

A critical evaluation of process safety management in the petrochemical industry in South Africa

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Graduation: April 2024

DECLARATION

I declare that the dissertation titled:

**A critical evaluation of process safety management in the petrochemical industry in
South Africa**

is my own work and that I have acknowledged all the sources used or quoted using complete referencing and in-text citation. In addition, I declare that I have not submitted this dissertation at another institution before for degree purposes.

DEDICATION

To ReINETTE Blake, my anchor in the storm and my unwavering source of support, this MBA is as much yours as it is mine. Your belief in my potential has been the driving force behind this achievement, and I dedicate this degree to you with profound gratitude. Here's to the shared triumphs and countless tomorrows we'll face together.

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'I can do all things through Christ who strengthens me.'

His unwavering support and guidance have been instrumental to every step of this journey.

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ABSTRACT

This study investigates the critical connection between safety, environmental responsibility, and economic development in South Africa's petrochemical sector. Businesses aim to comply with environmental rules to cut costs, save time, and promote a safe work environment in response to global competition and increased awareness of environmental issues. The global recognition of the relevance of risk reduction has led to businesses developing innovative ways to improve safety. Some have been linked to improved company performance and heightened confidence among shareholders. The petrochemical business has advanced significantly as technology changed the workplace, bringing new opportunities and risks. Yet accidents continue to occur despite global advancements in risk and safety management. This calls for an improved approach to safety in dangerous workplaces. The research highlights the importance of a safety management system (SMS) in improving working conditions and influencing employee behaviour and attitude towards safety, while also acknowledging the need for safer plant operations to fulfil market demands.

A strong SMS can mitigate the new risks brought about by plant automation and can promote occupational health and safety. To solve the issues that arise from new developments, the research proposes an inherent safety engineering design process that prioritises knowledge enhancement, design efficiency, and the avoidance of mistakes and omissions. The petrochemical industry requires close attention to safety because it is inherently dangerous due to chemical reactions, hazardous ingredients, and explosives. The study highlights the effectiveness of process SMSs in allocating resources and improving overall safety conditions. It promotes a positive safety climate and management system within the petrochemical industry.

The study examines Hazard and Operability Study (HAZOP) reports from petrochemical facilities to gain insights into safety engineering design. One complete approach emphasised is the intrinsic safety approach, which seeks to eliminate or limit risks during the design phase. The report emphasises the necessity of critical examination and ongoing improvement in safety systems within the petrochemical industry, acknowledging that design defects play a crucial role in accidents and incidents. The research is expected to contribute to the engineering field by allowing companies to improve their safety measures and learn from past failures, ultimately leading to a safer and more secure petrochemical industry in South Africa.

Keywords: process safety management, petrochemical industry in South Africa, safety systems, human error, PSM models, OSHA elements, HAZOP, petroleum industry, oil and

gas, energy sector, management of change, incident investigation and Occupational Health and Safety Act, 1993.

LIST OF ABBREVIATIONS

AIChE	American Institute of Chemical Engineers
BPR	Business process reengineering
CAAA	Clean Air Act Amendments
CAPEX	Capital expenditures
CCPS	Centre for Chemical Process Safety
DTI	Department of Trade and Industry
EI	Energy Institute
EPA	Environmental Protection Agency
E&P	Exploration and production
GDP	Gross domestic product
HAZOP	Hazard and Operability Study
HRSG	Heat recovery steam generator
HSE	Health and safety executive
ILO	International Labour Organization
IOGP	International Association of Oil & Gas Producers
LPG	Liquefied petroleum gas
MOC	Management of change
NFPA	National Fire Protection Association
NWU	North-West University
OGP	Oil & gas producers
OSH	Occupational safety and health

OSHA	Occupational Safety and Health Administration
POPI	Protection of Personal Information Act
PPE	Personal protective equipment
PSM	Process safety management
SAPIA	South Africa Petroleum Industry Association
SMS	Safety management system
TQM	Total quality management
TR	Training

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CHAPTER 1: SCOPE AND NATURE OF THE STUDY

1.1 Background and overview of the chapter

The petrochemical industry is essential to any country's economic development. Due to increased awareness of environmental issues and climate change, businesses now abide by environmental laws to compete globally, aiming to reduce cost, save time, and create a safe work environment (Cohen *et al.*, 2020:122). This awareness is the primary force that has created the drive to ensure that the levels of risk decrease (Knegtering & Pasman, 2009:164). Organisations worldwide are developing unique techniques to improve safety because superior safety performance results in favourable business performance and higher shareholder confidence, which may in turn raise investment or increase the organisation's share price (Rhaffora *et al.*, 2019:12). According to Thomas *et al.* (2014:22), the development, testing, and use of practical methodologies, tools, and models to understand and manage adverse events gave rise to safety as a distinct discipline.

The most effective approach to allocating funds for safety is to put in place a SMS. It enhances not only working conditions but also improves employees' attitudes about safety. This leads to better conduct and a safer environment. Petrochemical plants are high-energy, high-risk facilities that hold potential fire, explosion, and poisoning threats. They should therefore offer safe plant operations to meet market demands. A safety design method guarantees safety throughout the design phase, ensuring safety during plant operation. As with other global markets, the petrochemical industry has experienced significant technological advancements and intense competition, leading to a transformation of the workplace as it is traditionally known (ILO, 2010:1). Occupational health and safety (OHS) has changed, and in some cases, plant automation has decreased risks but also created new risks that should be addressed by using a SMS (ILO, 2010:1). Despite the significant improvements in risk and safety management in hazardous workplace environments around the world, particularly in the chemical industry, accidents, injuries, and fatalities still disturb society and the business scene (Venkataraman, 2006:63).

This study examines the contents of numerous Hazard and Operability Study (HAZOP) analysis reports for hydrogenation units from a petrochemical plant to meet the study's objective of proposing an intrinsic safety engineering design technique. This new design methodology resolves several issues with the current HAZOP analysis with regard to design, construction, and empirical knowledge. In addition to the conventional approach, a database is created and maintained to direct safety engineering design and achieve the plant's intrinsic safety. The petrochemical plant's inherent safety design uses technical solutions to reduce or eliminate hazards and prevent mishaps by minimising harm and monetary loss. To avoid omissions and

errors, the application of this method makes up for the lack of analysis and design knowledge while improving design efficiency.

1.2 Background to the study

Over the years, various methodologies have been used to assess process plant safety design. Early in the 1980s, a paradigm change brought about by the recognition of industrial installations as complex systems led to a focus on systems thinking theory as the best solution to safety design (Thomas *et al.*, 2014:22). The procedures that follow this direction depend on risk analysis methodologies and SMSs. However, they typically call for significant plant resources. The petrochemical sector is a hazardous industry because it involves chemical reactions, dangerous materials, flammable explosions, and any other risks that could harm company employees or contractors while performing their duties. Large volumes of hazardous chemicals are frequently handled under extremely high temperatures and pressures in petrochemical and petroleum refinery operations. Any mistake can lead to tragedy, resulting in severe financial losses and casualties (Vadimovna *et al.*, 2017:5466). The management section of such a company manages activities centred on the health, safety, and the well-being of their employees. Planning for a safety system first involves an analysis of the risk and the determination of the appropriate course of action to protect the workers from harm.

The importance of SMSs as the most practical and efficient way to allocate safety resources has been highlighted in recent research by Yoo *et al.* (2023), Zang *et al.* (2023), Chen *et al.* (2023) and Emtaubel *et al.* (2023). The work conditions of employees are greatly enhanced by SMS, and it promotes a culture of safety that rewards responsible attitudes and behaviours. These kinds of cultural changes are essential to improving an organisation's general safety atmosphere, especially in the petrochemical sector. The effectiveness of process safety management (PSM) systems in reducing industrial accidents in South Korea was highlighted in a 2023 study published in the *Processes* journal (Yoo *et al.*, 2023). The study noted that SMEs with fewer than 100 employees are particularly vulnerable. This research emphasises how urgently improved PSM systems and management techniques are needed to stop industrial mishaps (Yoo *et al.*, 2023). Another example of how digital technologies are being integrated to support safety protocols is the creation of a permit-to-work management system for petrochemical construction safety based on the POP model. These practices align with a broader industry trend that emphasises continuous development as a means of fostering a safety culture.

To minimise damage and losses, the petrochemical plant's intrinsic safety design requires the use of technology to reduce or eliminate risks and prevent accidents. This goal is accomplished by summarising the contents of various sets of the hydrogenation unit's HAZOP analysis reports

from the petrochemical plant. A design that eliminates risks rather than managing them by lowering the number of hazardous materials and the number of risky processes in a chemical plant, is safer (Hendershot, 2010:391). Methods should not be centred on determining how safe a suggested design is. Instead, they should emphasise the creation of a more secure plant. Both internal (inherent) and external methods can be used to ensure the safety of a chemical process. Intrinsic safety methods aim to eliminate or minimise risks rather than regulate them with additional safety measures.

Accident assessments show that design has a substantial role in various engineering fields, such as infrastructure, aircraft, railroads, and nuclear industries (Lopez *et al.*, 2010:405). Lopez *et al.* (2010:405) indicate that mistakes made during the design stage are to blame for 50 to 90 per cent of accidents and incidents. In the 1970s, designers did not accept the term 'design error' (Netessine *et al.*, 2007:117). Now that design quality control and design review are widely acknowledged and included in a design project, the situation has changed. However, many design firms are still reluctant to admit their mistakes for legal or reputational reasons. Even when designers do their best, there are still many design flaws that should be rectified. A critical evaluation of PSM in the petrochemical industry in South Africa can contribute to the study field of engineering, where there are more opportunities for companies to learn from previous mistakes and improve their safety systems.

1.3 Discussion of terms

The sections below outline the terminology and definitions used in the critical evaluation of PSM in the petrochemical industry in South Africa.

1.3.1 Safety systems

Vinodkumar *et al.* (2011) describe safety systems as: "the policies, strategies, procedures, and activities implemented or followed by the management of an organisation targeting the safety of their employees". Some definitions are quite formally descriptive, such as "an organisation's formal arrangement, through the provision of rules, resources, and processes, to assure the safety of its work activity." (Wold *et al.*, 2015:3). There is also a more general definition of safety systems as "a manifestation of the organisation`s safety culture" (Fernández-Muñiz *et al.*, 2007). Santos *et al.* (2013:29) define an occupational health and safety management system as "a set of tools that enhance safety risk management efficiency related to all the organisation`s work activities".

