asked/interviews conducted among the maintenance staff about the causes and sources of stoppages and breakdown during operation.

iv Historical data on failure of components and plant was gathered.

3.1.1 SOURCE OF DATA

The data of equipment failure history were obtained from the maintenance department of the LAB plant of the KRPC. These were extracted from the equipment maintenance cards for each equipment. This was done for the year 1990-1997 for the following components; pumps, heat exchangers, electric motors, pressure safety values, storage drums, compressors, flow meters, pipe and static mixer.

After which individual equipment failure rates were calculated and later on categorized as either a common-cause failure or dependent cause. Data for evaluation of down time and economic losses due to these failures were obtained from the production programming and control department.

3.1.3 IMPORTANCE OF THE METHOD

This method of analysis, has an edge over the other parametric methods of risk (failure-rate) analysis in the following wise:

i It is very easy to apply and has wide spread applications.

ii It can be used to model failures during operation or upon demand

iii It can be used to quantify common-cause failures of systems having identical redundant components. It also assesses the availability or reliability of such systems.

Some industries concern that has benefited immensely from the use of this method includes;

i The Nuclear Power Plants in France (EDF) A. M Smith (1984)

ii The American Nuclear Power Plants and some

iii Refineries in the USA and Chemical Companies such as the ICI, the Eko fish Oil rig e.t.c.

The richness of this method of analysis largely depends on the quality of the event data base on its exhausivity as well as the care taken recording and investigating these events.

3.1.4 THE CAUSE TREE METHOD (CTM)

The fault tree analysis (or cause tree method) was born in 1961-2 in Bell Telephone Laboratories. It was developed by Watson to assess and improve the reliability of the minuteman missile launch control system C. J. Henley (1981). It contributed to eliminate several weak points in this project and its use was considered successful.

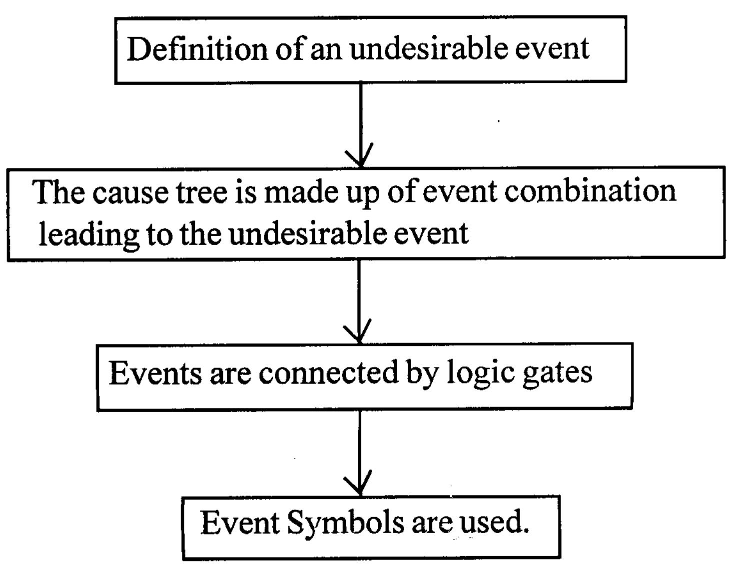
The objectives of these methods are:

i To identify the various possible event combinations leading to a single undesirable event.

ii To represent these combinations graphically by means of a tree-like structure.

Unlike the β-factor method, the CTM is a deductive approach and it is not a model of all the failures likely to occur in a system but rather, a model of the interaction logic between events leading to the undesirable event.

The cause tree approach goes as shown in the fig 3.14a below.



2.5.2 MBTF

An important criterion the maintenance engineer must know is how often an item breaks down. This is defined in two ways.

i *The Mean Time between Failure:-* This is a measure of the likelihood than an item/ equipment will break down in a given period. It is calculated by finding the reciprocal of the failure-rate (λ) or by dividing the operating time of the item by the number of times it failed. *Table 2.4a,b* shows the predicted values of the MTBF of some equipment based on investigations and calculations carried out by G.W.A et. al. (1994). This concept is usually adopted for repairable systems/items.

ii *MTTF (mean time to failure):* - This applies to non-repairable items. It is the average time an item may be expected to function before failure. It is found by stressing a large number of the items in a specified way (e.g. by applying certain electrical, mechanical heat or humidity conditions), and after a certain period, dividing the length of the period by the number of failures during the period.

The combination of these criterion above allows the elevation of how long – with a given period – an equipment is likely to be available and how serious the effects of non-availability during maintenance and breakdown are likely to be. These criterion assists in making decisions concerning the expediency of any stand-by equipment to obtain a certain aailability of service and avoid both expenses of stand-by equipment, which is not required and the extra costs due to the effects of equipment being out of action for longer periods than might otherwise have been anticipated.

