CONTRIBUTING FACTORS TO THE UNCONTROLLED REFINERY FIRES

by

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DECLARATION

I, Mlungisi Edward Buti, declare that the content of this mini thesis represents my own unaided work experiences, knowledge, and personal encounters with incidents at refineries in the Free State and Western Cape Provinces. The work represents my own opinions, and not those of the Cape Peninsula University of Technology.

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ABSTRACT

Investigations conducted on fires and explosions at refinery plants under study indicate that there is little or no strategy to deal effectively with the threat of fires and explosions at refinery plants. The incidents of fires and gas/hydro-carbon leaks appear to be unrelated to anyone with knowledge of them. This study plans to locate and identify the underlying causes of fires at refineries. A regression equation is one tool used to define, measure, and analyse data from the Refinery in South Africa (RSA), and it was found that the equation has a significant overall goodness of fit. There are several improvements required for the control of equipment and general communication, while the moral compass of employees needs to be improved. Many constraints were experienced due to limited access to the refinery. The data was collected from thirty-five employees. The findings of this research will serve as a basis to develop successful defensive mechanisms to eliminate, control and minimise risks to non-significant levels.

Keywords: Design and Maintenance (DM), Change-over (CO), Safety Culture (SC)

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Acronyms and Abbreviations (list of abbreviations)

CO	Change-over
DM	Design and Maintenance
MHSA	Mine Health and Safety Act
DMR	Department of Mineral Resources
DOL	Department of Labour
OHSA	Occupational Health and Safety Act
OSHA	Occupational Safety and Health Administration
PSM	Process Safety Management
RSA	Refinery in South Africa
SC	Safety culture
TMM	Trackless Mobile Machinery
TW	Training of workforce
Pa	Pascal
T_∞	Known Boundary Temperature
q	Heat Flux
T	Temperature

C_p Specific heat at constant pressure

C_v Specific heat at constant volume

Unit definition

$\mathrm{MPa} \approx \mathrm{Pa} \cdot 10^6$

$\mathrm{GPa} \approx \mathrm{Pa} \cdot 10^9$

$\mathrm{GPa} \approx \mathrm{Pa} \cdot 10^9$

$\mathrm{GPa} \approx \mathrm{Pa} \cdot 10^9$

Barg$\approx \mathrm{Pa} \cdot 10^5$

KN $\approx N \cdot 10^3$

DegC= $℃ \approx (1 + 273)K$

Psi= 6.894757kPa

Inch= $25.4mm$

Degree F= $\left\{\frac{5}{9}(°\mathrm{F} - 32)\right\} \cdot ℃$

Degree R=$\frac{5}{9}$·K

12″= $12inch = 304.9mm$

8″= $8inch = 203.2mm$

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CHAPTER 1
INTRODUCTION, BACKGROUND, AND OBJECTIVES

1.1 Introduction and motivation

This study looks at uncontrolled incidents in refineries. The aim is to develop an appropriate action underlying causes of such incidents. Identifying the underlying causes of uncontrolled incidents is a function of the appropriate action to be developed. Due to the size of these organisations, it is challenging to match any action/process to any uncontrolled incident/s.

Oil refinery is an industrial process plant where crude oil is processed and refined into more valuable products such as petroleum naphtha, gasoline, diesel fuel, asphalt base, heating oil, kerosene, and liquefied petroleum gas (Arsham, Hossein, 1994). In South Africa, they operate under the jurisdiction of the Department of Labour and Mineral Resources as far as Health and Safety is concerned.

The research looks at the impact of uncontrolled incidents (fires) associated with the implementation of Health and Safety laws regulating the refinery environment in South Africa. These are the Mine Health and Safety Act 29 of 1996 (MHSA) and the Occupational Health and Safety Act 85 of 1993 (OHSA). These laws are enforced by the Department of Mineral Resources (DMR) and the Department of Labour (DOL), respectively.

The MHSA is thought to be outcome-based, while OHSA appears to be fairly prescriptive. Both laws aim at promoting the culture of health and safety in the workplace (refineries). MHSA Regulation 23.4 requires the employer to report dangerous occurrences. The dangerous occurrences according to this law include fires, explosions, and flammable gas. Ibrahim et al. (2003) pointed out that the refineries possess a large inventory of hazardous materials that exceed the threshold quantities, and are, therefore, classified as major hazard installations. OHSA explains a major hazard installation as any installation:

(a) where more than the prescribed quantity of any substance is or may be kept, whether permanently or temporarily; or

(b) where any substance is produced, processed, handled, used, or stored in such a form and quantity that it has the potential to cause a major incident.

OHSA defines a major incident as an occurrence of catastrophic proportions, resulting from the use of a plant and machinery, or from activities at a workplace. OHSA defines the substance to include any solid, liquid, vapour, gas, aerosol, or combination thereof. Assembled refinery equipment is used to transport, transform, and separate refinery media. Kachanov et al. (2010) mention that refinery media includes hydrocarbons, sulphur compounds, and water. Pipes, valves, boilers, and heat exchangers are some refinery components that could leak (Paterson, J. 2011).

Tak, K. and Kim, J. (2018) observe the following in Corrosion effect on inspection and replacement planning for a refinery plant: Specifically, frequent inspection and replacement increases the respective cost by reducing the operating cycle. However, the use of more reliable material makes the pipes and equipment expensive. Meanwhile, the use of only occasional or no safety measures can severely damage the process, environment, and human life, leading to an increased failure cost. An appropriate strategy is needed to identify an optimal point in the trade-off relationship between the plant economy and process safety. The steel type and design wall thickness, in addition to the number of inspections and inspection timings, should be decision variables for the optimisation under the given operating conditions and corrosion rate. A large part of the corrosion reaction remains unknown according to Kim et al. (2011), Nesic (2007), and Tak et al. (2016).

Shell and British Petroleum (BP) South African Petroleum Refinery (SAPREF, 2007) observed the following in their refinery operations: The crude oil is passed into two crude distillation units; the crude is then heated and distilled, breaking it into different constituents known as fractions; fractionation is defined as the physical separation of crude oil components by boiling. The temperature inside the column rises to $350℃$ (SAPREF, 2007). Shvindin et al. (2010) showed that the feedstock into ovens is in the range of $350℃ – 400℃$ in temperature with a pressure of up to 6.0MPa. Such a temperature could be viewed as an essential boundary condition, which is a prescribed temperature boundary condition.

Ikeaggwuan et al. (2013) explained that the traditional approach to decision-making takes the form of “regulation by disaster”. This suggests that instructions regulating refineries are re-active. The regulators (DMR and DOL in South Africa) require proactive strategies to deal decisively with uncontrolled incidents (fires). MHSA Section 11 requires employers to identify hazards to health or safety to which employees may be exposed. Furthermore, employers are required to assess risks to health or safety to which employees may be exposed, and record significant hazards, and assess their risk. Employers must determine all measures including changing the organisation of the work and design of safety systems necessary to:

1. Eliminate any recorded risk at source,
2. Control the risk at source,
3. Minimise the risk, and
4. In as far as the risk remains:
    I. Provide Personal Protective Equipment, and
    II. Institute a programme to monitor the risk to which employees may be exposed.

1.2 Background to the research problem

Some refinery fire incidents lead to major losses which include human lives, damage to property, and damage to plants and equipment. Other costs associated with fire incidents include losses to production due to unavailability of equipment, expert investigation reports which also come at a price to the company, losses due to no productive use of labour during internal investigations and external statutory investigations. Refineries produce products which, when depleted, have a far-reaching effect in most spheres of economy. Developing countries are accompanied by the increase in energy products, which include refinery products. Increases in other components of the economy may lead to increases in demand for refinery products. The causes of fire incidents include lack of knowledge, lack of training, and poor maintenance amongst others (Det Norske Veritas, 2007).

An observation was made that gas leaks cause fires and explosions at refineries in South Africa. Fire incidents do not appear to be affected upon by either of the South

African laws mentioned above. Several initiatives, including internal and external inspections and audits, government inspections and audits, and third-party audits, do not seem to deter fire incidents. The consistency of the increase in fire incidents suggests that law enforcement actions have resulted in little or no deterrence to fire incidents. “The sharpest decline in fatal injuries occurred between 2007 and 2009, a period that coincided with economic recession” (Wilbanks, 2013). An inability to point to a specific or even a generalised breakthrough in safety practice does not ease this worry (Wilbanks, 2013). Management safety systems are employed by the Refinery in South Africa (RSA). These systems have proven to reduce refinery fire incidents, but it is not clear as to why the incidents of fire remain high.

Over a period of time, fire incidents at local refineries have been observed. Based on past OSHA (Occupational Safety and Health Administration) inspection history at refineries and large chemical plant, OSHA has typically found that these employers have extensive written documentation related to Process Safety Management (PSM) but implementing the plans has been inadequate (Sissell K, 2007). Currently in some mining houses in South Africa, there is a concept of rewarding one thousand shifts without losing injury time. This is viewed as an achievement and is celebrated and communicated to all participating employers. Bonuses, gifts, and certificates are given to maintain such achievements, although participation is voluntary. Most employers implement a suggestion box system for various reasons. The suggestion box is expected to be the eyes and ears for employers on matters which managers may not disclose but input is used to enhance health and safety. Some employers have put a reward system for employees participating in the suggestion box. What value does the suggestion box have in relation to the reduction of incidents? How can the suggestion box system be effectively implemented?

Refinery in South Africa (RSA) makes use of outsourced labour for the maintenance of its plants, thus delegating powers to contracting companies, which implies a lower level of control regarding the persons involved in the process and in performing their tasks and activities (Pereira et al. 2011). RSA does not know with certainty how many valves, flanges, and pumps are in its service. From the observation made in refinery incidents over a ten-year period, it has become necessary that refinery systems (input, process, and output) be further interrogated; the culture of safety should be examined, and the competency levels of human resources should be assessed. Some or all of the components mentioned above could be a key to the solution of these incidents.

1.3 Problem statement

The inability to identify with certainty the actual causes of uncontrolled refinery incidents (fire) in order to deal appropriately with them is worrisome. The repeat of related incidents with similar components is frustrating for the industry.

1.4 Primary research objectives and investigative questions

The study looks at possible gaps in various areas which include refinery inputs, various stages of processing, receiving and dispatch. The material, plant, and equipment from commissioning, operation, maintenance, and decommissioning; the people who interact with them and refinery components, and the flow of resources, be it human or otherwise. This looks at the following investigative questions:

1. How is the pressure presented by refinery media from the supply pipeline into in-house refinery components handled?
2. What effects have been observed regarding the shutdown and start-up on plant and equipment?
3. Why is the refinery experiencing repeat incidents? What measures are employed to maximise the benefits from historical information?
4. What can be done to improve the current safety strategies so that an early warning to failures is observed?
5. Which measures are necessary for responsive strategies to deal with gaps in the system?
6. How is the plant configured to deal with increased demand when no investment concerning increase in capacity has been made?
7. Why is the automatic adjustment system not employed on components which could leads to serious consequences when they fail?

1.5 Research objectives

1. Develop effective strategies to deal decisively with challenges which lead to refinery incidents (fires) at workplaces.
2. Establish a system that enforces the correct and consistent implementation of the current safety systems.
3. The danger employees are exposed too are communicated and correct training to respond to them is successfully completed before work is allowed.
4. Eliminate the possibility of shortcuts with regards to critical jobs such as hot work (welding), ensuring the responsibility of signatories on the job card for such work.
5. Make sure that self-adjusting safety components and their early warning signals with regards to their malfunction are continuously monitored.
6. Cultivate a safe proof plan for wear and tear of all components, removing all substandard components from the system, and making sure all current legal requirement are complied with.
7. Require that all those components, should they fail and could lead to major disasters, are incorporated with fail-safe mechanisms, installed with automatic adjustment devices (thus limit feed), and automatic warning systems before their failure.

1.6 Research design and methodology

1.6.1 Design

This study will use incident data collected over a period of ten years, a questionnaire, and a literature review to identify the actual causes of fire incidents at refineries. Data gathering, analysis, the cause and effect of incidents, suggest descriptive research. Action and case study research will be based on relevant indicators. Analysis of fire incidents will be investigated, and safety audits will be instrumentally employed. The grounded theory research will be based on observation, documents, and historical records.

1.6.2 Method

The incident data collected was put on the line graph to observe the trend and was used to derive the global regression equation. The questionnaire information was gathered from various departments. The regression equation was again derived making use of questionnaire responses. To confirm the usefulness of the sample, the goodness of fit (R^2) is calculated.

1.6.3 Procedure

The following procedure will be followed:

1. Require a supporting letter from Cape Peninsula University of Technology (CPUT) to authenticate the research student.
2. Use the letter from CPUT to ask Refinery in Southern Africa (RSA) permission to investigate at the refinery.
3. Design questionnaires based on refinery employees, materials & equipment, and employee culture.
4. Investigate at RSA.
5. Analyse reported incident(s) by RSA.
6. Analyse the results of the investigation at RSA.
7. Source relevant literature on the subject.
8. Observe possible solutions and make recommendations as to how to remedy the situation.

1.7 Data collection

Primarily the data for this study was collected through real-time incidents, which happened over a period of ten years. Further, after the permission was sourced from the CPUT and Petroleum South Africa (PETROSA), making use of the questionnaire information was collected from the refinery. The questionnaire is described in section 5.1.