From these multiple definitions, the researcher can conclude that SMSs are IT-based superstructures that contain instructions, descriptions, and checklists for the legal requirements,

safety standards, and corporate values. They are socio-technical systems that assist the organisation in knowledge production, storage, and retrieval.

1.3.2 Safety management systems

An SMS, according to Santos-Reyes (2009:958), is aimed at keeping the risk of the operations of a company within an acceptable range. This includes managing the risk of a company effectively (Koursi *et al.*, 2007). Another goal of SMSs, as stressed by several studies, is to assist the firm in meeting regulatory obligations (Wold *et al.*, 2015:3). According to Antonsen (2009:9), the greater attention paid to the organisational circumstances for safety in the 1980s, led to an increase in interest in SMSs. It was crucial to acknowledge that human error or failure is the primary cause of accidents. Therefore, developing management systems that specify objectives, distribute responsibility, plan, organise, and manage adherence to safety precautions is the best method to reduce the possibility of human mistakes and to make the organisation's work more safely (Antonsen, 2009:9). The vast majority of work processes are covered by the numerous procedures found in IT-based SMSs.

The analysis of accidents and other unintended situations, as well as already-known routines and statutory requirements issued by the authorities, are frequently used to build procedures (Wold *et al.*, 2015:4).

1.3.3 The petrochemical industry

Petrochemicals are products made from natural gas and crude oil. The primary raw materials used to create the majority of chemicals and petrochemicals are olefins (propylene, ethylene, and butadiene) and aromatics (toluene, benzene, and xylenes). These natural resources are used for synthetic dyes, rubbers, fibres, pharmaceutical drugs, packaging, surface detergents and industrial appliances (Rathi, 2003:585). The structure of the petrochemical industry is illustrated in Figure 1 below.

[Overview of the Petrochemical and Chemical Industry]

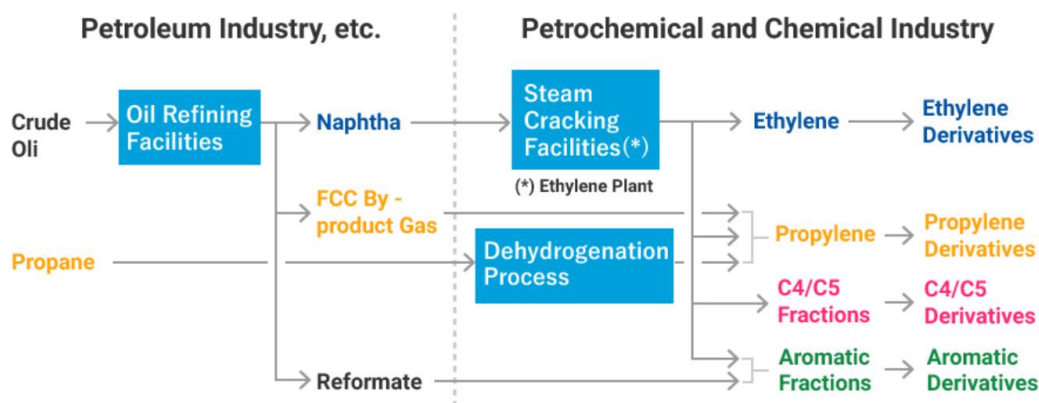


Figure 1: Overview of the petrochemical industry (Chiyoda Corporation, 2023)

The Portfolio Committee on Mineral Resources and Energy of Parliament was of the opinion that the government should consider constructing a "mega" fuel refinery in South Africa to secure the nation's energy supplies. The oil firms BP and Shell declared they would halt operations in Durban by the end of March 2022 in order to find a buyer. SAPREF is the largest refinery in South Africa that uses oil and gas. It produces 2.7 billion litres of gasoline annually, with 35% of the nation's crude oil refining capacity (Anon, 2022). These petrochemical plants make it important to critically evaluate the PSM in the petrochemical industry of South Africa.

1.4 Problem statement

Petrochemical industries play a crucial role in national economic growth by supplying raw materials for other sectors and final consumer goods. Today, petrochemical products touch almost every aspect of our lives, such as housing, transportation, and food (Saisandhiya *et al.*, 2020:778). Petrochemical operations are intrinsically hazardous because the chemical transformations during processing are either exothermic or endothermic reactions. The safe operation of processing plants depends entirely on an understanding of the risk associated with the chemical. A large number of highly toxic materials are used and handled in industries such as chemicals, petrochemicals, petroleum refineries, fertilisers, pesticides and distilleries where flammable and explosive materials are manufactured, stored, and held in large quantities. These create a hazard for the workers and the surrounding communities (Uehara, 2006:89). Organisations aim to achieve a "zero harm" by implementing various safety precautions to reach these objectives. The three main factors contributing to the process of investigating safety precautions are (Reada-Consulting, 2014):

- Team and individual action

- Environmental conditions and different tasks
- Factors within the organisation

Using the factors mentioned above, the study focuses on critically evaluating PSM in the petrochemical industry of South Africa. This study aims to contribute to the safety of individuals and teams during the normal operation and maintenance of equipment. This is not limited to the petrochemical company's employees but extends to the contractors performing work during maintenance (shutdown) periods. The goal is "zero harm" for all employees working in the petrochemical industry. Part of the prevention is to ensure that maintenance plans are in place to protect equipment from failure and injuries to employees.

The petrochemical industry has had many injuries and fatal accidents that could have been prevented if employees had adhered to safety precautions. A report published by the Chemical Association of South Africa in 2015 shows that ten deaths were recorded by signatory organisations in South Africa (CAIA, 2015). Petroleum companies have to provide health care programmes for their employees. Exposure to petrochemicals has been linked to higher cancer and respiratory disorder risks. Chemical-resistant gloves, overalls, eye protection and respiratory supports should be provided as appropriate personal protective equipment (PPE). The appropriate PPE would depend on the employee's role and the application (Anon, 2019).

Critically evaluating PSM in the petrochemical industry of South Africa can decrease the risks on site and ensure that employees will have a safe working environment, providing the managers with a framework to follow during HAZOPS.

1.5 Research objectives

1.5.1 Primary and secondary objectives

- The primary objective of this study is to critically evaluate the PSM in the petrochemical industry of South Africa.

The secondary objectives are:

- To create an understanding of the PSM in the petrochemical industry in South Africa;
- To determine the PSM elements that significantly contributed to the occurrence of adverse process safety incidents in the petrochemical industry in South Africa; and
- To identify the PSM failures that resulted in process safety incidents in the petrochemical industry in South Africa.

1.5.2 Primary research question

What are the factors that affect PSM in the petrochemical industry of South Africa?

1.6 Scope of the study

The research environment is a part-time, two-year operations management programme at the North-West University, a business school in South Africa. The recommended techniques were used in the primary empirical investigation.

1.6.1 Field of study

Operations management is the focus of this study. Every organisation can distinguish between three functional areas: marketing, finance and operations (Wolniak, 2020:11, Pacana *et al.*, 2014:26). Knod and Schonberger (2000) illustrate these three components as in Figure 2 below:



Figure 2: Three basic functions of business organisation (Knod & Schonberger, 2000)

Each area has its function in the company:

Finance as a functional area includes budgeting, obtaining financial resources at reasonable prices, allocating those resources across the firm, analysing investment ideas and managing budgets throughout the financial year (Wolniak, 2020:11).

Marketing as a functional area is responsible for determining consumer demands and needs and marketing and selling the organisation's products or services. The primary goal is to sell and promote an organisation's products or services (Wolniak, 2020:11).

Operations as a functional area are responsible for creating the products or providing the services offered by the organisation (Wolniak, 2020:11).

Operations management can be broken down into the following (Galvin, 2009):

- Generating goods and services, which involves managing people, technology, resources, information, and other resources.
- Planning, coordinating, organising, and controlling all the resources required to produce a company's goods and services.
- The business function oversees the production of goods and services.

A critical evaluation of PSM in the petrochemical industry in South Africa forms part of operation management, where people, technology, resources, information, and other resources are managed to complete the manufacture of goods and services.

1.6.2 Sector under investigation

The sector under investigation in this study is the petrochemical industry in South Africa. This industry includes engineering companies that complete the design phase. They ensure that the design is code-compliant and safe to implement in the petrochemical industry. The other petrochemical industry sectors involve procurement, construction, safety, environmental, production, and maintenance.

1.6.3 Geographical demarcation

The geographical boundary for this study is the South African borders.

1.7 Research design and methods

1.7.1 Literature review

The literature review is a written argument that supports a mini-dissertation by building a case from credible evidence from previous research. This study critically evaluates PSM in the petrochemical industry in South Africa based on contemporary theory. The following steps should be taken to understand more about the research question and to answer the secondary research objectives:

- Defining the keywords
- Defining PSM
- PSM focus areas
- PSM models

- OSHA elements
- HAZOP
- Management of change
- Incident investigation
- Previous case studies

This study used document analysis to generate and select data. Electronic data, legislation, policies, articles and minutes of meetings were used for the document analysis. Because the study focuses on the safety systems and management in the petrochemical industry in South Africa, it is essential to collect numerous data from various sources, such as:

- African Journals
- ERIC
- BASE
- JSTOR
- Google Scholar
- Microsoft Academic

Note on the time distribution of literature sources: The topic of safety management systems came into the limelight during the early 2000s, when this was first recognised as a management discipline in developed countries, and to a lesser extent in developing countries. The basic theory, including most research on the topic, stems from this period. Hence, most sources used for the literature study are from the period. Where possible, recent developments have been documented using more recent sources.

1.7.2 Empirical study

Research based on empirical observation and the monitoring of phenomena relies on what the researcher personally encountered (Fisher, 2020:172). This information can be compared to a hypothesis or theory, but the conclusions are still based on experience. Empirical research includes the following elements (Fisher, 2020:172):

- A research question that will help define the study's goals;

- A specific and well-planned research design that based on the research topic and looking for ways to address it while making the most use of available resources;
- The collection of source data, followed by analysis;
- A specific method of gathering and analysing the data;
- Limiting the data to a defined group, region, or time frame, known as sampling; and
- The capacity to replicate the study and validate the findings, also known as reliability.