2.5.3 VALUES OF MTBF

Some approximate MTBFs for electronic equipment as proposed by G.W.A. Dummer (1981) are given in table 2.4a below. One important point that must be taken into consideration is that conditions vary considerably and are different for each equipment.

MTBF for items/equipment like radios, TV sets, refrigerators, cars, e.t.c are not so readily available but an approximate value for them is as shown in table 2.4b.

Table 2.4a

S/NO	EQUPMENT/ITEMS	( ) MTBF (hours)
1	Computers and Electronic equipment in laboratories	5,000 – 10,000
2	Shipboard Electronics	5,000 – 2,500
3	Airborne Electronics	100 – 1,000
4	Missile electronics	1 – 500
5	Military Grouped Equipment	1,000 - 5000

2.3.3 THE SYSTEM FUNCTION

This deals with the;

i The main functions or missions or goals to be achieved

i The secondary functions or missions should be taken into consideration

iii The significance level of the function

2.3.4 THE SYSTEM STRUCTURE

This encompasses the various;

i System components, their role, their characteristics, and their performance

ii The component interrelation

iii The component location

2.3.5 HOW THE SYSTEM FUNCTION

In the event of an accident or incident, the operators are supposed to follow certain instruction, which should be based on the knowledge of;

i The operating status of the system

ii The operating conditions of the components and of the system

iii The changes in the configuration of the system.

2.3.6 HOW THE SYSTEM IS OPERATED

This should include;

i The system monitoring condition like checks, inspections, and e.t.c.

ii The service schedule of the system e.g. preventive maintenance, corrective maintenance e.t.c.

iii The technical operational specification i.e. the conditions which should be met in operating the system.

2.3.7 THE SYSTEM ENVIRONMENT

This comprises of;

i The other elementary systems in the facility or in the overall process the system under study is part of e.g. the auxiliary systems.

ii All the operators working on the system

Unfavourable ambient conditions (dust, humidity), particular weather conditions (frost, snow), natural phenomena (earthquakes) or industrial hazards (expression, fire, etc).

However, having outlined the characteristics above, it must be envisaged

That during the various phases of the system design, all these data may not be immediately available thus, approximation and assumptions are therefore necessary. But as soon as these data are available, the dependability analysis must be corrected, modified or updated.

2.3.8 TYPES OF SYSTEMS

A chapanis (1986) proposed that, systems can generally be considered in three classes (based on the ergonomics of work) as;

i Manual system, which consist of hand tools and other aids, which are coupled together by the human operator who controls the operation.

ii Mechanical systems, which comprises of well integrated physical parts such as, various types of poured machine tools. They are generally designed to perform their functions with little variation.

iii Automated systems, which are designed to perform all operational functions including sensing information processing and decision making and action. Such a system is fully programmed in order to take appropriate action for all possible contingencies that are sensed.

2.4.0 THE FAILURE RATE CONCEPT

A failure is simply an event that changes a system from an operational ($n > 1, k < n$) to a non-operational ($n < k$) state condition of primary interest in systems risk analysis are the failure rates (λ) and the mean time between failures (MBTF). The failures rate (λ) represents;

i A percentage of failures among the total number of equipment/components being used.

$$\lambda(\%) = \frac{\text{Number of failures}}{\text{Total number of components in use.}}$$

ii A number of failures per given operating time

$$\lambda_{(n)} = \frac{\text{Number of failures}}{\text{Operating time}}$$

$$\text{The mean time between failure (MTBF)} = \frac{\text{Operating Time}}{\text{Number of failures}}$$

2.4.1 FACTOR AFFECTING FAILURE RATE

Components failure rates, depends on many factors. Some of the major and easily identifiable ones are;

i Component Type

ii Component Technology

3.1.5 IMPORTANCE OF THE METHOD

The main importance of this system stems form the fact that, it allows the analyst to identify the various causes responsible for the top event via application of deductive reasoning. That is the top event is the resultant of the occurrence of the precursor: it ensues from the event of the level just below it. These two top events and precursors are connected by Gates or Logic operators. Deductive reasoning process is continued until the basic event or fundamental causes are identified. These events may be independent of one another.