1.8 Research assumptions and constraints

Responses from people interviewed are assumed to have provided honest information. The refinery example used to calculate components at the refinery is assumed to be a general method used in the industry. The real-time fire incidents depicted in figure 5.1 indicate that the average straight line went from 20% in 2002 to 60% in 2010. The refinery is assumed to be a linear component for simplicity. The researcher was not provided with full access to the plant and equipment, corresponding documentation, and refinery stake holders.

1.9 Conclusion

The introduction and motivation include important information about the refinery. The background to the research indicates helplessness concerning dealing decisively with refinery incidents amongst other things. The problem statement, research questions, research objectives, research design, data collection, assumption and constraints were briefly discussed.

CHAPTER 2
RELATED LITERATURE REVIEW

This chapter looks at three general areas related in some way to our study. These are refinery system failures, refinery equipment and materials, and people. The failures vary from single to multiple sources. The information in this literature review helps to build an inclusive strategic response to such failures. To understand refinery workings, the related literature is reviewed under the following topics: -

1. Refinery system failures,
2. Equipment and materials, and
3. People

2.1 Refinery system failures

Turner and Pedgeon, (1997) define refineries as highly complex and tightly coupled organisations. Shrivistava (1992) pointed out that accidents in complex, tightly coupled, interactive technological systems are caused by multiple failures in design, equipment, supplies and procedures. Most system failures do not occur without any warning signs (Guo et al., 2015). This is especially true for failures caused by degradation.

An electric fault on the plant 46kV line would result in a loss of both co-generator units as well as the connection to the local utility which would cause complete electrical and steam outages (Mraz et al., 2015). A failure of one of these transformers would result in a prolonged electrical outage for the downstream equipment until a replacement transformer could be placed in service (Mraz et al., 2015).

The load shedding system is the last resort as a backup measure in cases where an electrical power system faces a disturbance that causes an imbalance between the mechanical power supplied and the power required by the load (Kucuk & Energy, 2018). Based on the evaluation of the power generation capacity, loads, and the interconnection constraints of the new and existing refineries, it is possible to estimate the main load shedding scheme for inadequate generation capacity logic used as the main protection against islanding power imbalance conditions (Kucuk & Energy, 2018).

Lack of correct and instant information relevant to safety often leads to the failure of accident exclusion and the delay of emergency rescue (Fang et al. 2008). The methods used to allocate the safety integrity requirements to safety-related systems and other risk reduction facilities depend, primarily, upon whether the necessary risk reduction is specified explicitly in a numerical or in a qualitative manner (Fang et al., 2009).

Internal energy is defined as the total energy contained by a thermodynamic system (Joel, 1987). The internal energy of a system can be changed by heating the system or by doing work on it (Oliver, MTD Lecture Notes, 2013). If the substance within the system is some type of fluid or gas, then there may be some degree of turbulence within the substance (Joel, 1987). Heat is the transfer of energy accomplished through random and chaotic atomic motions (Zabaras, 2012). According to Zabaras (2012), one can show that generally.
$C_p > C_v$:

- There is a larger difference between C_p and C_v for gases than for liquids.
- For solids, the difference between C_p and C_v is negligible.

Seawater concrete pipes suffer from a variety of problems such as concrete deterioration and corrosion of the steel inner core and the pre-stressing wires (Wardany, 2015). These problems affect the structural integrity of the pipes and may lead to their catastrophic failure and the costly shutdown of the refinery (Wardany, 2015).

In areas related to the scheduling of operation modes, such as long-term aggregate production planning (Coxhead, 1994 and Reklaitis, 1996), and blending problems (Dewitt et al. 1989, Rigby et al. 1995 and Amos et al. 1997), optimisation models have been used. Other works related to the scheduling of operation modes concern unloading and blending of crude oil, feed management, and to some extent tank and pipe management (Lee et al. 1996 and Shah 1996). The decision in the process scheduling problem is to decide which run-mode to use in a particular point in time, or equivalently, when to change between run-modes, to meet the planned deliveries from the refinery (Persson et al., 2004). Furthermore, there are additional resources limiting the production, which may prohibit the use of certain combinations of run-modes (Persson et al., 2004).

Zhidkov (2008) noted the following in increasing the level of safety in the operation of tube furnaces in oil refineries and petrochemical plants: -

1. Almost all the furnaces built before 2004 did not satisfy the corresponding Rostekhnadzor (RTN) standards.
2. Selecting and adjusting the sensors and programming are relatively individual, creative processes.
3. Serving the sensor consists of visual monitoring of the condition and replacement once a year.
4. Devices for monitoring the draft level in the furnace are installed at the radiation chamber outlet.
5. Not all old furnaces can be equipped with these sensors for organising control of rarefaction and use of an automatic vacuum control circuit in the furnace.
6. The furnace with underground gas conduits equipped with guillotine gates cannot be equipped with rarefaction control and automatic control systems.

Linear Programming (LP) has been the most widely used technique in refinery planning and optimisation (Favennec, 2001). According to Aguilar et al, (2012) a petroleum refinery is in fact highly nonlinear. It is critical to understand the original equipment manufacturers (OEMs) requirement for the various filters installed in the system, and to follow their instructions as they pertain to use and lifecycle (Sullivan, 2017).

Naturally occurring polar substances in the crude such as resins and asphaltene assist the formation of water in oil (w/o) type emulsions (Harpur et al., 1997). Various techniques are used to destabilise these emulsions, among which the most widely used method consists of adding a small amount of demulsifiers (Avvaru et al., 2017). These surface-active molecules absorb at the oil-water interface, displace the asphaltene and accelerate phase separation by destabilising the emulsions (Avvaru et al., 2017). For these extra heavy crude oils various methods like multi-stage desalting processes, crossflow membrane, microwave-assisted demulsification techniques were developed (Diehl, 2011), Tan et al., (2007). However, even with three stages of the electrostatic desalting operation, the crude oil specification cannot meet the desired level of quality suitable for further processing (Avvaru et al., 2017). Hence, the need for demulsification and the impetus for developing new methods for effective treatment of oil became more important (Avvaru et al., 2017). It is very difficult to hydrogenate sulphur compounds with conventional technology like hydrodesulphurisation (HDS) unless it is done at a high temperature pressure and with a special type of catalyst (Avvaru et al., 2017).

Knegtering and Pasman (2009) mention the following issues in the safety of process industries in the 21st century:

1. A changing need for process safety management for a changing industry
2. Current accidents seem almost always the result of a combination of organisational issues, lack of (or weak) competency and the technical failures of (ageing) equipment.
3. Contributing aspects of today’s situation are increasing turnover while at the same time, reduction of labour and staff and a growing complexity of process installations facilitated by continuous (and faster) development of sophisticated designs of process control and safeguarding technology.
4. Due to the number of successive changes, a new situation originates.
5. This enhances the need for a new kind of process safety management.

Persson et al. (2004) explained that whenever the run-mode of the central distillation unit (CDU) is changed, it needs time to stabilise under the new operating conditions. The characteristics of the products obtained are, therefore, uncertain and fluctuate for 1-2 hours after a changeover (Persson et al., 2004). The Texas City refinery explosion and fire may be summarised by the following:

1. The investigation team determined that the explosion occurred because the BP Isom unit managers and operators greatly overfilled and then overheated the raffinate splitter.

2. The fluid level in the tower at the time of the explosion was nearly 20 times higher than it should have been.
3. The presence of water or nitrogen in the tower may also have contributed to the sudden increase in pressure that forced a large volume of hydrocarbon liquid into the adjacent blow-down stack, quickly exceeding its capacity.
4. The resulting vapour cloud was ignited by an unknown source.

2.2 Equipment and materials

The organisation of automatically stopping fuel feed for combustion when the vacuum in the furnace falls is not complicated for furnaces of all types (Zhidkov, 2008). Problems can be due to the physical state of the furnace alone (Zhidkov, 2008). If the housing of a pyramidal furnace is in poor condition, the underground flue is partially filled or flooded with subsoil water, the vacuum in the furnace will be minimal (sometimes positive) and will vary as a function of external factors, for example, the wind speed, precipitation, and the atmospheric pressure (Zhidkov, 2008).

According to Pengelly and Ast, (1988) the Canadian refinery has a crude capacity of 8000 B/D (Barrels per day). Production is divided between Plant No.1, built in 1958, and Plant No.2 built in 1974 (Pengelly & Ast, 1988). In the early years following the Plant No.2 start-up, several fires were initiated by mechanical failure of centrifugal pump bearings and/or mechanical seals (Pengelly and Ast, 1988).

According to Paterson (2011), pipes, valves, boilers, and heat exchangers are some of the refinery components that could leak. It is said that the suitability of materials, which build the refinery components, must be determined, and tested for resistance to overall corrosion; corrosive cracking; hydrogen sulphide embrittlement; point-pitting; crevice, intercrystallite and structural strength at a given temperature (Kachanov et al., 2010). According to the European approach, the selected construction, welding, and gasket materials must ensure a defined lifetime with the minimum number of breakdowns, i.e., a high reliability of the equipment. The American approach stipulates an operating life of 20 years for heat-exchanger bodies, five years for carbon-steel tube banks, and 10 years for stainless steel tube banks.

The breakdown of a heat exchanger or tank not only involves repairing the structure (correspondingly shutting down the unit and manufacturing less product) but also possible environmental damage and fire hazards (Kachanov et al., 2010). These researchers also noted that, in recent years, the customers of developed equipment have been stipulating the maximum corrosion rate of construction materials at $0.1\, mm/year$. For equipment operating in a medium containing hydrocarbons, sulphur compounds, and water, the maximum content in the construction steel should be 0.2% for carbon (C), 1.3% for manganese (Mn), 0.01% for phosphorus, 0.005% for sulphur, 0.4% for silicon, 0.4% for nickel, 0.3% for chromium(Cr), 0.4% for copper (Cu), 0.12% for molybdenum (Mo), and 0.015% for vanadium (V) and niobium (Kachanov et al., 2010). These researchers also contended that one of the requirements for selecting materials for use in wet hydrogen-sulphide-containing media is to limit the carbon equivalent (C_{eq}t) as a function of the thickness to the metal:

$$C_{eq} = C + Mn/6 + (Cr + Mo + V)/5 + (+Cu)/1$$

Kachanov et al. (2010) observed the following:

1. Steels 20YuCh and 20KA with a carbon equivalent for the upper limit of the content of the alloying components of 0.41 and 0.49, and for a lower limit of 0.3 and 0.4, are recommended for fabricating heat exchanger and tank equipment operating with hydrogen-sulphide-containing media.
2. The testing of experimental designs made of nickel-molybdenum alloy H70M27F (EP-814) showed that welded joints, made from this alloy, undergo intercrystallite corrosion.
3. The corrosion rate of molybdenum-containing steels was less than $0.05\,\mathrm{mm/year}$ with uniform corrosion.
4. The results of investigating the causes of pitting corrosion of tubes in the T-3/3 heat exchanger, made of steel 08X13, showed that atmospheric corrosion and the condensation of moisture in the inter-tube space became the causes of the destruction of the heat exchanger tubes.

Asea, Brown and Boveri, (2011) recommended using austenite steel only for the internals (heat exchanger) since carbon and low-alloy steel are not subject to hydrogen sulphide brittleness in an aqueous medium at a hydrogen sulphide content of less than 50 ppm[1]. Large world suppliers and designers of oil refinery equipment, such as Shell and Axens, have restricted the use of gasket materials containing asbestos and partonite due to their carcinogenic (cancer-related) properties. Materials made of thermally expanded graphite and Graflex are alternatives to such material. Carbon has a relatively high positive potential. In contact with iron and iron-based alloys, it can increase the corrosive failure of metal, primarily because graphite paired with a metal is an effective cathode. It absorbs foreign anions and oxygen, which is a powerful cathode depolariser that determines the corrosion process in neutral and basic media. Steels are anodes and, in aqueous solutions, their surface in contact with the graphite can undergo increased corrosion failure. Rollett (2007) observed that materials tend to creep at high homologous temperatures. In their calculation of leak/no-leak emission factors, Lev-on et al. (2014) found that a model refinery of 250,000 barrels per day typically has 50,000 valves, 150,000 flanges and 1000 pumps. Although refineries throughout the United States vary in size and complexity, their component count ratios (valves-to-flanges-to-pumps) will be like the one used here at the model refinery (Lev-on et al, 2014).

The following information was accessed from Gamble and Schopf (2010):

1. There are no positive consequences of leaks and fires.
2. Examination of the leak history from diphenyl and diphenyl oxide handling systems indicated that the primary sources are flanged connections, flexible connectors or rotary joints and pump seals.
3. In cases where insufficient flexibility is provided in piping networks, the resulting force applied to the flange pair reduces compression on a portion of the gasket, leading to leakage.
4. The close proximity of these devices to the nearby ignition sources can lead to the ignition, or even auto-ignition, of a released cloud of heat transfer fluid mist if surface temperatures exceed 593℃.

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[1] Part per minute

5. Three necessary components make up the fire triangle (fuel, oxygen, and heat) with the ignition source. Low chlorides, less than 10 parts per million, ensure the long life of stainless-steel system components without excessive risk of stress-corrosion cracking.

In Process Safety Management (PSM), Jayaraman (2013) focused on proactively avoiding incidents in oil refineries, fertilisers, pharmaceuticals, explosives, and chemicals. The PSM framework includes the following training (Jayaraman, 2013):

1. Elements covered in mechanical integrity.
2. Relief device management.
3. Pre-start-up safety reviews.
4. Hot work permits.
5. The status of the employee's participation.