The research approach, paradigm, methodological choice, research strategy, time horizon, sampling, collecting data, data analysis, and trustworthiness should be considered during an empirical study.

1.7.3 Research paradigm

Creswell (2014) suggests that the research paradigm guides the actions of the study. The philosophical world can be divided into four dimensions known as ontology, epistemology, methodology and axiology (Creswell, 2014). Thomas Kuhn used the term “*paradeigma*”, which means pattern, for the first time in 1962 when he represented a conceptual framework for a community of scientists who wanted to study problems and discover solutions to these problems (Thomas, 2010). The fundamental driving force behind the development of qualitative research methodologies has been interpretivism, which has given rise to techniques that critically interpret reality with the available data. This study focuses on a critical evaluation of PSM in the petrochemical industry in South Africa, which involves autonomous elements like expectations for achievement, effort, and facilitating circumstances. As a result, information pertinent to the research problem was gathered using the interpretivism paradigm. This study applied an interpretivism research paradigm based on the idea that people express their thoughts, words, and behaviours because they are creative and purposeful while actively creating their social worlds. Additionally, it recognises that everyone has a complex, multi-layered reality that can be interpreted differently based on their interactions.

Theory was developed after the research had been completed, based on the data gathered during that procedure. As a result, information was obtained and examined using a grounded theory approach (Kivunja & Kuyini, 2017). Even though this research sought to tackle an issue at work where people have built up work experience through time, the interpretivist paradigm emphasises that knowledge should be developed based on the knowledge of those who work in the organisation. If the organisation exists independently of the beliefs of its social groups, that is what interpretivism demands (Bryman *et al.*, 2018:20).

1.7.4 Research approach

A research approach is a strategy to answer specific questions on social phenomena in the world with the aim of better understanding such phenomena (Croker, 2009: 22; Hancock *et al.*, 2001:141). Knowledge of the research paradigm, the literature study and the characteristic of qualitative research is essential as all these aspects contribute to the selection of the participants, the collection and analysis of the data and the ethical standards the study must meet. The three most popular research methods are quantitative, qualitative, and a mixed method. To test objective hypotheses, quantitative researchers concentrate on gathering numerical or quantified data to provide statistical evidence (White & Millar, 2014:55). Using linguistic information and meaning-based analysis, qualitative research techniques strive to give researchers a comprehension of people in diverse situations or contexts, in contrast to quantitative research techniques (Bengtsson, 2016). A balance of qualitative and quantitative research is used in the mixed-method approach. The differences between qualitative and quantitative research approaches, according to Bryman *et al.* (2018:51), is indicated in Table 1 below:

Table 1: The differences between qualitative and quantitative research (Bryman *et al.*, 2018:51)

Qualitative	Quantitative
Descriptions and words	Measurements and numbers
Viewpoint of the participants	Viewpoint of the researcher
Researcher is involved with subjects	The researcher is detached from subjects
Theory and concepts emerge from data	Testing theory and concepts
Flexible investigation	Structured data collection
Rich, deep, thick data	Hard, reliable data
Micro, small-scale explanations	Macro, large-scale patterns
Meaning of action	Behaviour of people

This study was conducted by means of content analysis, without the involvement of human participants. Given the nature of the research, which revolves around the examination of

documents and existing literature, qualitative research methods were adapted to explore the variations of PSM within the specified context. This approach is particularly suited for situations where (McCusker & Gunaydin, 2015:539):

- The research does not have the usual prerequisites of qualitative studies, such as direct participant engagement.
- An interpretivist paradigm is applied not to understand participants' experiences directly but to gain deeper insight into the challenges and dynamics of PSM through the analysis of textual data.
- The aim is to interpret the perspectives and contexts reflected in the documents, thereby providing a comprehensive understanding of PSM practices, challenges, and outcomes in the South African petrochemical sector.

This approach aligns the study's methodology with its objectives, focusing on the critical examination of PSM through document analysis.

Although specific hypotheses are put forward in the comprehensive qualitative analysis, as would be the case for grounded theory, the qualitative element of the current research study is primarily content analysis (Cho & Lee, 2014:5). In this study, the researcher used a research paradigm to guide the content analysis systematically, focusing on principles and assumptions about knowledge and reality pertinent to PSM within the South African petrochemical industry. This paradigm shaped the methodological choices, influencing the selection, interpretation, and meaning derived from the analysed documents. It facilitated a critical examination and contextualisation of the findings within the broader theoretical and practical landscape of safety management, ensuring a comprehensive and reflective approach to unpacking the complexities of the topic.

1.7.5 Methodological choice

According to Saunders (2019:130), the 'research onion' reveals six different methodological choices, namely: mono-method qualitative, mono-method quantitative, multi-method qualitative, multi-method quantitative, mixed method complex and mixed method simple, as seen in Figure 3 below:

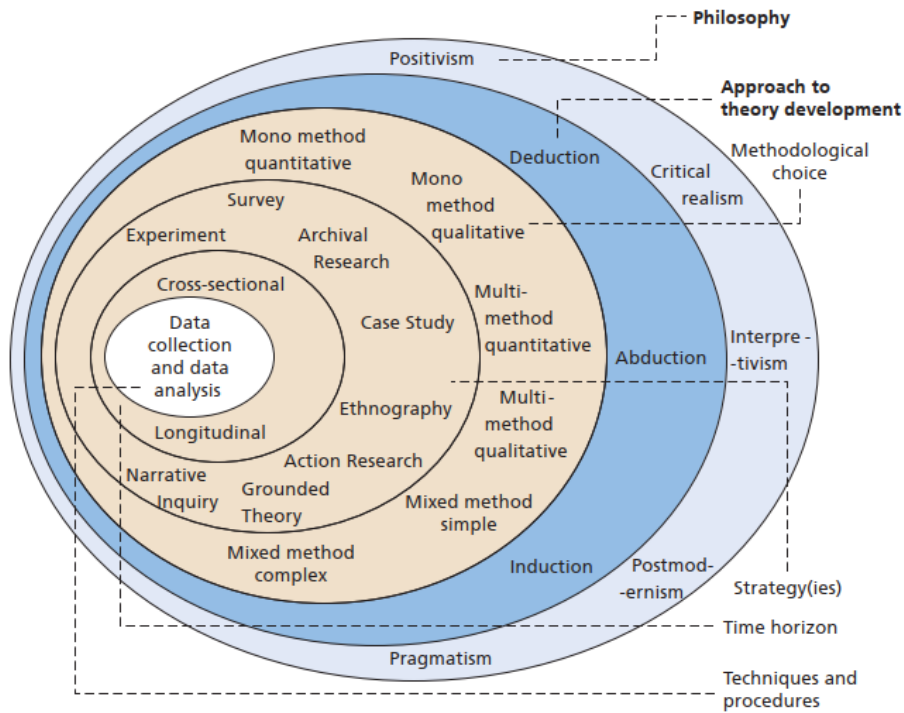


Figure 3: The 'research onion' (Saunders, 2019:130)

This study used a monomethod qualitative methodological design. Document analysis was done to collect data using various search engines to find appropriate qualitative data for the critical evaluation of PSM in the petrochemical industry in South Africa.

1.7.6 Research strategy

According to Saunders (2019:130), the 'research onion' indicates that there are numerous research strategies to take into consideration. These strategies include surveys, experiments, archival research, ethnography, case studies, action research, narrative inquiry, and grounded theory. The following research strategies were used to conduct this study:

- **Case studies** have been used extensively in the social sciences. They are particularly useful in fields that focus on practical application, such as social work, management, education, and public administration (Starman, 2013:29). The definition and characteristics of case studies are strongly related to the interpretivist paradigm, constructivism, and the phenomenological approach as a paradigmatic base for qualitative research. According to Sturman (1997), "a case study is a general term for exploring an individual, group or phenomenon". Simons (2009) defines case studies as:

“... an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in a ‘real life.’”

- **Archival research methods** feature a wide range of actions, making it easier to look into texts and documents created by and about organisations. The research of historical documents, which are records created relatively recently that offer access to people, groups, and events the researcher might not otherwise have, is the most standard description of archival methods (Ventresca *et al.*, 2017:4).
- **Ground theory** produces in-depth explanations of challenging procedures, methods, and changes where information is gathered on a specific topic (Bryman *et al.*, 2018:42).

1.7.7 Time horizon

This study adhered to a time frame of eight months to collect and compile data to research the topic of the critical evaluation of PSM in the petrochemical industry in South Africa.

1.7.8 Sampling approach

No human participants were involved during this study, as the study involved content analysis where documents were used to complete the research of critical evaluation of PSM in the petrochemical industry in South Africa. The research timeline will also not be affected by participants since content analysis was used to conduct the research. As such, this study was not sensitive regarding race, gender, or vulnerable groups. Compliance with the Protection of Personal Information (POPI) Act was ensured through the exclusive use of publicly available documents in this research, thereby eliminating the need for sharing or handling the personal data of participants. All researchers should take note of the applicable ethical codes for their study (Cohen *et al.*, 2007). This research complies with the ethics guidelines of the North-West University, and the researcher must respect and obey these aspects. All research was publicly available on the following search engines: African Journals, ERIC, BASE, JSTOR, Google Scholar, and Microsoft Academic.

1.7.9 Collection of data

This study used document analysis to generate and select data. Electronic data, legislation, policies, articles and minutes of meetings were used for the document analysis. Because the study focuses on the PSM in the petrochemical industry in South Africa, it is essential to collect numerous data from various sources, such as:

- African Journals
- Company documents
- ERIC
- BASE
- JSTOR
- Google Scholar
- Microsoft Academic

The method followed can be characterised as case study research. Specific incidents of accidents or risky situations were selected to analyse, from which conclusions could be drawn. The selection of cases to use were subject to the permission by the companies where the research was done, and only cases were selected that would not directly reveal the companies identity. This limited the number of cases that could be studied in depth to four specific cases. However, as is the case in case study research, the learning points from these four cases are sufficient to draw conclusions and make recommendations.