3.1.6 DEPENDABILITY DATA FOR HF ALKYLATION UNIT (LAB) OF THE KRPC (1990-1997)

3.1.7 CALCULATION FOR LOSS IN PRODUCTION.

The HF Alkylation unit (LAB) was designed to produce 30 metric tonnes of linear alklybenzene (LAB) per annum, all things being equal. The plant was also designed to operate for eight thousand, seven hundred and sixty (8760) hours in a year i.e. 365 calendar days. Thus the plant is supposed to operate throughout the year for four years non-stop unless compelled by circumstances to act otherwise. These circumstances could be due to the faults, component failure, accident or failure of a major equipment, which if continued might eventually lead, to a severe undesired event or death.

The design throughput of the unit is 299,484 MT/Y

Thus production rate per day $= \frac{299,484 \times 10^3}{365} = 820504.1096 \text{kg / day}$

$\Rightarrow$ Production rate per hour $= \frac{820504.1096}{24} = 34,187.67 \text{kg/hr.}$

The programmed throughput = 287,176 MT/Y

Per day $= \frac{287,176 \times 10^3}{365} = 7.8678365 \times 10^5 \text{ kg/day}$

Per hour $= \frac{7.8678365 \times 10^5}{24} = 32,782.6484 \text{ kg/hr}$

The actual throughput = 137,055 MT/Y

Per day $= \frac{137,055 \times 10^3}{365} = 375,493.1507 \text{ kg/day}$

Per hour $= \frac{375,493.1507}{24} = 15,645.54795 \text{ kg/hr.}$

The calculation above is for the year 1990. The other years 1991-1997 are also calculated for using the procedures above and are as tabulated in table II.

Table I 1990 DEPENDABILITY FOR HF ALKYLATION UNIT (LAB)

COMPONENET	FAILURE MODE	FREQUENCY	FAILURE RATE
Pumps	Failure to start on demand		
	Failure to run	13	1.4840×10^{-3}
Heat Exchanger	Failure to cool Product to the desired temperature	1	1.415×10^{-4}
Electric Motors	Failure to start	50	5.7077×10^{-3}
Pressure Safety Valve	Failure to open	1	1.1415×10^{-4}
Reactor			
Drum Storage	Leakages	6	6.8493×10^{-4}
Compressors	Failure to operate on demand	6	6.8493×10^{-4}
Flow meter	Failure to Remain Open (Plugged)	4	4.5662×10^{-4}
Explosion pipe	Rupture	3	3.4246×10^{-4}
Static Mixer	Failure to attain the required homogenity of the Reactants (Benzene - Olefin).	-	
1991			
Pumps	Failure to start on demand	9	1.02739×10^{-3}
Heat Exchanger	Failure to cool product to the required temperature	1	1.1415×10^{-4}
Electric Motors	Failure to Start	41	4.6803×10^{-3}
Pressure Safety Value	Failure to open	1	1.1415×10^{-4}
Reactor			
Drum (Storage)	Leakages	1	1.1415×10^{-4}
Compressor	Failure to operate on Demand	6	6.8493×10^{-4}
Flowmeter	Failure to open (Plugged)	3	3.4246×10^{-4}
Pipes	Rupture	3	3.4246×10^{-4}
Static	Failure to Attain the required Homogenity of the Reactants, (Benzene-olefen)	-	

Table I 1992 DEPENDABILITY FOR HF ALKYLATION UNIT (LAB)

COMPONENET	FAILURE MODE	FREQUENCY	FAILURE RATE
Pumps	Failure to start on demand		
	Failure to run	18	2.0491×10^{-3}
Heat Exchanger	Failure to cool Product to the desired temperature	16	1.8214×10^{-3}
Electric Motors	Failure to start	45	5.1229×10^{-3}
Pressure Safety Valve	Failure to open	2	2.2768×10^{-4}
Reactor			
Drum Storage	Leakages	17	1.9353×10^{-3}
Compressors	Failure to operate on demand	8	9.1074×10^{-4}
Flow meter	Failure to Remain Open (Plugged)	4	4.5537×10^{-4}
Explosion pipe	Rupture	1	1.1384×10^{-4}
Static Mixer	Failure to attain the required homogenity of the Reactants (Benzene - Olefin).	1	1.1384×10^{-4}
1993			
Pumps	Failure to start on demand	10	1.1415×10^{-3}
Heat Exchanger	Failure to cool product to the required temperature	26	2.9680×10^{-3}
Electric Motors	Failure to Start	18	2.0547×10^{-3}
Pressure Safety Value	Failure to open	2	2.2831×10^{-4}
Reactor			
Drum (Storage)	Leakages	12	1.3698×10^{-3}
Compressor	Failure to operate on Demand	5	5.7077×10^{-4}
Flowmeter	Failure to open (Plugged)	4	4.5662×10^{-4}
Pipes	Rupture	3	3.4246×10^{-4}
Static	Failure to Attain the required Homogenity of the Reactants, (Benzene-olefen)	6	6.8493×10^{-4}