Jayaraman (2013) further identified the three pillars of mechanical integrity as the following: operational integrity, which includes training and safe work practices; plant integrity, which includes hardware design, maintenance, construction and reliability and design integrity, which includes process design, process safety information, engineering, and material of construction. OSHA's PSM standard and OISD GDN-206 require a mechanical integrity programme to ensure that equipment is designed, installed, and operated as intended, without chances of failure. To meet this requirement, the refinery implemented a mechanical integrity and asset reliability programme (Jayaraman, 2013). This programme is focused on preventing catastrophic failure and improving the reliability of critical equipment (Jayaraman, 2013). Jayaraman explained that pre-start-up safety reviews verify the following:

1. Construction and equipment are in accordance with design specifications.
2. Safety, operating, maintenance and emergency procedures are in place and are adequate.
3. Where applicable, the management of change procedures has been followed and all HAZOP (hazard and operation) recommendations have been implemented before start-up.
4. Employee training has been completed.

Jayaraman (2013) stated that relief device management ensures the following:

1. Adequate inspection, pressure tests and maintenance.

2. Isolation is properly managed.
3. Changes in settings are critically reviewed and approved.
4. The basis for sizing is evaluated and documented.
5. Employees must obtain a permit to conduct hot work anywhere inside the refinery complex, and the primary focus is on ignition control.

2.3 People

Ranade et al., (2011) held the following views about equipment integrity, its reliability and safe operation:

1. Operators are the “eyes and ears” of the enterprise closest to the unit. They play a significant role in ensuring safety operation, regulatory compliance, and high uptime for petroleum-refinery units.
2. Maintenance technicians ensure integrity, reliability, and safe operation of all the assets. A typical refinery with ten process units employs about 300 operators and about 100 maintenance technicians.
3. A variety of factors including a shift in the median age of workers worldwide and the impending skills shortage due to attrition and early retirements have created a need to find fast, reliable methods, and tools for mapping the technical competencies of professionals in the chemical processing industries (CPI). Typically, competency-mapping projects in the CPI begin with some form of task or hierarchical job analysis.
4. Historically, many of these initiatives have been slowed down or have even failed due to incomplete or excessive lists of competencies, lack of sense of ownership among the workers and a lack of fit between generic competency maps and project-specific requirements.
5. Some competency map designs capture “what needs to be done” with “how it is done and who does it”. Such a map has a short shelf life because they have to be recreated every time there is a change either in reporting structure or in tools being used.

It was identified that a significant correlation of perceptions to safety climate exists with the following variables: Age, Academic Qualifications, Professional Experience and having been the Accident Victim (Pereira et al, 2011). According to Matew, Quintan and Ferris (1997), their research shows that the subcontracting companies tend to show more problems in terms of safety when compared with contracting companies. Vinodkumar et al. (2009) found that an increased level of academic qualification seems to point to an improved perception of safety climate.

Incorporating “If you see something, say something” into a company’s health and safety programme is a novel idea for getting all employees involved in day-to-day safety (McGuire et al., 2018). Scace (2017) summarised Ragain’s research to highlight several things, which may contribute to an employee’s unwillingness to speak up when they see something that is unsafe:

1. The pressure to produce – when employees feel pressure to produce, they tend to block out everything around them and do not see the unsafe actions they or their co-workers may be taking to get the job done.
2. Unit Bias – will wait to say something to a supervisor or co-worker until they finish the task on which they are working.
3. Deference to Authorities – as a rule, employees will not speak up to their supervisors or “the boss”.
4. Bystander Effect – assumed someone else will help or speak up.
5. Defensiveness – natural reaction when confronted about doing something wrong.
6. Stress – if an employee speaks up, it may place the employee in a stressful situation with co-workers. Rationalisation – no one else has said anything, so it must not be a big deal.

2.3.1 Human contribution in incidents

“Societal coping mechanisms reveal a collective frustration experienced, even among safety professionals, when people interacting within complex systems (people, equipment, materials and environment) appear to contribute directly, even excessively, to their own demise,” (Bird, Germain & Clark, 2003). It appears that employees were central to Heinrich’s 1941 Unsafe Act. Heinrich’s (1941) pioneering Central Factor Theory helped many to better grasp the concept of cause and effect. Incidents were understood to be caused by careless people. This is because the theory emphasised that an unsafe act could be quickly identified by the fault of one or more persons. Manuele (2003) believed that this emphasis on the unsafe act has had the greatest impact on the practice of safety, and that it has also done the most harm, since it promotes preventive efforts being focused on the worker, rather than on the operating system. Manuele (2003) further suggested that the worker is part of the operating system. This further suggests that, if there is any incident, all or some of the components forming part of the operating system could have contributed. Bird et al., (2003) replaced “unsafe act” with “substandard act and substandard conditions”. Bird et al., (2003) further considered both the substandard act and the substandard conditions to be symptoms of an event’s underlying or root causes.

The management system was identified as the greatest opportunity for incident control (Wilbanks, 2013). The management system includes the concept of pre-contact, contact and post-contact (Wilbanks, 2013). Wilbanks (2013) also pointed out that organisations with highly developed safety and health management systems continue to incur major injury events, however infrequent. Legislation in South Africa places the responsibility for ensuring safety on the employer, while employees can refuse unsafe instructions (instructions that can lead to incidents). Reason’s (1990) dynamics of causation show a trajectory of accident opportunity penetrating several defensive systems. These are results from a complex interaction between latent failures and a variety of local triggering events. Moreover, in highly defensive systems, one of the most common scenarios involves the deliberate disabling of engineered safety features by operators in pursuit of what, at the time, seemed a perfectly sensible goal. On other occasions, the defences are breached because the operators are unaware of concurrently created gaps in system security, as they have an erroneous perception of the “system’s state” (Reason, 1990).

2.3.2 Safety culture

We define the safety culture as a set of norms, values, attitudes, beliefs, and perceptions shared by spontaneous groups that determine the way people act and react, with regards to risks and systems control of risk (Hale, 2000). Safety climate, shared employee perceptions, and attitudes about safety reflect safety culture in the workplace (Jin & Chen, 2013). The socio-technical system approach was used to better link safety management and safety culture to the general organisation design (Grote & Künzler, 1996). Ineffective management decisions, which are called "latent errors", endanger the optimal functioning of the socio-technical system, and increase the likelihood of errors (Reason, 1993). Latent errors have become the core of safety-related system assessments, especially in those systems where a high safety margin has already been reached (Reason, 1993). Grote and Künzler (1996) assert that indicators frequently used to assess an organisation's safety culture include: -

1. management's commitment to safety,
2. safety training and motivation,
3. safety committees and safety rules,
4. record-keeping on accidents,
5. sufficient inspection and communication,
6. adequate operation and maintenance procedures,
7. well-designed and functioning technical equipment, and
8. good "housekeeping."

(Grote & Künzler, 1996) found that, for chemical workers, high degrees of automation, combined with lower degrees of job autonomy were linked to a stronger emphasis on technology as a risk factor, while higher degrees of job autonomy were related to a stronger emphasis on the human as a risk factor. Leplat (1987) reported similar results indicating a link between autonomy and taking over safety responsibility. However, Perrow (1984) pointed out that the tight coupling of technical systems limits the possibilities for the decentralised regulation of a system.

Grote & Künzler, 1996 discusses culture in the following: -

1. As with any cultural approach to understanding organisations, attempts to measure safety culture have to meet the challenge of evaluating invisible norms and assumptions based on visible indicators, which themselves only gain meaning through the knowledge of those norms and assumptions.
2. Noted that cultural analyses allow a description of norms and assumptions shared by the members of the social system, and more or less supportive of achieving the systems expressed goals.

3. Assessing safety culture is, therefore, not an issue of determining whether an organisation does or does not have a safety culture, but rather an issue of determining shared as well as conflicting norms within and between groups in an organisation, and the relationship between these norms and safe performance.
4. Judgements can be made by using externally set criteria for good safety culture, like those described in the socio-technical model of safety culture (Grote & Künzler, 1996).
5. Another possibility is to have members of the organisation judge both themselves and how helpful the organisation's culture is in achieving safety goals, assuming that safe performance is one of the central and explicit goals of the company.
6. Employees more bound to safety by strict control, instead of motivated for safety by information and interesting tasks, indicated less frequently that learning from near misses occurred in the plant.
7. Any cultural approach to understanding organisations and attempts to measure safety culture have to meet the challenge of evaluating invisible norms and assumptions based on visible indicators, which themselves only gain meaning through the knowledge of those norms and assumptions. any cultural approach to understanding organisations and attempts to measure safety culture have to meet the challenge of evaluating invisible norms and assumptions based on visible indicators, which themselves only gain meaning through the knowledge of those norms and assumptions.

Management, being more responsible for safety measures, might perceive them more positively, in favour of a more positive self-image, which is a finding similar to the self-serving bias frequently reported in attribution research (Zuckerman, 1979).

2.4 Conclusion

This chapter discussed the refinery system, refinery equipment and material, and people working in work areas of refinery. It looked at possible causes of challenges found in refinery activities. Refinery activities assumed to follow a linear theory. The failures with regards to the operating system, component failure e.g., heat exchangers, and people failure e.g., safety culture.

Strategies to deal decisively with challenges in refinery institutions must consider all the applicable information from input, processing, and dispatch. The objectives of MHSA section1(h)(i) is to promote the culture of health and safety in the industry.

CHAPTER 3
RESEARCH DESIGN AND METHODOLOGY

The chapter discusses design and methodology aimed at arriving at objectives of this research. The research objectives are listed in section 1.5 of this research. The chapter covers the design of tools used, the method used, and the procedure followed in gathering information.

3.1 Design

The research design seeks to deal with the research objectives. The literature review looks at refinery systems failures, refinery equipment and material, people employed at refineries, and the safety culture at these institutions.

The questionnaire is focussed on design and maintenance failure DM, change over failure (CO), safety culture shortcomings SC). The refinery is used to feed condensate (fluids transferred through the pipeline) from the offshore platform. No surge tank is assumed to control the feed from other sources. In chapter four, offshore operations and some accidents are discussed. The assumption is that the questions will be answered honestly.

The questionnaire consists of open and closed-ended questions. The incident data collected for the period of ten years was also interrogated to extract information. Data gathering, analysis, incident cause and effect, suggest descriptive research. Action and case study research will be based on relevant indicators. Analyses of fire incidents will be investigated, and safety audits will be instrumentally employed. The grounded theory research will be based on observation, documents, and historical records.

3.2 Method

The incident data collected was put on the line graph to observe the trend and was used to derive the global regression equation. The questionnaires were done under the control environment. The questionnaire information was gathered from various departments. The regression equation was again derived making use of questionnaire responses. To confirm the usefulness of the sample the goodness of fit (R^2) is calculated.

3.3 Procedure

The following procedure will be followed:

1. Require supporting letter from Cape Peninsula University of Technology (CPUT) to authenticate the research student.
2. Use the letter from CPUT to ask a refinery in Southern Africa permission to investigate at the refinery.
3. Design questionnaires based on refinery employees, materials & equipment, and employee culture.
4. Conduct investigation at a refinery in Southern Africa.
5. Analyse reported incidents by a refinery in Southern Africa.
6. Analyse the results of the investigation from a refinery in Southern Africa.
7. Source relevant literature on the subject.
8. Observe possible solutions and make recommendations as to remedy the situation.

The topic “dealing with uncontrolled refinery fires” is composed of three components which all/some must be investigated.

These are refinery system, equipment and material, and people.

1.3.1 Refinery System Failures

1. Input system
2. Process system
3. Output system.

1.3.2 Equipment and material

1. Maintenance and Failure pattern
2. Equipment behaviour under load
3. Installation and decommissioning

1.3.3 People

1. Ratios of people to machinery
2. Reporting structure (Outsourcing issues)
3. Early retirement and similar turnover.

3.4 Conclusion

The chapter discussed the design, method, and procedure to gather information. Since the topic is “dealing with uncontrolled fires”, the investigative procedure is focussed on refinery systems, equipment and materials, and people.

CHAPTER 4

PIPELINE FEEDING REFINERY AND SOME INCIDENT EXAMPLES

The chapter discusses the challenges faced by a pipeline network in operation. Fatigue strength and erosion velocity of fluids were evaluated. The pipeline from offshore, some incidents, and major chemical industry around the world table are presented.

4.1 Pipeline from offshore

Some refineries are fed condensate fluid in direct form from an offshore platform. To prevent imbalance/shocks on a refinery pipe network, some refineries use surge tanks (receiving tanks). Such refineries will be feeding from the surge tank instead of directly from the offshore pipeline. A refinery plant is mainly a pipeline network. The example looks at the pipeline supply from the offshore to refinery:

User requirements:

- *304.9mm* pipe
- *203.2mm* pipe.

The assessment study must include:

- Wall thickness design calculations.
- Temperature and pressure considerations (this is a high temperature, high pressure development).
- Material selection (the type of material needed on the design conditions and operational requirements).
- Stress analysis and buckling checks.
- Corrosion considerations.
- Pipe coating.

Legal requirements and restrictions:

The following guidelines must be noted:

- The impact on the environment shall be reduced as far as reasonably possible.
- No releases will be accepted during the operation of the pipeline.
- There shall be no serious accidents or loss of life during the construction period.