Data were collected from specific petrochemical plants in South Africa to obtain their safety precautions policies and HAZOPS. Using various data sources and collecting company policies and documents made this study executable. The data were not sensitive, making it a low-risk research study with respect to ethics.

1.7.10 Data analysis

Data analysis is the most crucial stage of any research project. Data analysis summarises gathered information. It involves looking for patterns, correlations, or trends in data by using logical and analytical reasoning. Data analysis entails comparing the outcomes to

the research questions to meet the research objectives. After data had been collected, it was necessary to analyse it to find patterns and themes that frequently appeared in behaviour, emotions, objects or a body of knowledge. Once these patterns are found, the researcher is ready to interpret the data. According to Polit and Beck (2004:570), data analysis is to arrange and structure the information gathered to draw a relevant conclusion. This method moves in analysis cycles rather than in a fixed linear fashion (Creswell, 2007:150).

In this study, the chosen documents were analysed using content analysis to find recurrent themes, patterns, and insights about PSM in the petrochemical industry. Instead of following a linear path, the analysis proceeds in repetitive cycles, enabling a dynamic examination of the data as themes develop and change. This strategy is in line with qualitative research approaches, which arrange and structure data to arrive at a thorough comprehension of the topic and produce well-founded conclusions in accordance with Polit and Beck's recommendations.

1.7.11 Trustworthiness

Validity in qualitative research refers to the “trustworthiness” or “appropriateness” of the tools, processes and data (Elo *et al.*, 2014:8). Included in this is a review of the validity of the research objectives for the desired result, the appropriateness of the methodology for the research objectives, the design's fit with the method, the suitability of the data collection and analysis to the design, and the appropriateness of the conclusions given the context (Leung, 2015:325). Leung (2015:325) recommends asking many questions to determine the validity and contends that if the responses make sense, they will imply validity. A judicial decision is made based on the implications of each response for the reliability of the study.

This study is a document analysis. The focus is on the original authors of the documents. Furthermore, the following ethical aspects are relevant to the study (Denscombe, 2010):

- The researcher must remain objective throughout the study, reproducing only what the author of the source claims.
- The data must reflect the reality as reproduced by the authors.
- The information and data gathered for this study will be on file for five years.

The researcher collected data and has permission to use the company's policies for this research.

1.8 Ethical considerations

This study is a non-intrusive qualitative study where no human participants are used, but rather secondary analysis through documents from previous researchers. The possible ethical dilemma that should be considered at the beginning of this study is that there might not be enough research available in the specific field of critical evaluation of PSM in the petrochemical industry in South Africa. There is also the possibility that data is available but that companies within the petrochemical industry do not want to share or expose their safety management.

It is of the utmost importance during any research study that ethics guidelines are strictly adhered to. In this regard, Cohen *et al.* (2007:71) point out that all researchers should be informed about the various ethical codes that may apply to a study. Therefore, the proposed research must comply with the ethics guidelines of NWU. The focus was on the critical evaluation of PSM in the petrochemical industry in South Africa to offer recommendations. According to Denscombe (2010), the following ethical issues are relevant to such a study:

- The researcher should remain objective at all times.
- The information and data generated by the researcher should be kept safe.
- The consent of the ethics research committee of the relevant research institution should be obtained.
- The focus should be on identifying progress, not just gaps or problems.
- Data should at all times be a reflection of reality.

The NWU assigned an ethics clearance code to this study.

1.9 Contribution of the study

There is a large gap in the field of study regarding the value of the critical evaluation of PSM in the petrochemical industry in South Africa (Zang *et al.*, 2023) and the identification of best practices to improve it. Conclusions and recommendations are provided in Chapter 5. There are three contributions to consider during this research, namely theoretical, practical and industry contributions.

1.9.1 Theoretical contribution

Various companies focus on “zero harm” to improve productivity and decrease fatalities. With this aim in mind, this study not only provides critical evaluation of PSM in the petrochemical industry in South Africa but also answers the following secondary objectives of this study:

- To create an understanding of the PSM in the petrochemical industry in South Africa.
- To determine the PSM elements that significantly contributed to process safety incidents in the petrochemical industry in South Africa.
- To identify the PSM failures that resulted in process safety incidents in the petrochemical industry in South Africa.

The theoretical contribution lies in the analysis of the current state of PSM in the industry, including the policies, procedures, and practices in place. It will provide a comprehensive overview of the strengths and weaknesses of the existing PSM systems in the petrochemical industry in South Africa.

1.9.2 Practical contribution

Employees and contractors in the Petrochemical industry will have the advantage of improving the PSM in this sector in South Africa and maintaining or achieving the “zero harm” objective. They can improve regulatory compliance by updating existing regulations and enforcing existing safety standards more rigorously. The industry can encourage the continuous improvement of PSM by incorporating lessons learned from past incidents and conducting regular audits and assessments.

1.9.3 Industry contributions

The study contributes to the study field of MBA and the petrochemical industry by sharing best practices and lessons learned from previous incidents. The petrochemical industry has a wealth of experience and knowledge about PSM that can be shared to help improve the effectiveness of PSM in the industry.

There are limited studies that focus on these objectives and research phenomena in South Africa.

1.10 Limitations of the study

The study has some limitations such as relying on previous research. This may be a limitation due to the gap in research available on the specific topic of PSM in the petrochemical industry in

South Africa. Furthermore, this study only focused on the PSM in the petrochemical industry in South Africa. This limits the generalisability of the findings to other contexts. Another limitation is that private companies will not necessarily feel the need to share their PSM systems with the researcher.

1.11 Layout of the study

The research includes five chapters. The process chart below in Figure 4 indicates the five different chapters as well as the main focal point of each chapter.

1.11.1 Chapter 1: Introduction

The first chapter of this research gives the reader important background and knowledge on the PSM in the petrochemical industry in South Africa to outline the research problem. The inadequacies of previous research that is pertinent to this research on the petrochemical industry are highlighted to identify the goals of the study.

1.11.2 Chapter 2: Literature review

A literature review makes up the second chapter of the study. In this section, the existing solutions and tools used to construct the methodology are discussed in greater detail. These solutions and tools were examined in Chapter 1 of this research. Several of these initiatives are critically evaluated. This acts as a review of the literature related to the methodology.

1.11.3 Chapter 3: Research methodology

Chapter 3 outlines the research methodology used to evaluate the current solutions presented in Chapter 2 and to address the problem stated in Chapter 1. This acts as the adaptation of current approaches and their integration to create a new method of PSM in the petrochemical industry in South Africa.

1.11.4 Chapter 4: Empirical study

Chapter 4 presents the findings of the empirical study. The findings are analysed at the hand of the theoretical application. This offers a useful platform for formulating recommendations based on the various findings of the theoretical and applied studies.

1.11.5 Chapter 5: Conclusions and recommendations

The study is concluded in the last chapter of the research. The success of the proposed technique is assessed to meet the. Future research suggestions are also be discussed.

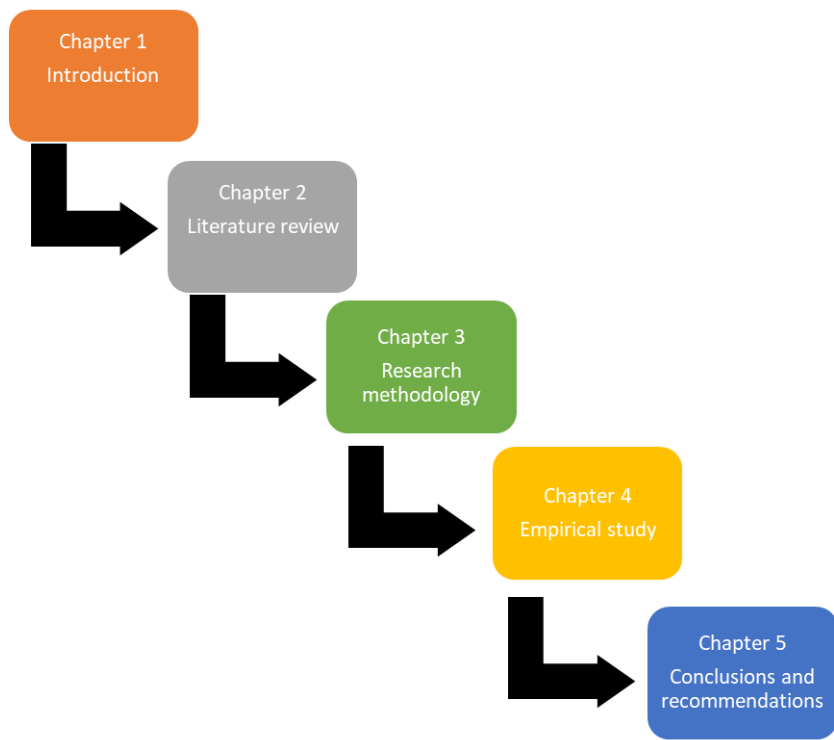


Figure 4: Chapter layout for dissertation

CHAPTER 2: LITERATURE REVIEW

This chapter explores the research environment, focusing in particular on South Africa's petrochemical sector. Along with a brief overview of South Africa, it elaborates on the historical background, the sector's contributions, and brief profiles of the petrochemical businesses participating in this chapter. The study identifies a number of crucial topics for definition and investigation to fully comprehend the research issue and meet the secondary objectives, including:

- Defining keywords
- Defining PSM
- PSM focus areas
- PSM models
- OSHA elements
- HAZOP
- The management of change
- Incident investigation

This study attempts to provide important insights into the safety management practices of the industry by defining key words, delving deeply into PSM's core areas, and assessing its models and regulatory frameworks. This analysis seeks to address the research goals while also offering practical suggestions that improve safety protocols and management strategies, ultimately resulting in a safer and more efficient petrochemical sector in South Africa.

2.1 History of South Africa

This section briefly outlines South Africa's geographic location, and socioeconomic development since the country's oil and gas discoveries to support the detailed discussion that will follow in this study.