Table I 1994 DEPENDABILITY FOR HF ALKYLATION UNIT (LAB)

COMPONENET	FAILURE MODE	FREQUENCY	FAILURE RATE
Pumps	Failure to start on demand		
	Failure to run	7	7.9900×10^{-4}
Heat Exchanger	Failure to cool Product to the desired temperature	5	5.70776×10^{-4}
Electric Motors	Failure to start	8	9.1324×10^{-4}
Pressure Safety Valve	Failure to open	2	2.2831×10^{-4}
Reactor			
Drum Storage	Leakages	1	1.1415×10^{-4}
Compressors	Failure to operate on demand	4	4.5666×10^{-4}
Flow meter	Failure to Remain Open (Plugged)	7	7.9908×10^{-4}
Explosion pipe	Rupture	3	3.4246×10^{-4}
Static Mixer	Failure to attain the required homogenity of the Reactants (Benzene - Olefin).	7	7.9908×10^{-4}
1995			
Pumps	Failure to start on demand	14	1.5981×10^{-3}
Heat Exchanger	Failure to cool product to the required temperature	16	1.8264×10^{-3}
Electric Motors	Failure to Start	5	5.7077×10^{-4}
Pressure Safety Value	Failure to open	1	1.1415×10^{-4}
Reactor			
Drum (Storage)	Leakages	8	9.1324×10^{-4}
Compressor	Failure to operate on Demand	7	7.9908×10^{-4}
Flowmeter	Failure to open (Plugged)	6	6.8493×10^{-4}
Pipes	Rupture	4	4.5662×10^{-4}
Static	Failure to Attain the required Homogenity of the Reactants, (Benzene-olefen)	9	1.0273×10^{-4}

Table I 1996 DEPENDABILITY FOR HF ALKYLATION UNIT (LAB)

COMPONENET	FAILURE MODE	FREQUENCY	FAILURE
RATE			
Pumps	Failure to start on demand		
	Failure to run	16	1.8214×10^{-3}
Heat Exchanger	Failure to cool Product to the desired temperature	15	1.7076×10^{-3}
Electric Motors			
Pressure Safety Valve	Failure to open	1	1.1384×10^{-4}
Reactor			
Drum Storage	Leakages	8	9.1074×10^{-4}
Compressors	Failure to operate on demand	9	1.0245×10^{-3}
Flow meter	Failure to Remain Open (Plugged)	8	9.1074×10^{-3}
Explosion pipe	Rupture	4	4.5537×10^{-3}
Static Mixer	Failure to attain the required homogenity of the Reactants (Benzene - Olefin).	9	1.0245×10^{-3}
1997			
Pumps	Failure to start on demand	17	1.9406×10^{-3}
Heat Exchanger	Failure to cool product to the required temperature	12	1.3698×10^{-3}
Electric Motors	Failure to Start	1	1.1415×10^{-4}
Pressure Safety Value	Failure to open	1	1.1415×10^{-4}
Reactor			
Drum (Storage)	Leakages	7	7.9908×10^{-4}
Compressor	Failure to operate on Demand	10	1.1415×10^{-3}
Flowmeter	Failure to open (Plugged)	9	1.0273×10^{-3}
Pipes	Rupture	5	5.7077×10^{-4}
Static	Failure to Attain the required Homogenity of the Reactants, (Benzene-olefen)	11	12557×10^{-3}

The component failure rates are calculated as follows

$$\text{Failure rate} = \frac{\text{frequency of failure}}{\text{Operating time}}$$

Since the plant was designed to work all year round, the operating time is 8760 hours with exceptions to the year 1992 and 1996 whose operating time was 8784 hours.

Thus for the year 1990 the respective failure rate of the components are as calculated below.

Pump: $\lambda_1 = \frac{13}{8760} = 1.4840 \times 10^{-3}$

Heat Exchanger $\lambda_2 = \frac{1}{8760} = 1.4840 \times 10^{-4}$

Electric Motors $\lambda_3 = \frac{50}{8760} = 5.7077 \times 10^{-3}$

Pressure Safety Value $\lambda_4 = \frac{1}{8760} = 1.1415 \times 10^{-4}$

Drum Leakage $\lambda_5 = \frac{6}{8760} = 6.8493 \times 10^{-4}$

Compressors $\lambda_6 = \frac{6}{8760} = 6.8493 \times 10^{-4}$

Flowmeters $\lambda_7 = \frac{4}{8760} = 4.5662 \times 10^{-4}$

Pipe $\lambda_8 = \frac{3}{8760} = 3.4246 \times 10^{-4}$

Static Mixer $\lambda_9 = \frac{0}{8760} = 0.00000 \times 10^{-0}$

Cumulative down time = 6,513 hours.