Pipe requirements: the relevant factors in choosing material:

- Resistance to corrosion.
- Permissible hydrocarbon velocities.
- Physical and mechanical properties of the material.
- The initial cost of pipe and components, and the cost of fabricating and installing systems.
- Life expectancy and the value of the scrap when the system is dismantled.
- The pipeline must be easy to inspect and service.
- It must allow for early problem detection.
- It must be easy to transport, fit and maintain.
- It must be able to handle high temperature and high-pressure developments.
- It must not buckle; possible high-stress points must be identified and efficiently handled.
- It must comply with all national and international laws applicable to its relevant operation. environment, including Health and Safety Executive (HSE) requirements.

Input data:

SMYS = 450 MPa	Specified minimum yield stress
SMTS = 680 MPa	Specified minimum tensile stress
$\mathrm{E_{mod}} = 200\ \mathrm{GPa}$	Young modulus at design temperature
$\nu = 0.3$	Poisson ratio
t_{tab} = 10.0%	Fabrication allowance
$f_o = 2.5\%$	Ovality
$d_{min} = 145m$	Minimum water depth
$d_{max} = 155m$	Maximum water depth
d_{ss} = 2.76m	Storm surge and tide
$P_d = 440barg$	Design pressure at seabed
$\gamma_{inc} = 1.0$	Incidental pressure ratio
$\rho_{sw} = 1025kgm^{-3}$	Sea water density
$T_{res} = 0.KN$	Residual tension
$\propto = 1.35 \cdot 10^{-3} \cdot \frac{1}{℃}$	Coefficient of thermal expansion

$\propto_U \quad = 0.96$ Material strength factor

$P_d = 440barg$ Design pressure

$T_d = -10℃/+130$ Design temperature

DNV - OS – F101 Design code

Material Grade X60 with 3mm alloy 825 internal clad

Line pipe type longitudinally welded.

$\Psi \quad =$ Angle from bending plane to plastic neutral axis

$\sigma = stress; y = distance; M = bending\ moment; I = moment\ of\ inertia;$

And $R = radius\ of\ curvature$

Parameters of the 304.9*mm* main pipeline-high temperature, effective length, and the 203.2*mm* pipe highlight the effect of refinery media on infrastructure.

For twisting:

Mohitpour et al. (2000) presents the combined thermal expansion stresses as follows:

$$S_E = (S_b^2 + 4S_t^2)^{0.5}$$

$$S_E = combined\ thermal\ expansion\ stress$$

$$S_E \leq 0.72\{0.96(450 - 90)\}$$

$$S_E = 248MPa$$

$S_{B(D+L)}$ $absolute\ value\ of\ longitudinal\ bending\ stress\ from\ dead\ and\ live\ loading$

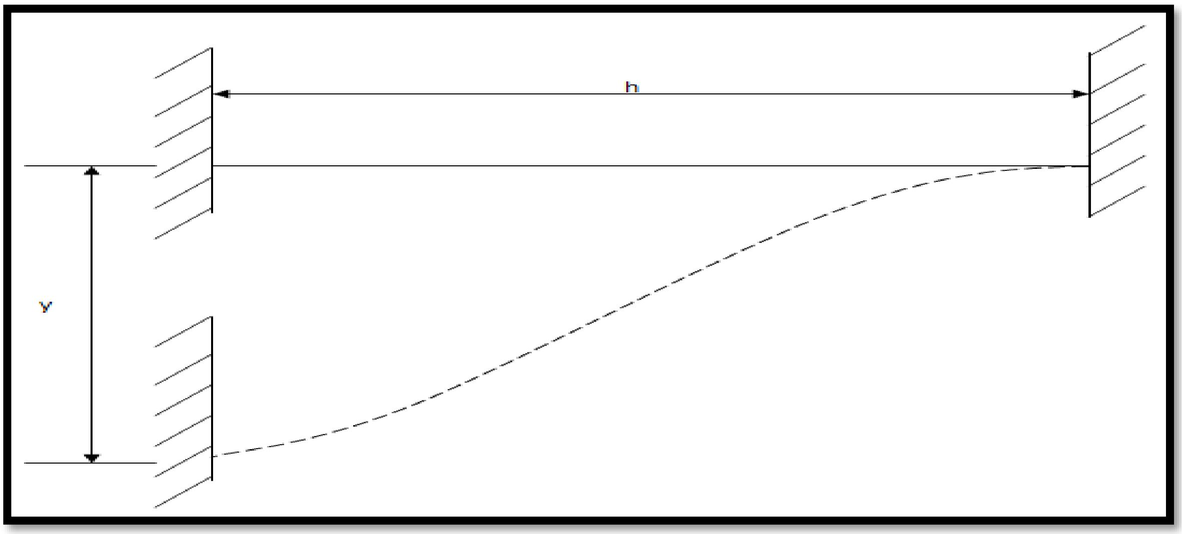
$$S_E + S_L + S_{B(D+L)} \leq S$$

$$S_L = \frac{PD}{4t} = \frac{S_h}{2}; \qquad S_L = \frac{44\times10^6\times0.13002}{4\times0.03175} = 45.05MPa$$

P is the internal pressure, D is the internal diameter of the pipe, and t is the thickness.

$$S_{B(D+L)} = 345.6 - 248 - 45.05 = 52.55MPa$$

Figure 3.1: Expansion loop of the pipe (Mohitpour et al., 2000):



Shigley, (2004) holds the following regarding fatigue failure:

1. Many static failures give visible warnings in advance, but a fatigue failure gives no warning; it is sudden and therefore dangerous.
2. Fatigue failure always begins at a local discontinuity, such as a crack, a notch, or other areas of stress concentration.
3. When the stress at the discontinuity exceeds the elastic limit, plastic strain occurs.
4. When reliability is important, fatigue testing must be undertaken.

The 304.*9mm and* 203.2*mm* pipes are sometimes designed for 25 years and 15 years, respectively. The pipe system is in the finite life region. The frequent starting up and shutting down are some of the operational dangers the pipe system will have to endure for the duration of its life. The pipes are exposed to loading conditions like twisting, bending and temperature changes. The Technical Report SAE J1099 (1975) activities are the following:

1. reported that life reversals to failure are related to strain amplitude$(\frac{\Delta\varepsilon}{2})$.
2. Explains the total strain as the sum of the elastic and plastic components $\frac{\Delta\varepsilon}{2} = \frac{\varepsilon_e}{2} + \frac{\varepsilon_p}{2}$.
3. Fatigue cracks nucleate and grow when stresses vary.
4. Fatigue cracks fluctuate between the limits of minimum stress $(\sigma_{\min})$ and maximum stress (σ_{max}).

5. Fatigue studies are conducted to approximate the safety factor. For this, the endurance limit must be approximated.

For endurance limit is calculated in the following way (Shigley, 2004):

$$\frac{S_e}{f_u} = 0.504 \quad \therefore for\ 304.9mm \;\; S_e = 566.4 \times 0.504 = 285.47MPa$$

From (page 326 of Shigley's Engineering Design), the following can be deduced:

$$b = -\frac{1}{3}\log\left(\frac{ff_u}{S_e}\right)$$

$$f = 0.909 \therefore b = -0.333\log\left(\frac{0.909\times566.4}{285.47}\right) = -0.0854$$

$$a = \frac{(ff_u)^2}{S_e} = \frac{(0.909\times566.4)^2}{285.47} = 928.57MPa$$

Fatigue strength $S_f = aN^b$

Approximate N from the design pressure 440Barg

$$N = \left(\frac{44}{928.57}\right)^{\frac{1}{-0.0854}} = 0.0474^{-11.7096} = 3.215 \times 10^{15}$$

Hence, $S_f = 928.47(3.215 \times 10^{15\times-0.854}) = 156.3MPa$

Approximating endurance limits and fatigue strength helps us to deal with the factor of safety.

Pipe Erosion:

Mohitpour et al., (2000) said that, when fluid passes through a pipeline at high velocity, it can cause both vibration and erosion in the pipeline, which will erode the pipe wall over time. According to Mohitpour et al. (2000), if the gas velocity exceeds the erosion velocity calculated for the pipeline, the erosion of the pipe wall is increased to a rate that can significantly reduce the life of the pipeline. Erosion velocity for compressible fluids is expressed as $u_e = \frac{C}{\rho^{0.5}}$ (Mohitpour et al., 2000) where:

$u_e = erosional\ velocity\ in\ m/sec$ and $\rho = gas\ density\ in\ kg/m^3$.

C is a constant defined as 75<C<150. The recommended value for C in gas transmission pipelines is C=100.

Also, $u_e = \frac{100}{\sqrt{\frac{29G\cdot P}{Z\cdot R\cdot T}}}$ where:

$G = gas\ gravity, dimesionless$

$P = minimum\ pipeline\ pressure, kPa$

$Z = compressibility\ factor\ at\ specified\ pressure\ and\ temperature$

$T = gas\ temperature\ in\ K$

$R = gas\ constant$

The maximum velocity is given as follows:

$u_{max} = \frac{0.75 \times gas\ flow\ rate \times Z}{Pd^2}$

P and d mean the pressure and the internal diameter of the pipe, respectively. When the maximum velocity is lower than the erosion velocity, the system is in the safe velocity region. Erosion gas flow is defined as follows:

$Q_e = u_e \cdot A, (m^3/sec)$

Where is A is the cross-sectional area, m^2.

4.2 Some incidents

It is difficult to avoid fire occurrences in the absence of comprehensive data and experience in tackling such incidences (Ikeagwuani, & John, 2012). In their work entitled "Safety in the maritime oil sector: Content analysis of machinery space fire hazards", Ikeagwuani and John, (2012) identified that machinery space is an area where fire erupts due to the nature of compartments. These researchers further concluded that, among other things, fires are caused by substances or mechanical failures, such as leaking oil on hot surfaces. The following three incidents are some of the incidents analysed: ***Incident 1***: A naphtha leak occurred in a T-piece on 1 September 2012. The flammable naphtha caught fire. The leak was caused by corrosion, producing pinholes in a T-piece in a pipe, which allowed the naphtha to escape under pressure. The damage was estimated at R16 994 million. The incident resulted in additional non-destructive testing (NDT) measures being put in place to check for corrosive damage. ***Incident 2***: - A gas-leaking tube on the inlet header of the start-up heater caught fire. This tube was one of the 18 tubes that transported fuel gas from the common header. The leak was caused by a metallic scale external and internal corrosion produced two pinholes on a tube that transported fuel gas. The damage was estimated at R95 000. The furnace was shut down and made safe. The corroded section of the pipe has been replaced. ***Incident 3***: An explosion occurred inside the motor casing of 11KC101 (identification of the structure) on the 1st of June 2013. The hood and integral water cooler were blown off the top of the motor enclosure. The explosion was caused by total nitrogen failure in the entire plant. Equipment damage included the motor, the hood, and the water cooler. The spare resistance temperature detector probe was faulty, and the warning system failed. All damaged equipment was replaced, and a pressure transmitter was installed on the nitrogen purge line for the electrical motor.

Table 4.1

MAJOR CHEMICAL INDUSTRY ACCIDENTS AROUND THE WORLD

Year	Explosion	Vessel Bleve	Gas release	Fire	Fatalities	Injure
1970	1				29	10
1972	1				8	21
1973			1		18	65
1974		2			128	65
1975		1			6	13
1976			1			2000
1977			1		30	22
1982				1	150	500
1984	1	2			3665	6422
1988	1				167	
1989	1				23	130

4.3 Conclusion

Pipeline challenges were discussed. Three refinery incidents were looked at as an example of typical refinery incidents. Major chemical industry accidents around the world were Tabled. It is concluded that fatigue of equipment, erosion velocity of fluids, and equipment leaking, are some of the things that need to be dealt with. No pattern can be identified on the table, hence its value for use is minimal. The table depicts repeat incidents. Thus, experience not used effectively will continue repeating negative incidents.

CHAPTER 5
DATA COLLECTION AND ANALYSIS

This chapter deals with the collection, processing, and analysis of the data collected. It covers data collection, sample and instruments, and data treatment and admissibility. The possibility that the fire caused by not following procedures is looked at. The variables which include design and maintenance, changeover, and safety culture are used to calculate each based on the total number of incidents.