2.1.1 South Africa's geography

South Africa is situated between latitudes 22° and 35° S and longitudes 16° and 33° E at the southernmost point of the African continent. With a total land area of about 1 219 090 square

kilometres, it ranks as the 24th largest country in the world. The terrain of South Africa is varied and includes a variety of grasslands, woodlands, deserts, and mountain ranges. A number of significant rivers, including the Orange, Limpopo, and Zambezi rivers, as well as numerous lakes and wetlands may be found across the country. Regional differences in average temperatures result in milder conditions along the coast than inland. While temperatures can drop to below 0°C in some places during the winter, summer temperatures can range between 25°C and 40°C (Draper & Scholvin, 2012:8).



Figure 5: Map of South Africa (Google Maps, 2023)

2.1.2 Migration and demography

Over 60 million people call South Africa home, and that number has been rising over time. Black Africans make up the majority of the population, accounting for about 80% of the total, with the remaining 20% being made up of whites, coloureds, and Indians/Asians. With almost 60% of the population under the age of 30, the nation has a young population. The people of South Africa come from a variety of ethnic and national backgrounds. The principal sources of foreign labour include, among others, Zimbabwe, Lesotho, Mozambique, Malawi, and Namibia (Statistics South Africa, 2021).

2.1.3 South Africa's economy and energy sector

South Africa boasts one of the biggest economies in all of Africa. Natural resources, including gold, platinum, diamonds, and coal, are abundant in the country and have greatly aided in the expansion of the economy. In addition to its mining industry, South Africa boasts a thriving

manufacturing sector that contributes significantly to its economy. The country's economy is diverse, with the real estate, tourism, and finance industries making substantial contributions. However, the country still faces difficulties, including high unemployment rates, income inequality, and the economic effects of COVID-19 (World Bank, 2021).

South Africa is reported to have 15 billion barrels of oil in reserve. Over 30% of the petroleum industry's revenue comes from the private sector, accounting for around 8% of South Africa's GDP. South Africa also boasts a sizable mining sector that includes gold, diamonds, platinum, and other minerals, as well as a robust agricultural sector. Also, the nation draws a sizable number of visitors each year who generate temporary jobs in the hotel and tourism sectors (Biglarbigi *et al.*, 2010). In 1994, South Africa established the Department of Trade and Industry (DTI) to promote economic development, particularly in the manufacturing sector. Since then, the South African government has made efforts to attract foreign investment and boost economic growth. In 2018, the government launched a campaign called "InvestSA" to facilitate and promote foreign investment. South Africa has also developed special economic zones to attract foreign investors and has implemented various incentives for companies investing in specific sectors. The government has privatised some state-owned enterprises, such as South African Airways, and has plans to privatise others, such as Eskom, the country's electricity supplier. Additionally, South Africa is working to expand access to high-speed internet and improve the country's infrastructure to further support economic growth (Department of Trade and Industry, 2021).

Since 2012, the South African government has implemented several national development plans to reduce unemployment, inequality, and poverty while promoting sustainable economic growth. These strategies include creating industrial parks and special economic zones, investing more in infrastructure, improving education and skills development, and encouraging small company growth. The government has also set targets to improve employment prospects for South Africans, notably in industries like manufacturing and technology. The country is still facing difficulties in accomplishing these objectives due to the persistence of high unemployment and inequality rates (National Planning Commission, 2021).

2.1.4 The petrochemical industry

In the petrochemical industry, there are two main categories: upstream and downstream operations. Upstream operations involve extracting crude oil and gas from natural reserves and using geophysical and seismic surveys for potential drilling for oil and gas. This is also called the exploration and production sector (E&P sector). Downstream operations refer to processing oil into products that businesses can sell. It includes oil and gas distribution through pipelines and facilities to refine liquefied natural gas, as well as refineries, petrochemical plants, and gas

processing. Midstream operations are located between upstream and downstream processes; these include the transportation of resources using pipelines and gathering systems (Shi *et al.*, 2019:28).

A number of factors influence the value chain of the petroleum sector, including activities related to crude oil, head office operations, capital expenditures (CAPEX), refinery operations, distribution operations, storage operations, wholesale operations, and retail operations.

The following value chain image indicates the impact of the petroleum industry on South Africa's economy.

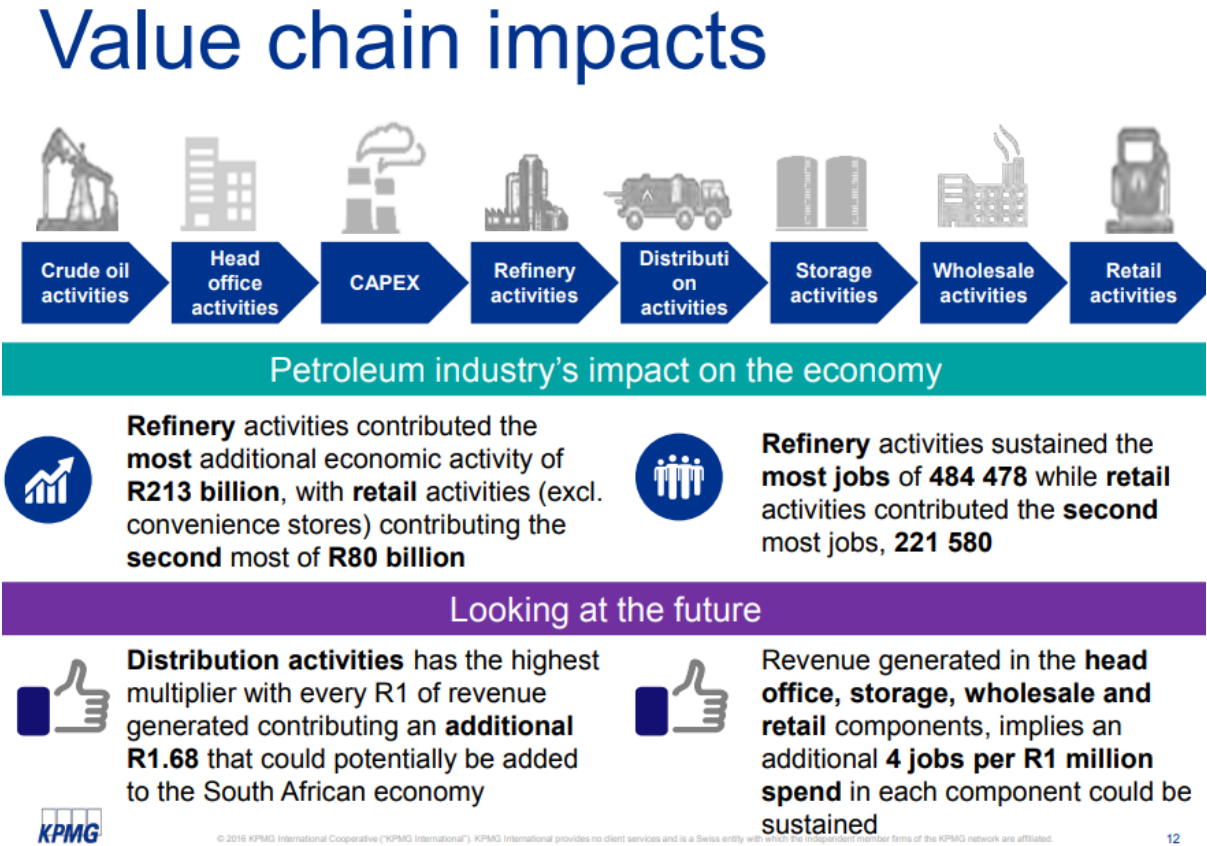


Figure 6: Value chain impact (SAPIA, 2017:12)

The exploration, production, and transportation of crude oil are all part of the crude oil industry. These actions affect the environment and may benefit or harm South African local communities' socioeconomic conditions. The management and administrative tasks associated with the petroleum industry's head offices include finance, marketing, and human resources. It is possible to assess how these activities affect the whole value chain and how corporate governance promotes sustainability and social responsibility. Investments in new machinery, buildings, and technology that boost productivity are referred to as CAPEX.

Examining CAPEX along the entire value chain allows for an assessment of both the benefits of innovation and the risks associated with significant investments. It involves analysing how capital expenditures influence operational efficiencies, product development, market competitiveness, and financial performance across the value chain. This approach helps in understanding the potential for innovation-driven growth and the financial vulnerabilities that large-scale investments can introduce, ensuring a balanced perspective on strategic decision making. Processing crude oil into refined goods like gasoline, diesel, and jet fuel is a component of refinery operations. These actions affect environment and human health, and it is possible to talk about how technology can help with efficiency gains and emissions reductions. The transportation and storage of refined goods from refineries to wholesale and retail clients are distribution activities. It is possible to analyse the effects of these actions on the entire value chain, including the potential advantages of logistics optimisation and the dangers of supply chain disruptions.

Before being delivered to clients, refined products are stored in tanks and terminals as part of storage activities. Analysing storage activities along the value chain highlights the critical balance between managing inventory effectively and mitigating the risks associated with accidents and spills. Storage, including the use of tanks and terminals for refined products before delivery to clients, plays a vital role in ensuring product availability and meeting market demand. However, it also introduces risks, such as environmental hazards from spills. Effective inventory management can optimise supply chain efficiency and reduce costs, showcasing how strategic storage operations contribute to the overall value chain's success and resilience.

The sale of refined goods in bulk to clients, including petrol stations, airports, and industrial users, is a part of wholesale activity. It is possible to discuss how these activities affect the entire value chain, including the potential advantages of economies of scale and the dangers posed by price volatility and market rivalry. The sale of refined goods to end users, like drivers and homes, is a component of retail activity. It is possible to examine how these actions affect the entire value chain, including the potential advantages of ease and customer service and, the dangers related to shifting consumer trends and preferences.

A pertinent subject related to the effects of the petroleum industry on the value chain is the critical evaluation of PSM in the South African petrochemical industry. PSM is essential to ensuring that petrochemical plants run safely and reliably, which in turn affects the effectiveness and efficiency of the entire value chain. To ensure process safety and reduce the risk of accidents and incidents, the present legislation, guidelines, and practices can be critically evaluated. A strong safety culture and adherence to process safety standards can be promoted by a strong safety culture, which can be explored through an evaluation of organisational, leadership, and cultural aspects.