From the data in tables I, the failure rates for the year 1991-1997 are calculated as above and are as tabulated in table IV

TABLE II

YEAR	DESIGN THROUGHPUT	PROGRAMME THROUGHPUT	ACTUAL THROUGHPUT	DT – PT KG/DAY	PT - AT KG/DAY
1990	34,187.67	32,782.6484	15,645.54795	1,405.621	17,137.100
1991	34,187.67	32,782.6484	17,303.881	1,405.021	15,478.767
1992	34,281.27	12,883.9041	7,556.621	21,397.365	5,327.283
1993	34,187.67	27,152.7397	16,371.347	7,034.930	10,781.392
1994	34,187.67	24,733.7899	20,190.296	9,453.830	4,543.493
1995	34,187.67	33,241.4383	15,703.424	946.231	17,538.014
1996	34,281.27	19,954.337	12,091.780	14,326.993	7,862.557
1997	34,187.67	17,220.913	8,933.675	16,966.757	8,287.238

DT = designed throughput unitkg/hr

PT = Programmed throughput

AT = actual throughput

PT – AT = the actual loss in production due to the various equipment breakdown or failure and management decisions e.t.c but the loss, due to only the equipment failure rate is calculated by:

Production loss = average failure rate x (PT - AT)

$$\text{Average failure rate} = \frac{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8 + \lambda_9}{9}$$

For 1990, $\sum_{i=1} \lambda = 9.58894 \times 10^{-3}$

$\Rightarrow \lambda_{1990} = 9.58894 \times 10^{-3}/9 = 1.06543 \times 10^{-3}$

For 1991, $\sum_{i=1} \lambda = 7.41999 \times 10^{-3}$

$\Rightarrow \lambda_{1991} = 8.2444 \times 10^{-4}$

For 1992, $\sum_{i=1} \lambda = 0.01275017$

$\Rightarrow \lambda_{1992} = 1.41668 \times 10^{-3}$

For 1993, $\sum_{i=1} \lambda = 9.81709 \times 10^{-3}$

$\Rightarrow \lambda_{1993} = 1.0907 \times 10^{-3}$

For 1994, $\sum_{i=1} \lambda = 5.02283 \times 10^{-3}$

$\Rightarrow \lambda_{1994} = 5.5809 \times 10^{-4}$

For 1995, $\sum_{i=1} \lambda = 7.99059 \times 10^{-3}$

$\Rightarrow \lambda_{1995} = 8.8784 \times 10^{-4}$

For 1996, $\sum_{i=1} \lambda = 6.02024368$

$\Rightarrow \lambda_{1996} = 2.24929 \times 10^{-3}$

For 1997, $\sum_{i=1} \lambda = 8.3305 \times 10^{-3}$

$\Rightarrow \lambda_{1997} = 9.2589 \times 10^{-4}$

Thus, the risk involved is as calculated and shown in the table below.

TABLE III

YEAR	PT – AT (MT/Y)	$\bar{\lambda}$	PRODUCTION LOSS (PT - AT) x $\bar{\lambda}$
1990	150121	1.06453×10^{-3}	159.94
1991	135594	8.2444×10^{-4}	111.78
1992	46667	1.41668×10^{-3}	66.11
1993	94445	1.0907×10^{-3}	103.01
1994	39801	5.8409×10^{-4}	23.24
1995	153633	8.8784×10^{-4}	136.40
1996	68876	2.24929×10^{-3}	154.92
1997	72589	9.2589×10^{-4}	67.21

3.1.8 CALCULATION OF β FOR THE VARIOUS COMPONENTS

The calculation of the failures into common-cause and independent failures is as shown in table IV. This classification is according to that enumerated in the literature review.