5.1 Data collection

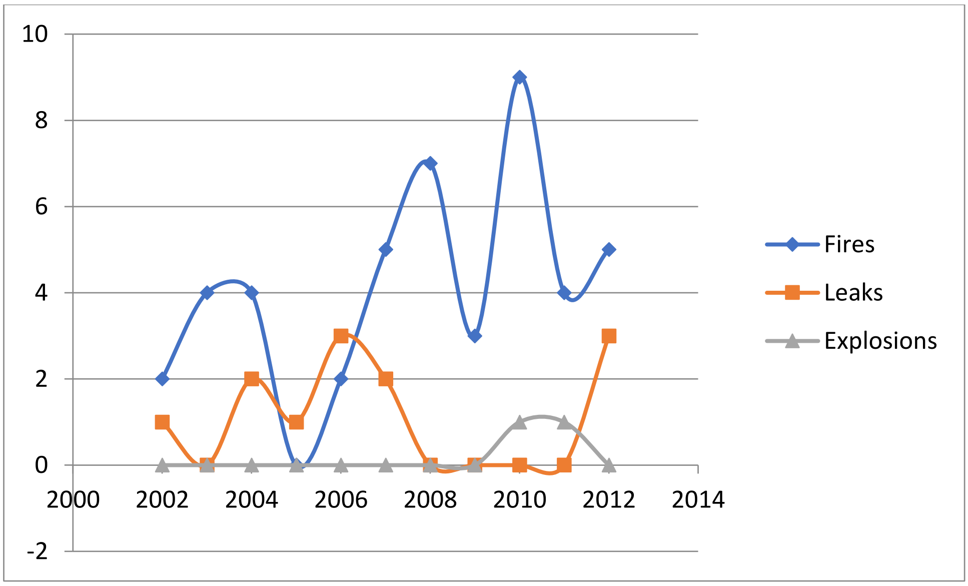
The primary data for this study was collected through real-time incidents, which happened over a period of ten years. From 2002 to 2012, there were forty-five fires, twelve gas leaks and two explosions reported at the Refinery in South Africa (RSA). It is noted that 73% of the fires reported happened in the last six years of the period indicated (from 2007 to 2012), while 25% of the gas leaks happened in the year 2012, and 100% of the explosions reported happened in the last three years of the period indicated (herein).

Table 5.1 below was taken from the Department of Mineral Resources (DMR) incident/accident registers. Figure 5.1 is drawn from table 5.1 of reported incidents observed over a period of 10 years, from 2002 through to 2012. It shows a general increase in fire incidents at the Refinery in South Africa (RSA). During this period, an average of four per year were conducted, as a minimum legal requirement. Turner and Pedgeon (1997) suggested that some contemporary technical installations are so complex and so closely meshed, that those accidents are inherent in their design. Such systems generate what Perrow (2003) calls “normal accidents.” Shrivistava (1992) pointed out that the accidents in complex, tightly coupled, interactive technological systems are caused by multiple failures in design, equipment, supplies and procedures.

Table 5.1: Incident Reported by Refinery in South Africa (RSA) from 2002 to 2012

YEAR	NUMBER OF FIRES	NUMBER OF LEAKS	NUMBER OF EXPLOSIONS
2002	2	1	0
2003	4	0	0
2004	4	2	0
2005	0	1	0
2006	2	3	0
2007	5	2	0
2008	7	0	0
2009	3	0	0
2010	9	0	1
2011	4	0	1
2012	5	3	0

Figure 5.1: Constructed from Table 1 above



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The above graph indicates the growing trend of uncontrolled fire incidents in one of the refineries in South Africa. According to Jayaraman (2013), there were 4261 fatalities while 27340 people were injured as a result of major chemical industry incidents, between 1970 and 1989 worldwide. Some of the factors which can affect incidents of fire at refineries include safety management, safety culture, competency requirements of human resources, refinery equipment, refinery media (fluid in pipes, speed of fluids, pressure, temperature, acidity, alkalinity, etc.), management of change, and the interface between human resources and refinery equipment. Table 5.1 reflects 45 fires and 12 leaks between 2002 and 2012. The highest peak of fire incidents occurred in 2010 with nine fires. This coincides with the hosting of the 2010 FIFA World Cup in South Africa. From 2005, the fire incidents increased from 0% to 90% in 2010. Recommendations regarding fire incidents suggest that most fires are caused by people not following procedures, a lack of training and a lack of design and maintenance (DM). The study makes use of the data in Table 4.1 and analyses fires caused by people not following correct procedures from 2006 to 2012.

All regression calculations are based on information gathered from Studenmund (2006). Table 5.2 below: Fires from 2006 to 2012 where x_a represents all the fires and x_p fires caused by people not following procedures during the period. Dependent variables and independent variables have a linear relationship (Studenmund, 2006).

								Sum
x_a	2	5	7	3	9	4	5	35.000
x_p	2	3	4	2	4	3	1	19.000
$p(x_a)$	0.057	0.143	0.2	0.086	0.257	0.114	0.143	1.000
$p(x_p)$	0.105	0.158	0.211	0.105	0.211	0.158	0.053	1.000
$x_p\left(p(x_p)\right)$	0.211	0.474	0.842	0.211	0.842	0.474	0.053	3.105
$(x-u)^2$	1.221	0.011	0.801	1.222	0.801	0.011	4.432	
$(x-u)^2 p(x_p)$	0.129	0.002	0.169	0.129	0.169	0.002	0.233	0.831

The mean u is calculated to 3.105, σ^2=0.831 where σ is the standard deviation, $p(x_a)$ probability of x_a, and $p(x_p)$ probability of x_p. The fire incidents can be described as discrete variables. If x_p is plotted against $p(x_p)$, peaks are observed and, 95% of all measurements should lie within two standard deviations: (2σ) of the mean (μ) (Mendenhall et al., 2009)

$\mu \pm 2\sigma \rightarrow\ 3.105 \pm 2(\sqrt{0.8291})$ or 1.2839 to 4.9261.

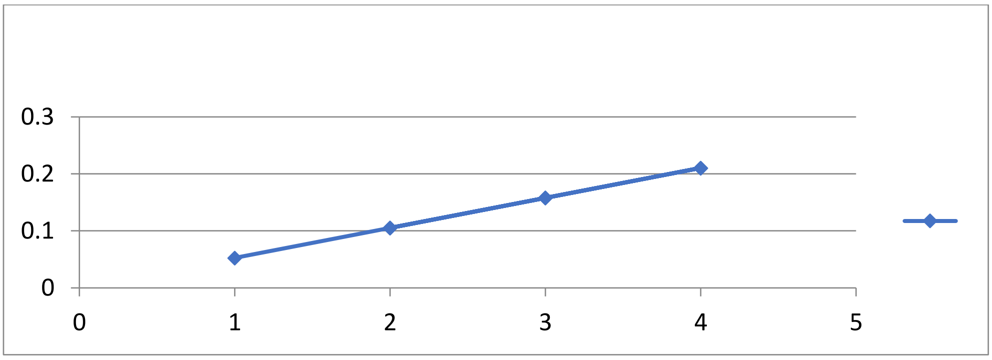
Since $x_p = 1$ lies outside of this interval, we can say that one or more fire/s, caused by not following procedures, will occur. $P(x_p \leq 1)$ *is exactly* 0.053.

Table 5.3 arranged from 1 to 4. Note that 2 to 4 lies within the interval.

x_p	1	2	2	3	3	4	4	19.000
$p(x_p)$	0.053	0.105	0.105	0.158	0.158	0.211	0.211	1.000

Below is the regression graph that illustrates the fires caused by not following the correct procedures:

Figure 5.2: Regression graph based on the data in Table 5.3.



The regression graph above can be explained by the following regression formula: Let Y=$p(x_p)$, which is the probability of fires caused by not following the correct procedure; X=x_p represents the fire incidents caused by not following the correct procedure; β_0 is the Y intercept, β_1 is the slope of the graph and ϵ is an error term. If we ignore $x_p = 1$ (lies outside the interval) then $Y = \beta_0 + \beta_1 X + \epsilon = 0.105 + 0.053X + \epsilon$. The global regression equation that explains fire incidents (F) is depicted as a function of not following procedure (P), lack of maintenance (M), lack of rewarding non-incident periods (R), and poor design (D). The global regression equation representing fire incidents is: $F = \widehat{\beta_0} + \beta_1 P_{1i} + \beta_2 M_{2i} + \beta_3 R_{3i} + \beta_4 D_{4i} + \epsilon_i$ where β_0 is a constant or an intercept term, βs are slope coefficients, and ϵ_i means error term. Studenmund (2006) explains the meaning of the regression coefficient β_1 in the above equation as the impact of a one unit increase in P_1 on the dependent variable *F*, while keeping the other included variables constant$(M_2, R_3, and\ D_4)$. The

F-test is an appropriate method to test any hypothesis involving a multi-variable equation.

The questionnaire is derived from the design and maintenance of infrastructure (DM), change-over (CO), and safety culture (SC). Repeat accidents were considered when drafting the questionnaire. The questionnaire includes the following:

1. Eight closed-ended questions on the design and maintenance of infrastructure, wherein participants are requested to rate their opinions by making a mark in the appropriate box, with the level of agreement in each of the questions, by indicating whether they strongly agree, agree, are uncertain, disagree or strongly disagree.
2. Eight closed-ended questions on change-over during operation, wherein participants are requested to rate their opinions by making a mark in the appropriate box, with the level of agreement in each of the questions, by indicating whether they strongly agree, agree, are uncertain, disagree or strongly disagree.
3. Twelve closed-ended questions on safety culture, wherein participants are requested to rate their opinions by making a mark in the appropriate box, with the level of agreement in each of the questions, by indicating whether they strongly agree, agree, are uncertain, disagree or strongly disagree.
4. Three open-ended questions on design and infrastructure, three open-ended questions on change-over, and four open-ended questions on safety culture.

5.2 Sample and instruments

The department that participated in the questionnaires has 350 employees for Production, 160 employees for Reliability, 30 employees for Metallurgy, and 25 employees for Process. The Production runs four shifts, and there are 88 employees at most per shift in this department. The population for this is 303 employees. From the fire incidents and literature review, three variables were identified. The questionnaire is located at Appendix A page 51 in the report. A sample of nine closed-ended questions on each of the three variables mentioned below was formulated for the questionnaire. Questions 21 and 23, and 22 and 24 were combined to form one question. The questionnaire had three open-ended questions for each variable as well. The variables (instruments) identified as design and maintenance (DM), change-over (CO), and safety culture (SC) were selected. The data was collected using three variables, namely, DM, CO, and SC. Any outcome reflected by the collected data will be equated to the current fire incidents. The fire incidents may be viewed as results in one or all three variable failures.

The calculation is needed to confirm whether data from the questionnaire can reveal something or nothing. For this, the goodness of fit is calculated. Based on Studenmund (2006), the following regression equation is explained and used

$$F = \beta_0 + \beta_1 DM_{1i} + \beta_2 CO_{2i} + \beta_3 SC_{3i} + \epsilon_i,$$

where β_0 is a constant term and is also known as the y-intercept and is the value of F when independent variables are equal to zero. The β_s are slope coefficients, and they indicate the amount by which F will change if DM increases by a unit while holding other independent variables constant. The error term ϵ_i introduces the variation in F that cannot be explained by the included independent variables. The regression analysis is a statistical technique that attempts to explain movements in one variable (dependent variable) as a function of the movements of a set of other variables (independent or explanatory variables).

$$F = \mathrm{f}(DM, SC, CO)$$

F is a dependent variable, while DM, SC and CO are independent variables. The F-test is an appropriate method to test any hypothesis involving a multi-variable equation. The incidents of fires and leaks totalled 57 during the period observed. This amounts to an average of 5.7 per year, using 6 incidents per year $\beta_0 = \bar{Y} - \beta_1 \overline{DM} - \beta_2 \overline{CO} - \beta_3 \overline{SC}$.

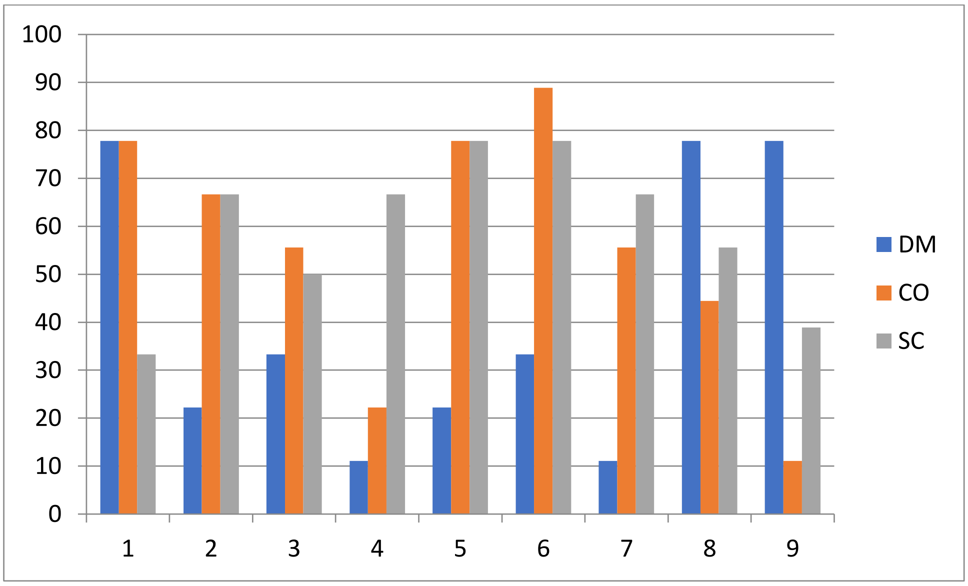
5.3 Data treatment and admissibility

Participants were accessed at their reporting stations. The questionnaire was explained to them and only signed questionnaires were distributed for completion in a controlled environment. There were seven sets of questionnaires (four for Process, two for Production, and one for Reliability) left at refinery management for employees who were not available when the 33 sets were completed and returned. The seven questionnaires were collected two days later, and only questionnaires with the original signature of the researcher and date were accepted. Management was asked to give the employees time to complete the questionnaire. It was emphasized that the participants' honesty in answering the questionnaire would be very important for anything positive to emerge from the questionnaire results. It was explained to the participants that it would be better for the study if they avoided the 'uncertain' option for closed-ended questions, as this would have the same effect as non-participation.

Table 5.4: Data derived from responses to open-ended questions.