Process safety incidents in the petroleum industry can significantly affect the value chain, leading to production losses, equipment damage, and reputational harm. These incidents not only disrupt operations but also incur financial costs from halted production, repairs or replacements of damaged equipment, and potential legal liabilities. Additionally, such incidents can damage the company's reputation, affecting customer trust and market position. This review aims to reach an in-depth understanding of these impacts, emphasising the importance of process safety in maintaining operational integrity and protecting the industry's value chain. Additionally, it can look into how well post-incident reviews and corrective measures work in averting such occurrences in the future and enhancing process safety administration. PSM directly affects the safety, efficacy, and reliability of petrochemical operations, making it a vital component of understanding the value chain implications of the petroleum industry in South Africa.

2.1.5 South African Petroleum Industry Association

The South African Petroleum Industry Association (SAPIA), which celebrated its 29th anniversary in July 2023, has collectively represented the interests of the South African petroleum sector since July 1994. As per its annual report in 2014, SAPIA contributes significantly to tackling multiple topics related to refining, distributing, and marketing petroleum products and supporting the socioeconomic and environmental progress of the industry in South Africa. To achieve this, SAPIA assists in formulating regulations in crucial areas of the country's policy, actively engages with key stakeholders, shares research data, provides expert advice, and advocates for the industry's with the government, the public, and the media (SAPIA, 2014:5).

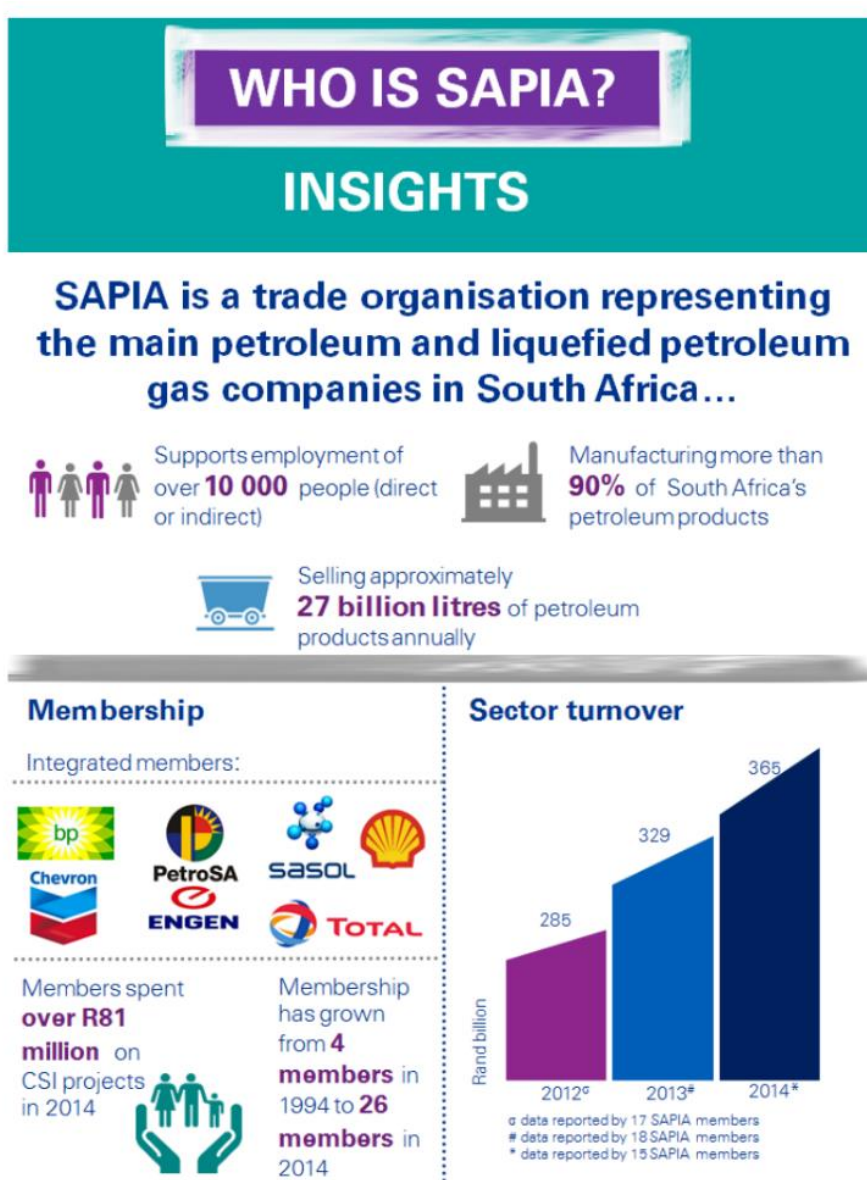


Figure 7: Who is SAPIA? (SAPIA, 2014:5)

South Africa has six active refineries, with four located on the coast and two inland, as seen in Figure 8 (NBI, 2021:22). The major petroleum products sold by oil companies in the country are petrol, diesel, jet fuel, illuminating paraffin, fuel oil, bitumen, and liquefied petroleum gas (LPG). Among these, petrol and diesel are the most used liquid fuels, comprising 40.3% and 46.8% respectively of the total petroleum products consumed in the country in 2014 (SAPIA, 2014:5).

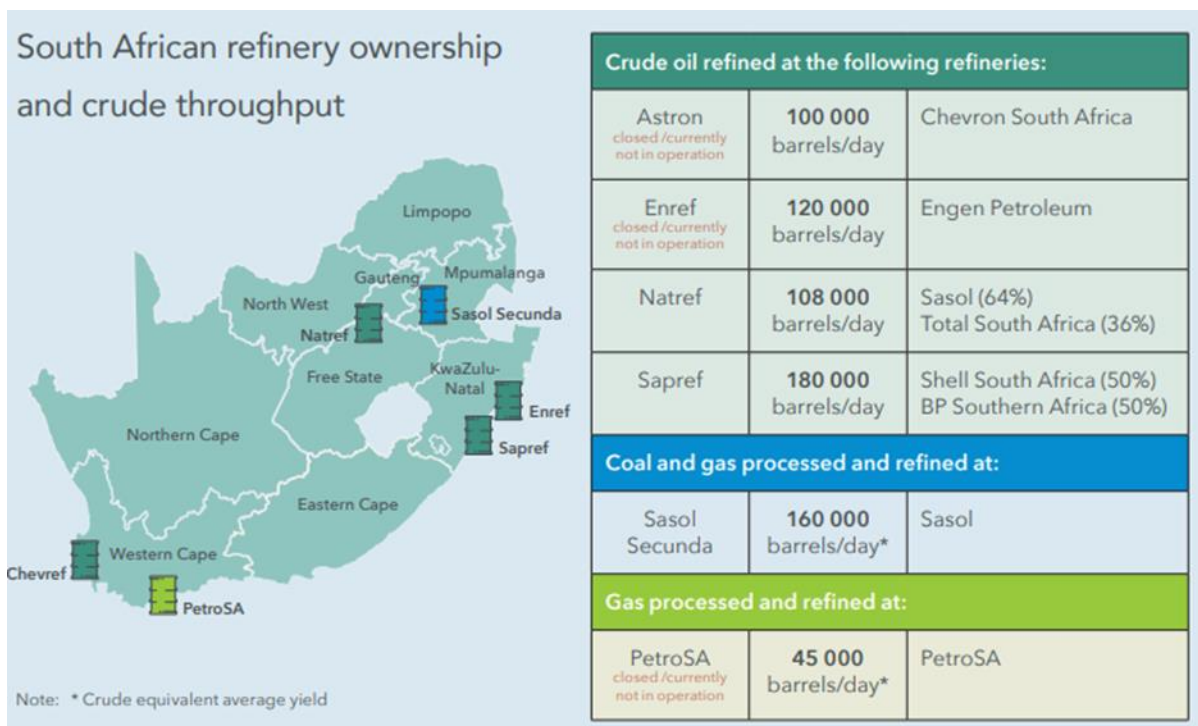


Figure 8: South African refinery ownership and crude throughput (NBI, 2021:22).

As seen in Figure 8 above, Sapref, Enref, Natref, and Astron (formerly Chevref) are four conventional refineries that process imported crude oil. Secunda CTL of Sasol refines and processes coal and gas at a rate of 160 000 barrels per day (bpd). With coal serving as the primary feedstock, the Fischer-Tropsch process is primarily used to produce liquid fuels with around 26 times more carbon content than traditionally processed petroleum. The manufacture of synfuels is closely linked to Sasol's GTC plant in Sasolburg (NBI, 2021:22).

South Africa's largest refinery, SAPREF, a joint venture equally owned by oil giants BP and Shell, decided to indefinitely halt operations in March 2022 (Anon, 2022). The refinery, located in Durban on the east coast, boasts a nameplate capacity of 180 000 bpd and holds a significant share, around 35%, of South Africa's refining capacity, which relies on importing petroleum products (Anon., 2022). The operation pause was prompted by the owners' contemplation of selling the plant as a sale is the most preferred option among several possibilities. The shareholders cited the need for informed deliberation on the plant's future, including potential ownership changes, as a reason for pausing further investment in the refinery (Parker, 2022). This move was also influenced by the warnings from SAPIA in September that the country's refinery capacity could soon become obsolete due to government regulations aiming to reduce sulphur emissions from 2025. The deadlock in negotiations between SAPIA and the government regarding the financing of refinery upgrades for cleaner fuels, estimated at \$3.9 billion, further contributed to the decision to halt SAPREF's operations (Parker, 2022).

2.1.6 Petroleum industry performance in South Africa

The confirmed crude oil reserves in South Africa are small, and little crude oil is extracted locally. Because of this, South Africa must rely on imported crude oil and refined fuels to meet its needs for liquid fuels. This requires proactive engagement with key stakeholders, the sharing of research data, the provision of expert advice, and the dissemination of the sector's viewpoints to the government, the general public, and the media (SAPIA, 2014:15). With a total refining/liquid fuels capacity of 703 000 bpd, South Africa, behind Egypt, has the second-largest refining capacity in Africa. Of this capacity, over 72% (503,000 bpd) is used to refine crude oil, while the remaining portion is used to refine synthetic fuels (SAPIA, 2014:15).