TABLE IV

YEAR COMPONENT	1990 λc	1991 λc	1992 λc	1993 λi	1994 λi	1995 λi	1996 λc	1997 λc
'umps	1.484×10^{-3}	1.027×10^{-3}	2.0491×10^{-3}	1.1415×10^{-3}	7.9908×10^{-4}	1.598×10^{-3}	1.8214×10^{-3}	1.9406×10^{-3}
Ieat Exchangers	(λi) 1.1415×10^{-3}	(λc) 1.1415×10^{-3}	(λi) 1.8214×10^{-3}	(λi) 2.968×10^{-3}	(λc) 5.707×10^{-4}	(λi) 1.8264×10^{-3}	(λi) 1.7076×10^{-3}	(λc) 1.3698×10^{-3}
Electric Motors	(λc) 5.707×10^{-3}	(λc) 4.680×10^{-3}	(λc) 5.123×10^{-3}	(λi) 2.054×10^{-3}	(λi) 9.132×10^{-4}	(λi) 5.707×10^{-4}		(λc) 1.1415×10^{-4}
Pressure Safety Valve	(λi) 1.1415×10^{-4}	(λc) 1.1415×10^{-4}	(λc) 2.277×10^{-4}	(λc) 2.283×10^{-4}	(λi) 2.283×10^{-4}	(λi) 1.1415×10^{-4}	(λi) 1.1384×10^{-4}	(λi) 1.1415×10^{-4}
Drum	(λc) 6.8493×10^{-4}	(λc) 1.1415×10^{-4}	(λc) 1.935×10^{-3}	(λi) 1.3698×10^{-3}	(λi) 1.1415×10^{-4}	(λi) 9.124×10^{-4}	(λc) 9.107×10^{-4}	(λi) 7.990×10^{-4}
Compressor	(λc) 6.849×10^{-4}	(λi) 6.849×10^{-4}	(λi) 9.107×10^{-4}	(λc) 5.707×10^{-4}	(λc) 4.567×10^{-4}	(λi) 7.990×10^{-4}	(λc) 1.024×10^{-3}	(λc) 1.1415×10^{-3}
Flow meter	(λi) 4.567×10^{-4}	(λc) 3.425×10^{-4}	(λc) 4.553×10^{-4}	(λc) 4.526×10^{-4}	(λI) 7.991×10^{-4}	(λi) 6.849×10^{-4}		
Pipe	(λi) 3.425×10^{-4}	(λi) 3.425×10^{-4}	(λi) 1.138×10^{-4}	(λi) 3.425×10^{-4}	(λc) 3.425×10^{-4}	(λc) 4.566×10^{-4}	(λc) 4.553×10^{-3}	(λi) 5.707×10^{-4}
Static Mixer						(λi) 1.0273×10^{-3}	(λi) 1.0245×10^{-3}	(λc) 1.256×10^{-3}

TABLE V

λt, β Components	1990-1997 Σλi	1990-1997 Σλc	1990-1997 ΣλI + Σλc	1990-1997 $\beta = \frac{\lambda c}{\lambda i + \lambda c}$
Pumps	$3.5387 x10^{-3}$	$8.3225 x10^{-3}$	$1.1861 x10^{-2}$	0.7135
Heat Exchanger	$8.4376 x10^{-3}$	$2.0547 x10^{-3}$	$1.0492 x10^{-2}$	0.2063
Electric Motors	$3.5387 x10^{-3}$	$1.1562 x10^{-2}$	$1.9164 x10^{-2}$	0.6225
Pressure Safety Valve	$6.846 x10^{-4}$	$4.5598 x10^{-4}$	$1.4058 x10^{-3}$	0.3998
Drum	$2.5114 x10^{-3}$	$4.3299 x10^{-3}$	$6.8418 x10^{-3}$	0.6398
Compressor	$4.104 x10^{-3}$	$2.1689 x10^{-3}$	$6.2731 x10^{-3}$	0.3520
Flow meter	$1.9406 x10^{-3}$	$1.2477 x10^{-3}$	$3.1883 x10^{-3}$	0.3945
Pipe	$1.4836 x10^{-3}$	$9.6907 x10^{-3}$	$1.1175 x10^{-3}$	0.8784
Static Mixer	$2.8509 x10^{-3}$	$2.0790 x10^{-3}$	$4.929 x10^{-3}$	0.4266

To calculate the MTBF

$$MTBF = \frac{1}{\lambda}$$

But the period of study is between 1990 to 1997. Thus, we make use of the term average failure thus, we make use of the term average failure rate (λave) of equipment/component.

$$\lambda ave = \frac{\sum \lambda i + \sum \lambda c}{8} = \frac{\sum \lambda}{8}$$

(Since the data is calculated over a period of eight years)

Thus, the table of the MTBF, is generated as shown below.