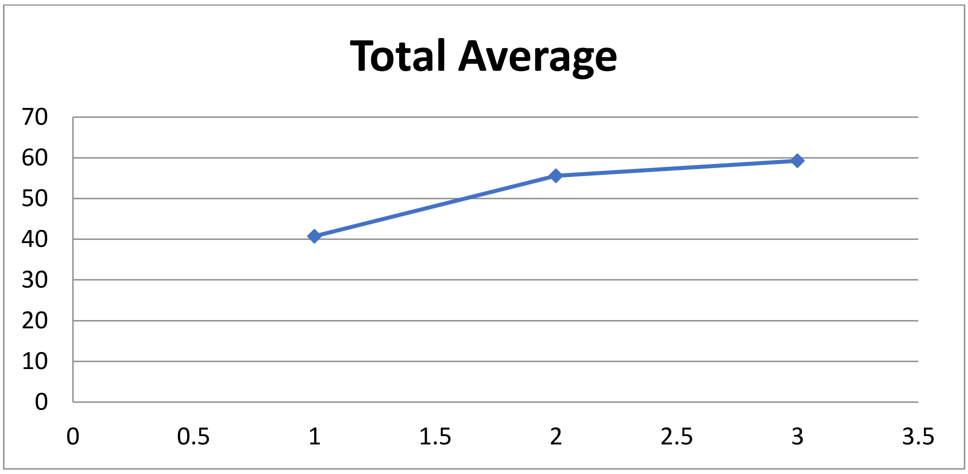
Observations	DM	CO	SC
1	77.778	77.778	33.333
2	22.222	66.667	66.667
3	33.333	55.556	50
4	11.111	22.222	66.667
5	22.222	77.778	77.778
6	33.333	88.889	77.778
7	11.111	55.556	66.667
8	77.778	44.444	55.556
9	77.778	11.111	38.889
sum	366.666	500.001	533.335
mean	40.74067	55.55567	59.25944

Figure 5.3: Data derived from responses to open-ended questions.



The graph below illustrates the positive responses of each total average for each variable. The positive responses for DM, CO and SC were 40%, 55% and 59% respectively.

Figure 5.4: Total Responses



The horizontal axis at point 1 represents DM, point 2 CO, and point 3 SC. The vertical axis represents positive percentage responses with 40% corresponding to DM, 55% to CO, and 59% to SC

5.4 Conclusion

Data collected used to calculate the probability that one or more fire/s caused by not following procedures was 0.053. Data from the questionnaire used to derive the regression equation. Only one observation of the nineteen incidents lies outside the two standard deviations. The questionnaire and the sample were explained. The responses in percentage form were tabled and the mean of each variable calculated. Responses are depicted on a bar chart and line graph

CHAPTER 6
ANALYSIS AND INTERPRETATION OF DATA FINDINGS

The previous chapter derived the regression equation from the data collected. This chapter deals with data processing which focuses on design and maintenance failures (DM), change over failures (CO), and safety culture differences (SC). Research constraints and assumptions, considering the literature, and results and discussion are also dealt with in this chapter.

6.1 Data processing

The Table below indicates the departments that participated, as well as how the questionnaires were answered by the participants.

Table 6.1: Departments' Responses to the Questionnaire

	Issued	Responses	CCE	COE	PCOE
Reliability	10	9	9	8	1
Production	10	8	8	7	1
Process	10	9	9	5	4
Inspection	10	7	7	5	2

In this table, CCE means 'completed closed-ended' questions; COE means 'completed open-ended' questions; and PCOE means 'partially completed open-ended' questions. The questionnaire responses for closed-ended questions were as follows: the calculation is focused on design and maintenance failures concerning safety culture shortcomings. The calculation makes use of all three variables identified.

The data below was derived from positive responses to open-ended questions. It is presented in a form of a percentage. The first column (observations) below represents positive responses to open-ended questions from question 1 to 9. There is a small difference between CO and SC. Both variables are labour intensive. DM has the lowest average of the three variables. To confirm the usefulness of the sample the goodness of fit (R^2) is calculated.

Table 6.2: DM outcomes with respect to SC outcomes

Observation	DM	CO	SC	X_1	X_2	X_3
1	77.778	77.778	33.333	37.03733	22.22233	-25.9264
2	22.222	66.667	66.667	-18.5187	11.11133	7.407556
3	33.333	55.556	50	-7.40767	0.000333	-9.25944
4	11.111	22.222	66.667	-29.6297	-33.3337	7.407556
5	22.222	77.778	77.778	-18.5187	22.22233	18.51856
6	33.333	88.889	77.778	-7.40767	33.33333	18.51856
7	11.111	55.556	66.667	-29.6297	0.000333	7.407556
8	77.778	44.444	55.556	37.03733	-11.1117	-3.70344
9	77.778	11.111	38.889	37.03733	-44.4447	-20.3704
Sum	366.666	500.001	533.335	0	0	0.000108
Mean	40.74067	55.55567	59.25944			
	X_1^2	$X_1 \cdot X_3$	$\hat{Y}_i$	e_i^2	ESS - M	TSS – M
1	1371.8	-960.2	42.511	1243.745	3.134917	1246.88
2	342.94	-137.2	14.241	63.69708	702.2347	765.9318
3	54.874	68.591	-1.096	1185.376	1750.331	2935.707
4	877.92	-219.5	0.2519	117.9206	1639.342	1757.263
5	342.94	-342.9	33.585	129.1238	51.19974	180.3236
6	54.874	-137.2	47.574	202.8066	46.69467	249.5012
7	877.92	-219.5	7.6521	11.96377	1094.851	1106.815
8	1371.8	-137.2	27.822	2495.567	166.8829	2662.45
9	1371.8	-754.5	21.958	3115.919	352.8042	3468.723
	6666.756	-2839.55	194.5	8566.118	5807.476	14373.59

The constant β_0 or intercept term and from section 4.2 in the last paragraph was assumed to be 6.

The mean of variables used as coefficients of each variable are presented in a percentage form. The regression equation is as follows:

$$F = 6 + 0.407DM_{1i} + 0.556CO_{2i} + 0.593SC_{3i} + \epsilon_i.$$

The +0.407 in the equation above means that the model implies that the i^{th} fires F will be reduced by 0.407 for every rand spent (R1) on design and maintenance, while SC and CO remain constant. The y-intercept 6 in the equation above is an assumption that there will be one fire or leak incident when variable DM, SC and CO equals zero. The ESS and TSS refer to the explained sum of squares and the total sum of squares, respectively. The multivariate regression coefficient indicates the change in the dependent variable associated with a one-unit increase in the independent variable in question, holding the other independent variables in the equation constant.

Based on both the design and maintenance failures, the goodness is $R^2 = \frac{ESS-M}{TSS-M} = \frac{5807.476}{14373.59} = +0.404$. The positive sign means that there is a positive correlation between the two variables. Goodness of fit, also called the coefficient of determination, is the ratio of the explained sum of squares to the total sum of squares. The calculation of goodness of fit, based on change-over and safety culture, can be calculated using the same approach. The higher the R^2, the closer the estimated regression equation is to fitting the sample data. The interval is $0 \leq R^2 \leq 1$. Goodness of fit cannot substitute the formal hypothesis test of overall fit. The null hypothesis in an F-test of overall significance is that all the slope coefficients in the equation equal zero simultaneously (Studenmund, 2006). The null hypothesis is a statement of values that the researcher does not expect.

$$H_0: \beta_1 = \beta_2 = \cdots = \beta_k = 0$$

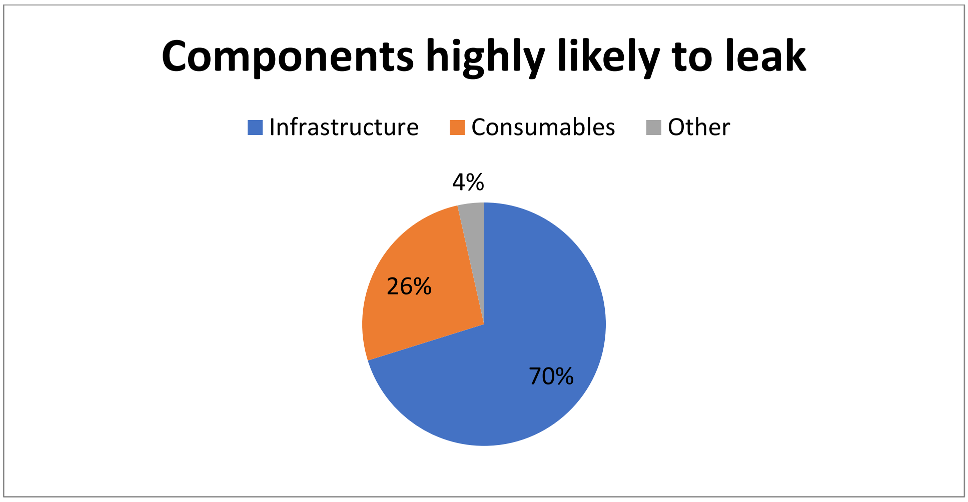
$$H_A: H_0 \ is \ not \ true$$

$$F = \frac{ESS/K}{RSS/(N-K-1)} = \frac{5807.476/3}{(14373.59 - 5807.476)/(27-3-1)} = 5.198$$

Where N is the number of observations (9 times 3 variables is 27, K is degrees of freedom equal to 3 (variables), and the denominator degrees of freedom equal 23 (N-K-1). Table B-2 of Studenmund (2006) provides a critical F-value for 3 and 23 degrees of freedom. The critical value $F_c = 3.03$ is well below the calculated F-value of 5.198, so we can reject the null hypothesis and conclude that the F equation does indeed have a significant overall fit.

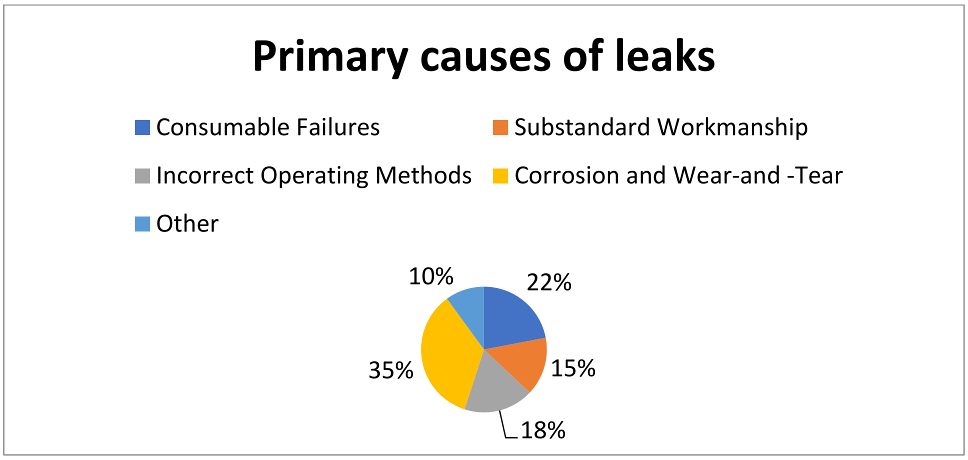
DM refers to design and maintenance failures; CO means change-over failures; and SC means safety culture differences. The questionnaire responses to closed-ended questions concerning design and maintenance are shown in Figure 6.1 below. The infrastructure includes heat exchangers, pump-seals, couplings, piping pinholes, mechanical seal leaks, flanged joint connections, valve glands and seals, among others. Also mentioned is that most of these uncontrolled leaks happened in the vicinity of high temperature and high pressure. It has been pointed out that the plant is old, with pinholes on pipes because of corrosion. Some participants feel that there is a lack of forward-thinking as far as maintenance is concerned. Consumables include gaskets, glands and sealing materials.

Figure 6.1: Components highly likely to leak.



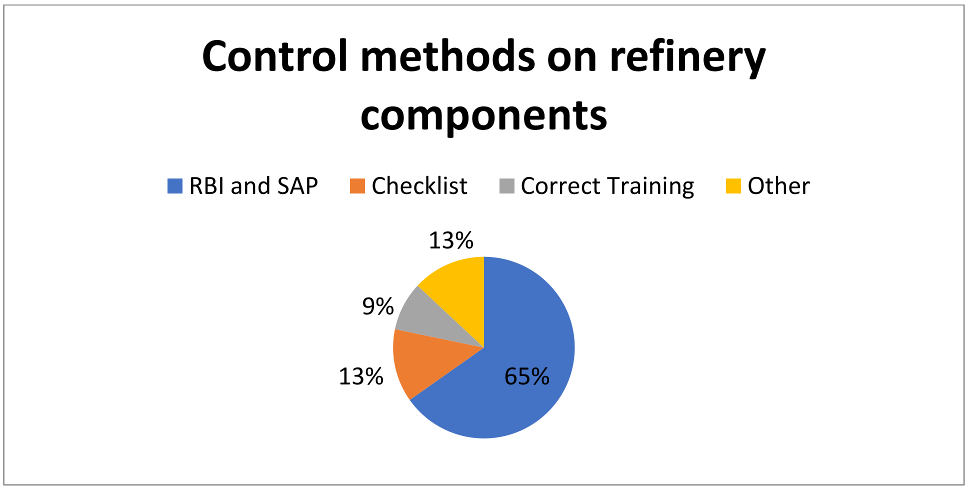
The primary causes of leaks include the behaviour of the hydrocarbons in pipes, the contraction and expansion of the refinery media as well as changes in pressure and temperature (thermal shocks). Based on the responses, 35% of participants believe wear-and-tear (corrosion of equipment) to be the primary cause of leaks. Consumable failures (gaskets and insulating material) were allocated 22% relative to other components, shown in Figure 6.2, while 33% is the combined result of incorrect operating methods and substandard workmanship. The process set-up, incorrect commissioning, internal erosion, gland-packing failure, and incorrect operating methods are some of the operational causes of these failures.