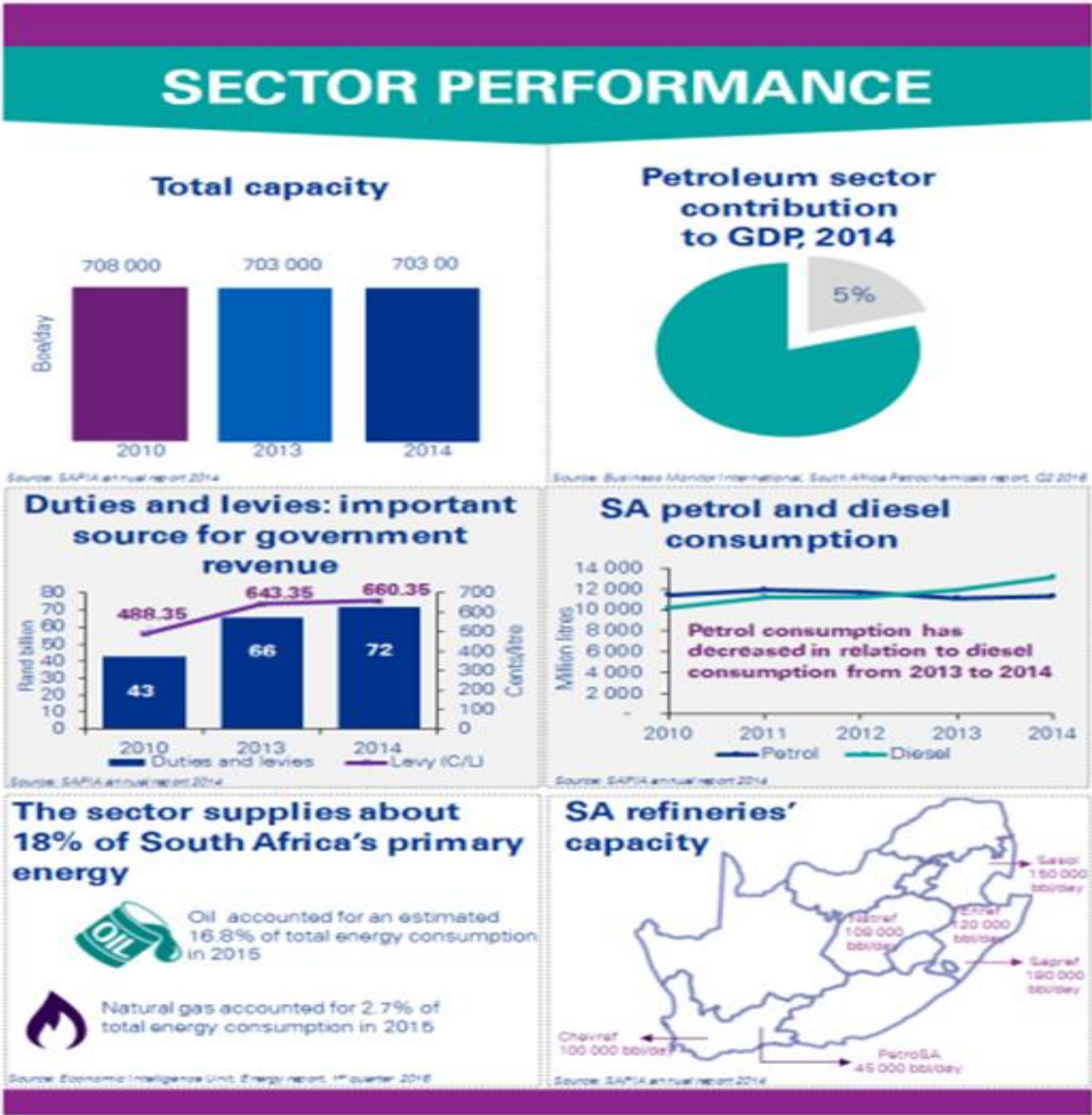


Figure 9: Sector performance (SAPIA, 2014:15)

In 2014, the South African market used 13 169 million litres of fuel and 11 344 million litres of gasoline. The majority of the petroleum used in South Africa comes from domestic refineries that import crude oil and coal-to-liquid (CTL) and gas-to-liquid (GTL) plants, according to the US Energy Information Administration. In 2014 South Africa imported 165 000 bpd (38% of the total imported) of crude oil from Saudi Arabia and 135 000 bpd (31% of the total imported) of crude oil from Nigeria. As illustrated in Figure 9 above.

In 2017, an estimated R213 billion worth of additional economic activity was generated by refinery operations, with R80 billion coming from retail operations (excluding convenience stores) (SAPIA, 2017:12). This is illustrated in Figure 7 above.

2.2 Defining keywords

Brown (1970) states that safety precautions have been part of the manufacturing industry since the nineteenth century (Rogers, 2009). Technical measures should eliminate or control risks and prevent accidents to achieve the intrinsic safety for petrochemical plants. Considering health and safety from a process safety and occupational health perspective is the best approach to attain intrinsic (inherent safety) for petrochemical plants. The policies that contain the basic safety precautions in the petrochemical industry are discussed in depth during this research. Critical strategies for ensuring that risks and hazards do not occur in the petrochemical industry include (Anon, 2019):

- Establishing early warning systems, such as monitoring pressure in gas and liquid conveyance systems and examining the mechanical health of processes, equipment and utilities at regular intervals;
- Simple safety training, such as identifying unsafe work procedures or conditions and wearing PPE while handling petrochemicals; and
- Installing unique emergency treatments for employees who have been contaminated with chemicals.

Smith and Wadsworth (2009) agree that appropriate risk management can achieve the abovementioned strategies. Risk management can include communication, reward systems and the empowerment of employees. The employees should also be able to comply with the safety rules and policies that are in place to prevent injuries. The Mine Health and Safety Act (29 of 1996) describes the operations of a mine. Without employee compliance, the Department of Mineral Resources can withdraw its operating license. The threat of a revoked license urges industries to motivate their employees to take extra precautions for safety at the workplace.

Once motivation is identified and industries can implement safety precautions with the support of their employees, communication is seen as a key factor in implementing and maintaining safety precautions. Communication is critical for any organisation to succeed, not only operationally but also to improve safety performance. The “zero harm” road can be followed with proper communication between employees and supervisors. Organisations can use three main communication strategies (Newnam *et al.*, 2016):

- The supervisor who values communication about safety precautions indicates that they appreciate the employee’s safety. This creates trust and respect between employees and supervisors.
- Daily communication in the organisation to discuss the safety precautions related to the work that should be completed.
- The supervisors and employees should guide safety activities and implement these activities daily.

The Department of Mineral Resources (DMR) affects safety practices. Organisations are bound to comply with the DMR. There is a regulator that implements and reinforces the Safety Act, 29 of 1996. The “zero harm” road is the main focus of the regulator’s efforts to ensure that organisations comply with all safety requirements. The Safety Act, 29 of 1996 compels organisations to that the safety behaviour of their employees seriously. All these factors mentioned above work together. One cannot achieve proper safety precautions without considering all the individual, team, and legal factors. The organisations in South Africa will be more productive and prevent injuries if they comply with the policies and updating their safety precautions.

A formal, top-down, business-like approach to controlling safety risk, known as a SMS, is based on fundamental system safety concepts. This includes goal setting, documentation, planning and regular performance evaluation to ensure that objectives and goals are met. SMS consists of the following system safety principles:

- **The evaluation of safety actions:** Risk management actions must be continuously evaluated for their effects to ascertain whether more corrective steps are necessary.
- **Management commitment to safety:** Senior executives must commit to the success of an SMS implementation because management's attitudes and behaviours can significantly impact the entire team.

- **Proactive identification of hazards:** Early detection and reporting of dangers can help an organisation save time and money in the long run.
- **Actions to manage risks:** A system must be in place to decide on logical strategies to mitigate known hazards for safe operation.

The petrochemical industry is under growing pressure to raise productivity, cut costs, increase efficiency and do so in a safe working environment. The safety design technique is frequently adopted to evaluate safety during the process design, considering the plant lifecycle activities.

Considering the managerial implications of this study

A thorough examination of PSM has left the South African petrochemical industry's operational management functions prepared for change. According to researchers like Rodionova *et al.* (2008) and Kumar *et al.* (2009), these duties include a variety of tactical and strategic tasks necessary for the effective and secure operation of petrochemical facilities.

- **Planning** includes deciding on a location for the company and planning the production. How successful a business will be is directly related to its location. This statement holds for newly established businesses and more established ones branching into a new region. The proximity to markets, raw resources, labour supply, and transportation facilities are variables to consider. The managers of petrochemical plants should consider planning a top priority as this also contributes to the safety of the employees and the availability of raw materials.
- **Scheduling** involves setting start and end times for each stage of the production process as part of operations. It involves organising and monitoring the usage of personnel, equipment, and supplies to ensure efficient production. It ensures that tasks are completed on schedule. The petrochemical industry runs on a strict schedule, and managers must ensure that each project's start and end dates are met.
- **Organising** is the process that creates a hierarchy of responsibilities and power. Operation managers establish the duties and information flow within the operations subsystem. They choose the actions needed to accomplish the objectives and delegate authority and are accountable for completing them. This is also clear in the HAZOPS. Each department is organised according to the project and its needs.
- **Purchasing:** The petrochemical industry needs raw resources to make its products or provide its services. This can include training supplies, equipment, and support. The purchasing department selects the most acceptable deal for the business at the best cost to ensure the quality of the product will still be met.

- **Controlling:** This is the set of actions that guarantee that the performance is carried out as expected. The operations manager must maintain control by assessing actual outputs and comparing them to planned operations management to make sure that the plans for the operations subsystems are carried out. The key responsibilities in this situation are controlling costs, quality, and timetables.
- **Quality control:** Checking the produced products' quality is known as quality control. It entails monitoring the products' quality or freshness, strength or usability, workmanship or design, safety, compliance with governmental or industrial regulations, and many other aspects.
- **Inventory control:** The petrochemical industry requires inventories or stockpiles of the resources they use to produce goods or provide services. Manufacturers and companies keep finished goods in inventories; these inventories must be under excellent management to ensure that products or goods are not wasted or lost.