TABLE VI

λave YEARS Components	**1990-1997 Σλ**	**λave 1990-1997 Σλ/8**	**MTBF 1990-1997 $(\lambda ave)^{-1}$**
Pumps	$1.1861 x10^{-2}$	$1.4826 x10^{-3}$	674.491
Heat Exchangers	$8.4376 x10^{-3}$	$1.0547 x10^{-3}$	948.137
Electric Motors	$3.5387 x10^{-3}$	$4.4234 x10^{-4}$	2260.704
Pressure Safety Valve	$6.846 x10^{-4}$	$8.5575 x10^{-5}$	11685.656
Drum	$2.5114 x10^{-3}$	$3.1393 x10^{-4}$	3185.424
Compressors	$4.104 x10^{-3}$	$5.130 x10^{-4}$	1949.318
Flow meters	$1.9406 x10^{-3}$	$2.4258 x10^{-4}$	4122.351
Pipe	$1.4836 x10^{-3}$	$1.8545 x10^{-4}$	5392.289
Static Mixer	$2.8509 x10^{-3}$	$3.5636 x10^{-4}$	2806.151

CHAPTER FOUR

DISCUSSION OF RESULT

"KRPC, poised to remove obstacles in the way of smooth operations". 'Health education for KRPC tin and drum plant operators". "Advance safety/fire-fighting course for Kaduna area safety supervisors". E.t.c. These are some of the numerous captions in the monthly publications of the "NNPC NEWS' highlighting efforts that are being channeled towards safety, loss, and pollution prevention in this particular process industry.

Furthermore, in an effort to instill safety awareness among staff and customers, KRPC fire and safety department organized a weekly safety refresher course, which is being, conducted every Tuesday and Wednesday. The contents of the course are: Fire fighting procedures, safety rules and regulations, use of harmful substances and chemicals, basic safety principles, work permit system, principle and practice of accident prevention and environmental pollution control.

Obviously, it could be seen that efforts are not being spared by the management of KRPC [this is also obtainable in some other industries as well] in order to bring to the barest minimum the menace of loss in the industry. Dependability data collected for the years 1990-1997 and the consequences of the analysis of these data, shows that more efforts still has to be channeled to various areas. Such areas include; equipment failure history, new methods of analysis and management of risk e.t.c.

Risk analysis is a method of estimating economic risk, such as the consequence of a failure producing a probable loss (PML) or in the worst case, a maximum probable loss (MPL). Thus, safety analysis, have always been an important part of the design process for high hazard /high technology plants.

Table 1 shows the dependability data of the plant under consideration for the years 1990-1997. The various failure modes and the frequency of the failure coupled with the respective failure rates of the items/components are contained in table 1 as well. These components are; pumps, electric motors, heat exchangers, pressure safety valves, compressors, storage drums, pipes and static mixer.

For the years 1990, as a result of the failure of these equipment's, the cumulative downtime of the plant was 4,107 hours, this translates to approximately six months in the year.

For the years 1991 to 1997, the respective downtimes were; 3,185 hours, 6,513 hours, 3,521 hours, 2,952 hours, 4,072 hours, 5,357 hours, and 6,064 hours. The causes of failures that led to these various downtimes is as classified in section 2.5.0 and 2.5.1 of this report. Table II, shows the designed, programmed, and the actual throughput of the plant for the years under consideration. All other years except 1992 and 1996 has their designed throughput as 34,187.67

Kg/hr. The exception to year 1992 and 1996 (34,281.27Kg/hr) is as a result of production above 100% capacity based on operating time of 8,784 hours i.e. Zg = (NS+N" S")(NV +N"V")-Cf.

Column V of the table II shows (DT-PT) the difference between the designed and the programmed throughputs. These are loses, that arises as a result of factors not related to equipment breakdown or failures. One of the major causes of this lack of steady feedstock from the adjoining refineries. This implies that the losses (DT-PT) is as a result of interdependencies between failures of systems as indicated in section 2.5.0 of this report. The implication of this is usually under-utilization of the system/plant. From the same table II, it would be seen that the year 1991 recorded the least loss of 946.231Kg/hr. This could be attributed to the effective utilization and steady supply of feedstock during the year –as shown in table I). Also, from table II, column IV shows the actual loss (PT-AT) in Kg/hr due to equipment breakdown and failure. This loss translates to the dependent economic loss for the company in that, the feedstock available could not be processed fully. This implies that lower volume of product is being pushed into the market, thus, reducing the income that should accrue to the company.

Table III, shows the production loss as a result of the cumulative effects of the different failures and breakdown of equipment. This is calculated by multiplying the actual loss (PT-AT) in MT/Y by the average failure rate (λ) per year. The production losses are ; 159.94 tons of (LAB) for 1990, for 1991 the value reduced to 111.78 tons this is as a result of a corresponding reduction of λ from 1.643×10^{-3} in 1990 to 8.24×10^{-4} in 1991, this also reflected in the downtime reduction from 4,107 hours to 3,185 hours.

In 1992, the production loss reduced by 37.16% i.e. to 66.11 tons despite the high failure rate of 1.41668 x 10-3, This was because, the majority of the failures that has the greater values were those that do not have a direct bearing on the production for example, the frequency of failure for drum, flow meter, and electric motors were, 17, 4 and 45 respectively as against 1,3 and 41 for the previous year (1991).