Figure 6.2: Primary causes of leaks



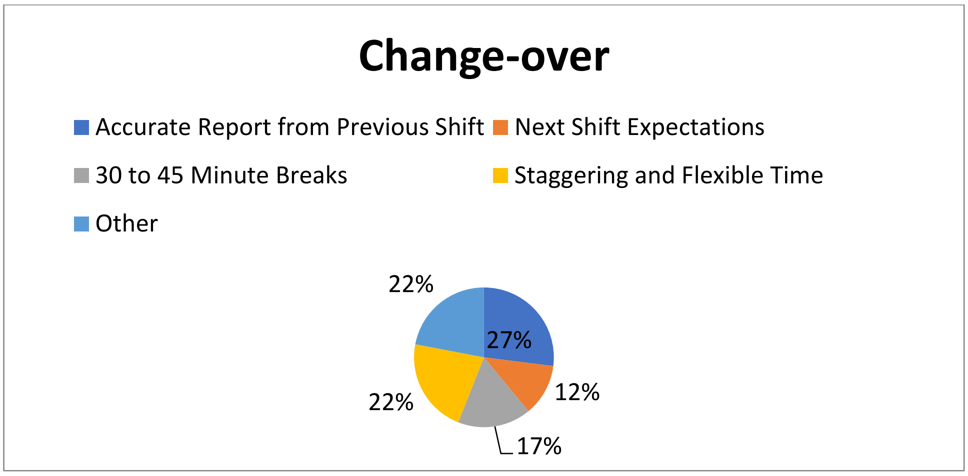
The questionnaire covering the methods used to control refinery components effectively is shown in Figure 4.3. Compared to other measures used, Risk Based Inspection (RBI) and the SAP system were given 65%, Checklist Inspections were given 13%, and Training was given 9%. The SAP system set up a register. The daily logbook is also used to keep the refinery components under control.

Figure 6.3: Control methods on refinery components



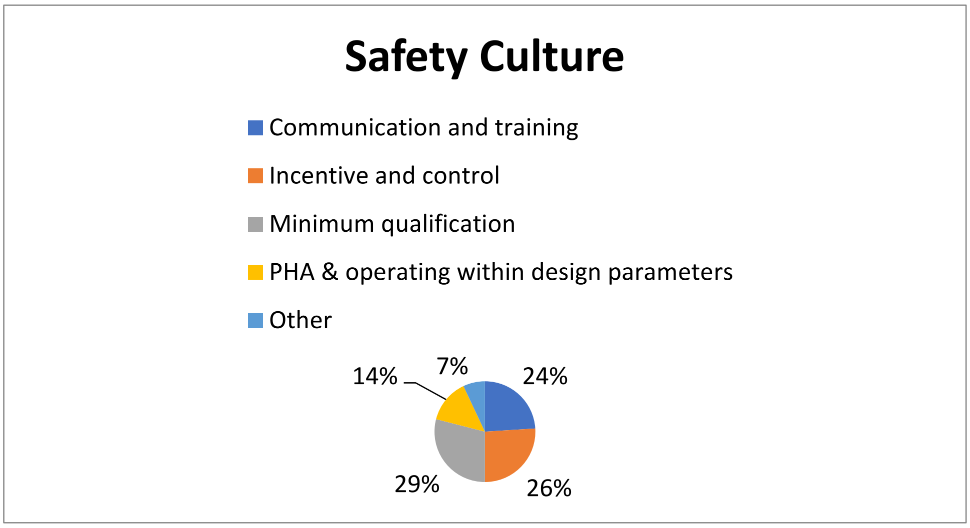
The following pie chart reflects the outcomes of the change-over questions. Compared to other issues, 27% of the responses reflect an accurate report on conditions in the previous shift, 22% felt that breaks should be staggered, and flexible times should be employed, 17% felt that 30-to-45-minute breaks are required and should be overlapped to the oncoming shift where necessary, and 12% felt that the oncoming shift should know what to look out for during the shift. The statuses of critical activities, breakdowns and defects ought to be identified during the closing shift. The two shifts should overlap to facilitate the proper transfer of the events of the previous work environment. Also noted is the fact that 39% of participants felt that the breaks should be staggered, flexible or 30 to 45 minutes long.

Figure 6.4: Change-over



The full picture of the closed-ended question responses to safety culture is reflected in Figure 6.5 below. It is observed that 79% is shared by three issues. The participants feel strongly about minimum qualifications. The issue of minimum qualifications is the biggest issue on safety culture at 29%. The minimum qualifications issue is followed by incentives and control at 26%. The elements that were most mentioned, on incentives and control, are recognition of good behaviour (by reward or appreciation), leading by example, and consequences against unwanted behaviour towards others. Communication and training are at 24%. Communication and training include issues like awareness sessions on official safety culture, clear policies and procedures, and proper formal training on safety culture. If clear policies and procedures are known by employees, this could foster compliance. Conducting regular process hazard analysis and always operating the plant within design parameters is the fourth biggest issue at 14% and is, in my view, one of the most important elements. Also noted was a mechanism to generate a strong identification between the operator and his/her machine. This could enhance the issue of regular process hazard analysis's (PHA), operating machines within their designed capacities, and could ultimately prolong the life of the machines under their jurisdiction.

Figure 6.5: Safety Culture



6.2 Research constraints and assumptions

The research plan includes visits to the refinery for visual inspection of the conditions on the ground, and conducting observations of equipment in operation and, the interaction between people and machinery. The plan will include meetings, information sessions, analysing the incident investigations, completing questionnaires, and work observation in the complete audit. The researcher does not have full access to the refinery. The researcher will use what is made available by management and refinery employees. The research is the study of existing theory, not the generation of a new model or theory.

The acceptable safety culture in refinery industries is viewed to be similar. Equipment deformation is analysed linearly. It is assumed that fire incidents emanate from changing conditions of refinery media and equipment. The location refinery infrastructure takes the pattern suggested by Lev-on et al., (2014) that model refineries with a capacity of 250,000 barrels per day will typically have 50,000 valves, 150,000 flanges and 1000 pumps. The valves-to-flanges-to-pumps component ratios of the refineries under study are assumed to be similar to that model refinery mentioned by Lev-on et al. (2014). Most of South Africa's refinery equipment was manufactured in America using American standards. Refinery stakeholders want to eliminate refinery incidents of fire.

6.3 Considering literature

The process units at Refinery in Southern Africa (RSA) are 45. From the interpolation from the work of Ranade et al. (2011) typically, Refinery RSA must have 1350 operators and 450 maintenance technicians. The actual workforce including management at RSA is 800.

RSA's capacity is 45000 barrels per day. If we were to make a reference point of the model refinery mentioned, it would be possible to calculate any refinery component count ratio (valves-to-flange-to-pumps). For example, if we were to assess the component count ratio of a refinery with the capacity of 45,000 barrels per day, using the model refinery of Lev-on et al., as a reference point, the calculation would result in the following:

$$\frac{model\ refinery\ capacity}{model\ refinery\ valves} \equiv \frac{new\ refinery\ capacity}{number\ of\ valves} \therefore v_n = \frac{(45000 \times 50000)}{250000}$$

$$= 9000 = \text{valves}$$

$$\frac{model\ refinery\ capacity}{model\ refinery\ flanges} \equiv \frac{new\ refinery\ capacity}{number\ of\ flanges} \therefore f_n = \frac{(45000 \times 150000)}{250000}$$

$$= 27000 = flanges$$

$$\frac{model\ refinery\ capacity}{model\ refinery\ pump} \equiv \frac{new\ refinery\ capacity}{number\ of\ pumps} \therefore p_n = \frac{(45000 \times 1000)}{250000} = 180$$

$$= \text{ pumps}$$

Interpolating from Lev-on et al. (2014) method to estimate required valves, flanges and pumps the following is calculated:

$$(valves: flanges: pumps) = (9000: 27000: 180)$$

Estimating the quantity and location of the components could be one of the methods to facilitate the pro-active prevention of leaks. The possible location of future leaks could be anticipated fairly accurately. Engineering leaders in RSA refinery do not know with certainty the number of valves, flanges and pumps employed in their refinery.

6.4 Results and discussion

"The sharpest decline in fatal injuries occurred between 2007 and 2009, a period that coincided with economic recession" (Wilbanks, 2013). It has been observed that not following procedures could result in a fire incident. These were the findings in different fire and leak incidents. The actual safety procedures that were not followed and the competence of the personnel qualified to follow the procedures safely were not analysed. Noted was the fact that fire incidents increased between 2006 and 2012. It was observed that the incidents peaked in 2010 with nine fires and one explosion. No direct causality could be connected to the hosting of the 2010 World Cup in South Africa. During the FIFA World Cup, there was an increase of people, thus demand for transportation between soccer venues, therefore, a heightened demand for energy which includes refinery products. The sudden increase in demand creates bottlenecks which could lead to an increase in incidents. In 2010, there were ten incidents. In 2011, there were five incidents, a 50% decrease in fire incidents. It is clear that more effort must be put into making sure that safety procedures are followed correctly and consistently.

The questionnaire has exposed several components. The regression equation, derived from the responses to open-ended questions, proved to have a significant overall fit. In this equation, fire (F) is equated to the corresponding failures. In this case, the corresponding good expectation will have an opposite sign to failure and will thus, ultimately reduce the incidents of fire. If, for example, the design and maintenance are improved by approximately 10 units, while holding safety culture and change-over constant, it will result in the following:

$$F = 6 + 0.407(-10) + 0.556(0) + 0.593(0) + \epsilon_i.$$

$$F = 6 - 4.07 + \epsilon_i = 2.07 + \epsilon_i$$

The residual e_i was calculated to be zero. Note that the error term is a theoretical concept that can never be observed, but the residual is a real-world value that is calculated for each observation. The residual value can be thought of as an estimate of the error term, and e_i could have been denoted as $\hat{\epsilon}$ (Studenmund, 2006). There will be two fire (F) incidents if the error term is equal to -0.07.

A fire incident takes place because of one or a combination of failures. In "dealing with uncontrolled fires" all possible failures have to be identified in order to deal with them promptly. This study has considered DM to be the design and maintenance failures, CO to be the change-over failures, and SC to be the safety culture failures. South Africa has been characterised by an adversarial relationship between employers and employees. This historical relationship could have a negative impact on current safety culture policies. The observation of ‘them’ and ‘us’ positions from the literature review indicates that the workforce is not united.

6.5 Conclusion

The regression equation from the data collected and processed was proved to have a significant overall fit. Components highly likely to be affected are infrastructure and consumables. Primary causes of leaks include corrosion, wear-and-tear, consumables failure, incorrect operating methods, and substandard workmanship. Control methods utilised on refinery components are risk-based inspections and the SAP system, checklist, and training. Changeover of shifts includes accurate reports from the previous shift, staggering and flexible time, 30 to 45 minutes breaks, and the next shift expectations. Safety culture (employees) includes minimum qualifications, incentives and control, communication and training, and process hazard analysis (PHA), and operating within design parameters. The method to calculate the quality of valves-to-flanges-to-pumps for the refinery was discussed. If some or all of the ratios are incorrect this could lead to the overloading of some or all of those components. Operators and maintenance technicians could be overworked if the number is incorrect. The sudden increase in demand creates a bottleneck and could lead to an increase in incidents as it did during the hosting of the 2010 Soccer World Cup. Any improvement in the design and maintenance of equipment appears to reduce the incidents. The employer-employee adversarial relationship was briefly discussed.

CHAPTER 7
CONCLUSION AND RECOMMENDATIONS

The study wants to identify with certainty the causes of uncontrolled incidents at refineries in order to develop mechanisms that will avoid such incidents. The study is to develop effective strategies to deal with causes of fire incidents; establish a system that enforces the correct and consistent implementation of current safety systems; communicate with and train employees to deal with all dangers they are exposed to; eliminate all shortcuts to critical (dangerous) jobs; self-adjusting safety components and ensure that early warning devices are continuously monitored; cultivate a safe-proof plan for wear and tear of plant and machinery; and require all components, which should they fail and lead to a major disaster, incorporate a fail to safe mechanism. This chapter deals with the conclusion and recommendations.

7.1 Conclusion

There is no evidence that suggests that sound policies by RSA are properly implemented and enforced. Whatever the RSA has been doing to deal with persistent incidents, is failing to yield positive results. The plant is more than 30 years old and the RSA was commissioned before 2004. Some of the refinery components are designed to have a life span of 20 years. The total number of valves, flanges and pumps could not be pronounced with certainty. Most leaks and fires emanate from such equipment. Proper safety management is not possible without the proper knowledge of all equipment. The refinery, with the capacity of 45000 barrels per day, must have 9000 valves, 27000 flanges and 180 pumps or close to such ratios. RSA has 45 process units and less than 1000 total employees during the time of the study. With 45 process units, RSA must have 1350 operators and 450 maintenance technicians or thereabout. RSA makes use of subcontractors, including for maintenance of refinery equipment. With subcontracting, RSA is not in total control of activities.