For 1992, the frequency of failure for pumps and static mixer was 1 and 18 respectively while it was just 0 and 9 for 1991 and these two are very important equipment for the process.

The production loss increased by 103.01 tons (60.90%) in 1993 due to reasons that are not far fetched as seen in table I.

One of the major factors that also contributed to this is the political instability in the country at the time, which led, to the partial closure of the refineries. The production loss for the years 1994, 1995, 1996, and 1997 are; 23.4 tons, 136.40 tons, 254.92 tons and 67.21 tons respectively. This showed an increase of 74% from 1994 to 1996 and a sudden reduction to 39.48% *in 1997*. This reduction is corroborated by a corresponding reduction in failures for the year.

Table IV, shows the classification of the various failures that led to the losses incurred above into dependent and common- cause failures. The majority of the failures for pumps in 1990 was of a common-cause nature (λ_c) while for the same item, it was of an independent cause (λ_1) nature. The values in table IV were used to calculate the value of β- for the equipments. Table V shows the values of β obtained for the various equipment investigated between 1990 and 1997. The 5th column of the table V shows that, for pumps, the value of β was 0.7135 or 71.35%. This shows that, 71.35% of the failures recorded by pumps is as a result of common-cause failures. The respective values of β for heat exchangers, electric motors, pressure safety valves, storage drums, compressors, flowmeters, pipes and static mixer are: 0.2063 or 20.63%, 0.6225 or 62.25%, 0.3998 or 39.98%, 0.6398 or 63.98%, 0.3520 or 35.20%, 0.3945 or 39.45%, 0.8784 or 87.84% and 0.4266 or 42.66%.

The combinations of these values and that of the MBTF in table VI could be used to workout a proper maintenance schedule for the equipments. Thus, from all the analysis and evaluation of risk in this work, it could be seen that risks in operating industries could be brought to the barest minimum if they are adequately taken into consideration during the conceptual and design stages. This justifies one of the main aims of this research work.

CHAPTER FIVE

5.1.0 CONLUSIONS

Based on the results of the findings of this study it can be concluded that, most of the production losses (economic risk) due to equipment's failure and breakdown, ensued as a result of obsolescence –due to inadequate turn around maintenance (TAM) over the years- ageing, human errors, and dependent common-cause failures such as those that emanates from the design, manufacturing, operating and assembly errors.

It can also be concluded that, the production loss that could evolve as a result of pump failures were as a result of dependent common-cause failures. This is as revealed by the value of β for pumps (0.7135) in table IV. Others are; pipe (0.8784), storage drum (0.6398) and electric motors (0.6225). For independent causes, we have; static mixer (β=0.3945), compressors (0.3520), pressure safety valves (0.3998), flow meters (0.3945), and heat exchangers (0.2063). In all, 40.97% of the failures were as a result of independent –failure causes while 59.03% were due to dependent-common-cause failures.

Comparing the results above with the set-out objectives of in section 1.1.3, it can be seen that some of the aims of carrying out this study were achieved.

5.1.1 RECOMMENDATIONS

One sure way of not having a loss is to eliminate the source of loss altogether. To drastically reduce the impact of equipment failure and breakdown and events like fire outbreak or explosions, the following recommendations are made.

1) Equipment failure history should be meticulously acquired and kept in an orderly manner and in a form that can be easily retrieved when needed.
2) The plant should be made to undergo turn around maintenance at the end of every four years irrespective of its working state.
3) Equipments should be made to undergo preventive maintenance at regular intervals instead of the prevalent breakdown maintenance strategy.
4) Based on the findings of this work, maintenance of items like pipes, pumps, storage drums, electric motors, should be channeled towards eliminating the source of dependent common-cause failures.
5) Some of the equipment's should be redesigned to conform to the technology of the present time i.e., the existing design should be upgraded, processes where analogue devices are being used for measurements should be replaced by digital devices.
6) Since human errors contribute immensely to the problem of risk and safety in organizations, operating personnel should be trained effectively on their work at regular intervals.
7) For risk management to work better with respect to design considerations, a staff specialist in the field of risk management should be assigned to supplement the other task of other line mangers.

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APPENDIX

APPENDIX I

TABLE VII

COMPONENTS	FAILURE MODE	VALUE OF β
High Pressure Pump	Failure to Start	0.1400
	Failure during Operation	0.0600
Motor Operated Valve	Failure during Operation	0.2300
Temperature, Flow meter, Pressure Level Sensors		0.2230
Pumps (Upon Starting and Operation)		0.2240
Air-operated Valves		0.2645