Design and maintenance mainly consist of infrastructure and consumables. Infrastructure includes tanks, pipes, pumps, heat exchangers, valves, motors, couplings, shafts, bearings, and separators. Consumables include all kinds of gaskets, glands, packing, insulating material, and lubricants. Most incidents have been encountered in areas where there are high temperatures and high pressures. The equipment is old, and some of the causes of incidents include corrosion (internal and external), substandard workmanship, incorrect operating methods, incorrect consumable material, and consumable material failure. Any change in design and maintenance, safety culture and change-over will affect the increase or decrease of fire incidents. External forces, such as demand, are highly likely to affect the internal operations of a refinery.

Different departments have different understandings of safety culture, and some employees have never seen any clear policy on safety culture. Interest, enthusiasm, and increased eagerness need to be regenerated in some employees. Departments are advised to communicate matters of safety culture in a brief and concise manner, with a suggestion of variance so that interest may be generated and maintained. Safety culture is mandatory in that it is a legal requirement. The employees are charged to refuse unsafe instructions. Safety is the right thing to do. The omission of doing the right thing at the workplace could lead to criminal charges of negligence. No clear reward or reprisal system for complying or not complying with the work safety culture was observed. Safety culture should be viewed as a qualifying element for appraising, recognising, and rewarding a desired behaviour. The qualifying elements of any job, in this researcher's view, include being interested in the job, valuing the job, understanding the hazards and risks associated with the job, and being able to deal with those hazards or risks associated with the job. The proactive integration of safety is to incorporate safety into organisational culture, as well as material and immaterial characteristics of the organisation.

The issue of minimum qualifications is important in building acceptable levels of competency and ability in order for employees to understand the concept of work safety culture. Concerning operating equipment within design parameters, perception that machinery is not always operated within the design parameters. Furthermore, as the equipment ages, several components would get devalued to low operating parameters. Machinery, processes, and people interact to produce a product during input, processing, and output. Both machinery and processes are controlled by people. The refineries are highly complex and tightly coupled organisations. Lev-on' s formula could be used for asset identification and resource allocation.

Change-over issues include the employees in the current shift collecting and recording all the significant data, unusual conditions, and extreme conditions. Current shifts must provide enough time to transfer that information both orally and in writing. Participants felt that transferring information during the overlapping of shifts should take at least 30 to 45 minutes. When the employee for the next shift does not arrive, a new risk develops. This study assumes that the management will always have a correct strategy to deal with the 'no show' phenomena. Staggered and/or flexible breaks were suggested to eliminate, control, or minimise the risk to non-significant levels. The employees in the oncoming shift should make themselves available to receive information from the previous shift. During their shift, they should record or log the information they received and record any other developing conditions. The number of operators and maintenance technicians employed suggest that related literature is not considered. Most of those incidents happen around valves, flanges, and pumps. RSA does not know how many of those components are in service or commissioned for service; furthermore, literature is available around this question.

The equipment life cycle, suitability, and failure patterns should be noted. Machinery components, particularly as they approach the end of their life cycles, should be frequently monitored. Employees should be encouraged to keep historical records, and to regularly update the capacity of the equipment. The suitability of materials that form part of refinery components should be determined and tested for resistance to overall corrosion; corrosive cracking; hydrogen-sulphide embrittlement; point-pitting; and crevice, intercrystallite and structural strength at a given temperature (Kachanov et al., 2010). Establish the maximum corrosion rate of components in 0.1mm/year for each component. Take note of the extreme conditions regarding refinery media, the lowest and highest temperatures, maximum pressure, and flow rate or velocity of flow in pipes. The new Quality Management Systems, comprised of components like the Learning Organisation, Continuous Process Improvement and Motivation, appear to diminish 'them' and 'us' positions. The literature review has also suggested that safety performance has to be one of the central goals of the organisation. Thus, productivity and safety culture will be working in the same direction; they cannot be separated. Mechanisms must be in place for employees to know, understand, adopt, and practise the work safety culture in such a way that it would be morally wrong not to comply with the workplace safety culture.

7.2 Recommendations

It is recommended that:

1. ***Infrastructure, Equipment, and Materials***

- ❖ Establish the exact number of valves, flanges, and pumps.
- ❖ Mechanisms to ensure that equipment cannot be operated beyond its capacity must be installed.
- ❖ Make sure correct materials used and maintenance of equipment is not overdue.
- ❖ Special measures must be taken on old equipment (those that are approaching the end of their projected lifespan or have passed it), and equipment should be re-rated where possible.
- ❖ Equipment should, therefore, be operated at safe, reviewed pressures and temperatures below their design capacity where possible.
- ❖ Surge tanks or silos to control feed to processes required.

- All equipment which could lead to disaster if they fail must be incorporated with a fail-safe mechanism.
- All safety self-adjusting components, and early warning devices are continuously monitored.
- All safety components must be automatic.

2. ***Personnel and Work Processes***

- Establish and implement correct ratios of operators and maintenance technicians to process unit.
- Safe procedures must be derived from a significant hazard identified.
- Hazards should be identified and, if there is a reasonable justification, the operation must be stopped where there is a possibility of any development that might constitute a significant danger, and thus communicated to the immediate supervisor at the earliest convenience.
- Equipment should, therefore, be operated at safe, reviewed pressures and temperatures below their design capacity where possible.
- Periodic measurement, inspection and over-inspection is conducted on all equipment.
- The current dimensions, the remaining lifespan of each component of equipment, and the corresponding changes in equipment capacity should be recorded.
- All equipment should be monitored with periodic tests, and equipment should be examined and measured.
- It is an offence to interfere with safety systems.

- ❖ All abnormal conditions are investigated and recorded, and the communication of all necessary changes is recommended.
- ❖ The management of changeovers should be improved such that responsibilities are shared equally.

3. ***Safety Culture***

- ❖ Communication programmes to communicate safety culture and its significance are to be effectively improved.
- ❖ Mechanisms to improve the free flow of information should be established.
- ❖ Safety achievements should be communicated and celebrated, recognise, and reward those instrumental to such achievements.
- ❖ Develop and enforce a safe work culture. Further study areas that still need to be undertaken should be identified.
- ❖ Learning knowledge-sharing and good behaviour is recognised and duly rewarded where possible.
- ❖ Detailed reporting should be encouraged, and continuous corresponding feedback should be conducted, with given reasons when feedback might not be possible.
- ❖ . Programmes are run where employees compete in drawing up effective safe operational plans relevant to their operation and in compliance with the company's safety culture.

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List of Annexures

Appendix A: Copy of the Questionnaire

June 2015

Dear Sir/Madam

RE: Design and Maintenance, Change-over, and Training Questionnaire

The research is an MTech module at the Department of Mechanical Engineering at the Cape Peninsula University of Technology (CPUT). The module is completed by producing sound conclusions and recommendations. This requires the collection of data on design and maintenance of the infrastructure in operations (DM), change-over during operations (CO), and the level of training of the workforce in operations (TW).

DM, CO, and TW are important components of a Quality Management System at a refinery; therefore, they must be assessed honestly and accurately to build an effective system. Data will be collected from the willing participants (refinery employees) in the form of answers to the questionnaire. The questionnaire is divided into three sections as shown below:

Part one consists of closed-ended questions, where participants can choose the appropriate answer with a “tick”. Part Two, however, consists of closed-ended questions, where participants are requested to rate their opinions by making a cross in the appropriate box, with the level of agreement in each of the questions, indicating whether they strongly agree, agree, are uncertain, disagree or strongly disagree. Part Three contains open-ended questions. This section provides an opportunity for the participants to give brief answers, which will be recorded.

There are no “correct” or “incorrect” answers. All the answers are based on actual individual and company information.

Thank you very much for your cooperation. Your participation in this research project is highly appreciated.

Yours sincerely,

Mlungisi Buti
mlungisib@gmail.com

PART 1: Individual and company information

Gender

Male	
Female	

1.1. Position held in the organisation

Administration staff	
Team leader/Supervisor	
Shop floor employee	
Other (Please indicate)	

1.2. Number of years of experience

Less than 2 years	
2-5 years	
5-10 years	
More than 10 years	

Your highest qualification

1. School	
1.1. Primary school	
1.2. Secondary school	
2. College Certificate	
3. University Degree	
3.1. National diploma	
3.2. Bachelors	
3.3. Masters	
3.4. Doctorate	
4. Other (Please indicate)	

PART 2: Closed-ended questions.

Decision options	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
Code	**1**	**2**	**3**	**4**	**5**

	Decision options				
	1	**2**	**3**	**4**	**5**
1. Pipes, valves, flanges, pumps and heat exchangers are some of the refinery components that could leak.					
2. Operating life is stipulated at 20 years for heat exchangers, 5 years for carbon-steel tube banks, and 10 years for stainless steel tube banks.					
3. Maximum corrosion for refinery equipment has been stipulated at $0.1mm / year$.					
4. Maximum content in the construction steel of refinery equipment should be 0.2% for carbon, 1.3% for manganese, 0.01% for phosphorus, 0.005% for sulphur, 0.4% for silicon, 0.4% for nickel, 0.3% for chromium, 0.4% for copper, 0.12% for molybdenum, and 0.015% for vanadium.					
5. Corrosion rate of molybdenum-containing steels was less than 0.05mm/year with uniform corrosion.					
6. Pipe repairs and other component replacements are always done on time.					
7. Leaks and fires are caused by recurring maintenance backlogs.					
8. Flanged connections, flexible connectors or rotary joints, and pump seals are identified as primary sources of leaks and fires.					
9. Pipe repairs and other component replacements are always done correctly.					

10. Management of change procedures is always implemented to ensure that changes do not introduce new hazards without control.					
11. All changes are recorded and monitored for knowledge monitoring.					
12. Gas leaks can be isolated by automatic remote control.					
13. All modified equipment approved to be changed should be of the same standard as the original design so that there are no unforeseen side effects.					
14. Mechanical integrity includes operation, plant and design integrity.					
15. The refinery has a safety device and a trip inter-lock bypass procedure in place and monitors bypass safety systems weekly.					
16. There is a system in place to prevent failure during shift hand-over and during operational breaks.					
17. Every 6 months, relief devices are visually inspected using checklists based on standards.					
18. At least 10% of all plant employees have completed a 15-day rotational training programme, which includes Management of Change (MOC), Mechanical Integrity, Asset Reliability, Process Hazard Analysis (PHA), and the Pre-start-up Safety Review (PSSR).					
19. Employees are involved in the creation of standard operating procedures.					
20. Any knowledge gained from internal/external incidents is shared with all employees.					

21. Every person receives a safety induction before entering the refinery complex.					
22. Employees complete a mandatory 5-day training course that consists of various modules that include Process Safety Management (PSM), incident reporting and investigation, toxic gas awareness, work permits, and hazardous area classification.					
23. Specialised, job-specific and personal development training is conducted throughout the year on each employee by the refinery.					
24. The organisation's culture is helpful in achieving safety goals.					
25. The unity of purpose exists between production and maintenance, and management is mostly in agreement with employees.					
26. Safety is achieved by strict control instead of motivation and interesting tasks.					
27. Organisational culture delays quick responses to enhance safety.					
28. Inspection and maintenance have no capacity to cover all problematic equipment in time.					
29. Planning schedules do not cover all the equipment in the refinery.					

PART 3: Open-ended questions (Please briefly answer the following questions)

1. Which component is highly likely to have leaks in the refinery?

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2. What is the primary cause of such leaks?

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3. Which method can be used to keep track of all refinery components?

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4. What critical information is to be shared at the shift change-over?

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5. How much time is required for the shift change-over?

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6. How can incidents be eliminated during operational breaks, like tea or lunch-time?

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7. What is the difference between the desired safety culture and the actual safety culture?

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8. How can the gap between the desired safety culture and the actual safety culture be closed?

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9. What is the acceptable level of competency for refinery employees?

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10. What can be done to keep refinery media and infrastructure under control?

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Appendix B

ACCIDENT INVESTIGATION REPORT

EMPLOYER		**DATE OF ACCIDENT**	
DEPARTMENT ACCIDENT NO.		**ACCIDENT NO.**	

REFERENCE NUMBER	
LOCATION OF ACCIDENT	
PERSON IN CONTROL	
INJURED	
ITEM INFLICTING INJURY	

DESCRIPTION OF HOW THE ACCIDENT OCCURRED

CONDITION RELATED TO THE ACCIDENT

HIRA	SCORING
Specific Hazard Identified	
Specific Risk Assessed	
Specific Risk Quantified	
Specific Risk Eliminated	
Specific Risk Controlled	

PROCEDURES	SCORING
Drawn from specific hazard identified	
Clear, simple, and to the point	
Complies with all the requirements of law	
Not introduce new hazards	
Open for reviews	

TRAINING	SCORING
Training modules correspond to specific hazard identified	
Training completed successfully	
Training register updated fully	
HIRA training	
Competency level	

EQUIPMENT	SCORING
Service record	
Legal compliance	
Compliance with COP's	
Over utilisation	
Ergonomics	

CONTROL	SCORING
Supervision	
Planed task observation	
Inspections and over-inspection	
Open to remedial action	
Reprimand and reward	

ACCIDENT CLASSIFICATION

Accident	Mining 01	Machinery 02	TMM 03	General 04