A critical evaluation of PSM in the petrochemical industry in South Africa can help the petrochemical industry decrease risk on site and ensure that employees have a safe working environment by providing the managers with a framework to follow during HAZOPS.

2.3 Defining process safety management

PSM is a systematic approach to managing the hazards associated with process industries, such as the petrochemical, chemical, and oil and gas industries. The objective of PSM is to prevent the release of hazardous chemicals that can cause fires, explosions, or toxic releases and to minimise the consequences of such releases if they occur (DuPont, 2008:1).

Shimada *et al.* (2009: 1) define PSM as, "... a management system that is focused on prevention of, preparedness for, mitigation of, response to, and restoration from catastrophic releases of chemicals or energy from a process associated with a facility".

According to Kelly (2010: 2), PSM is "a comprehensive framework of operations for managing the integrity of a hazardous (chemical) activity." The aim is to eliminate (prevent and mitigate) occurrences involving loss of containment. Events involving a loss of containment have the potential to cause a massive number of fatalities, fires, explosions, or other hazardous effects.

Toups (2003: 11) describes PSM as "the proactive and systematic identification, evaluation, and mitigation or prevention of chemical releases that could occur due to failures in process, procedures, or equipment".

From these definitions, it is clear that the following common points are important: keeping process equipment in good condition, compiling and institutionalising safe operating procedures, identifying process hazards and taking appropriate preventative and corrective action. Figure 10 gives an overview of PSM.



Figure 10: PSM overview (Thrower, 2013)

PSM involves safe product handling, safe product manufacture, and safe process operation. This is accomplished by managing systems, adherence to laws, and creating a safety culture.

2.4 PSM focus areas

A look at the areas of focus in PSM can reveal the current state of the South African petrochemical industry by identifying strengths, weaknesses, and areas for improvement. This approach not only aligns with the study's objectives but also sets the stage for the subsequent sections, paving the way for a deeper exploration of each focus area's specific challenges and opportunities. According to EI (2010), the focus areas include the following:

2.4.1 Risk management

Risk management is identifying, assessing, and prioritising potential risks to an organisation or an individual and then implementing measures to mitigate or manage those risks. It involves analysing the likelihood and potential impact of hazards and determining the most appropriate course of action to reduce or eliminate those risks. Risk management can be applied to various activities, including finances, operations, safety, and environmental hazards (EI, 2010). Effective

risk management helps organisations and individuals minimise the impact of adverse events, maintain resilience in the face of uncertainty, and make informed decisions about managing risks. The goal of risk management is to ensure that risks are managed proactively and systematically to minimise their effect on the organisation or individual.

2.4.2 Incidents in the petrochemical industry

Safety concerns are a priority in the petrochemical industry as it poses a significant risk to both humans and the environment. Petrochemical companies must implement active risk management and build a strong safety culture to prevent fire, explosions, toxic and hazardous material spillage, equipment failures, and other accidents. Hazard identification and assessment should involve all stakeholders, and the critical objective of PSM is to prevent fire, explosion, and the release of dangerous chemicals that may expose workers and the broader public to severe hazards. The petrochemical industry is vulnerable to personal injury, damage to equipment, mistakes committed by critical controllers, and risks to stakeholders and the environment. The industry should take pre-emptive measures such as risk avoidance and transfer and should establish safe operational procedures to reduce the number of severe or non-serious incidents. Safety in petrochemical plants should be incorporated in the design phase itself and must be based on the philosophy of 'inherent safety' (Mechhoud, 2016).

The fundamental and primary causes of major accidents are frequently linked to poor PSM (Kerin, 2017). The variety of process safety operations is vast. Process safety is a component of every activity performed on a petrochemical installation. If properly carried out, these actions can prevent accidents. Conversely, if improperly carried out or not adopted, they can result in accidents. PSM techniques are consequently required to lower the possibility of catastrophic incidents.

2.4.3 Process safety leadership

Process safety leadership refers to the management approach and commitment to ensuring the safe and reliable operation of process facilities, such as chemical plants, refineries, and manufacturing sites. It involves the integration of process safety into the overall management of a company and establishing a safety culture that prioritises the prevention of accidents and the protection of workers, communities, and the environment. The critical elements of process safety leadership include clear responsibilities and accountability, effective communication, and continuous improvement in process safety performance (EI, 2010). Effective process safety leadership requires top-level management commitment, engagement and leadership, and the integration of process safety into all aspects of the business, including design, construction, operation, maintenance, and inspection. By adopting a process safety leadership approach,

organisations can minimise the risk of process safety incidents, promote a safe and healthy work environment, and ensure the long-term sustainability of their operations.

2.4.4 Human error

In the petrochemical industry, human error has historically been a major contributor to accidents. Nwankwo *et al.* (2022:1642) found that 90% of accidents was due to human error. However, there have been significant efforts to address this issue in recent years. In the past, the impact of human error was typically limited to the immediate surroundings. Today, with high-tech facilities, including nuclear power plants, even minor errors could have devastating consequences that could last for generations and affect large geographical areas or even entire continents (Reason, 1990). The consequences of human error in industrial accidents have been enormous. Examples include the Tenerife runway collision in 1977, the Three Mile Island accident in 1979, the Bhopal methyl isocyanate disaster in 1984, the Chernobyl catastrophe in 1986, the capsizing of the Herald of Free Enterprise, the King's Cross tube station fire in 1987, the Piper Alpha oil platform explosion in 1988, the Deepwater Horizon oil spill in 2010, and the Fukushima nuclear power plant disaster in 2011 (Robertson, 2016).

2.4.5 Review and improvement

Review and improvement refer to the ongoing process of evaluating and updating systems, procedures, and practices to ensure they are practical and efficient. The goal of review and improvement is to identify areas for improvement and to implement changes that will result in better performance, increased efficiency, and reduced risks. Assessment and improvement can be applied to various activities, including business processes, safety systems, and quality management (EI, 2010). Effective review and improvement require a systematic approach that involves regular evaluations, the collection and analysis of data, and the identification of areas for improvement. It also requires a culture of continuous improvement that encourages feedback, learning, and the adoption of best practices. The benefits of review and modification include increased efficiency, reduced risks, improved quality, and increased customer satisfaction.

2.4.6 Risk identification and assessment

Risk identification and assessment entails the process of identifying potential risks to an organisation or individual and evaluating their likelihood and potential impact. It is the first step in the risk management process and is essential for making informed risk mitigation and management decisions. Risk identification and assessment aim to identify all relevant risks, including those that may be hidden or overlooked, and to prioritise them based on their potential impact and likelihood of occurrence. Risk identification and assessment can be performed using

various methods, including brainstorming, scenario analysis, and expert judgment (EI, 2010). The results of the risk assessment are used to inform risk management decisions, including the development of risk mitigation strategies, the allocation of resources, and the prioritisation of risk reduction efforts. Effective risk identification and assessment requires a systematic approach and the involvement of key stakeholders, including management, employees, and customers.

2.5 PSM models

Numerous other agencies have created PSM programmes after OSHA (2000) first implemented PSM legislation. The goal was to support businesses in their fight against process safety accidents. As a result, organisations developed and implemented PSM guidelines and standards specifically for the global industrial environment. In this section of the literature survey, models and approaches are reviewed and contrasted.

2.5.1 Occupational Safety and Health Administration

OSHA is a federal agency within the United States Department of Labor. Its mission is to prevent work-related injuries, illnesses, and deaths by setting and enforcing standards and by providing training, outreach, education, and assistance to employers and employees. OSHA was created in 1970 and is responsible for the administration and enforcement of the Occupational Safety and Health Act, which aims to ensure safe and healthy working conditions for workers in the United States (OSHA, 2000:7).

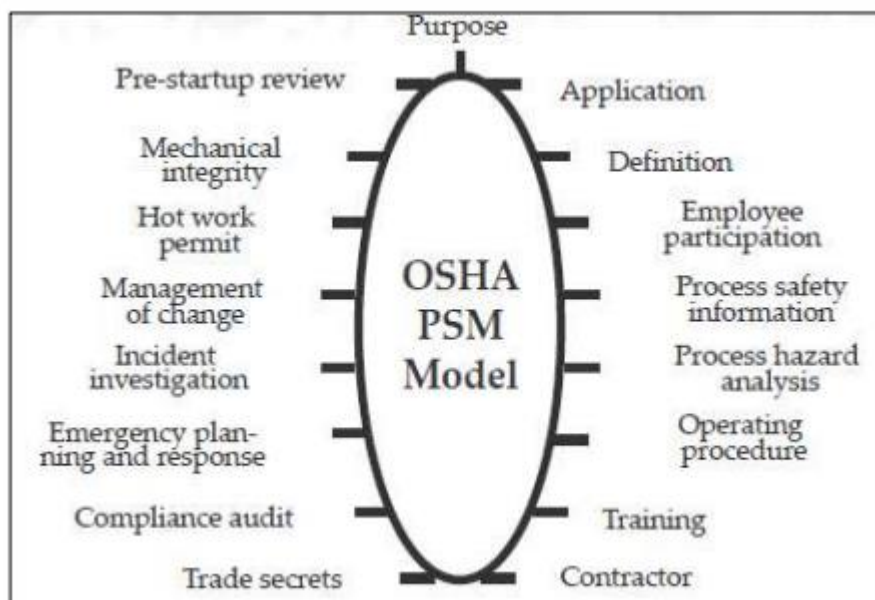


Figure 11: The OSHA model (OSHA, 2012)

As shown in Figure 11, this PSM model has 17 components that address various topics related to the management of an operational facility and process environment. According to OSHA (2000), PSM entails managing and training staff members and service providers, conducting safety risk analyses, managing work and modifications carried out in operational areas, maintaining plant equipment, and driving incidents.

In South Africa, the Minister of Labour has implemented the regulations listed in the schedule to comply with the Occupational Health and Safety Act, 85 of 1993 after consulting with the Advisory Council for Occupational Health and Safety. The government's dedication to protecting workers' health and safety in various industries is evident from these regulations, which were put in place to promote workplace safety and health standards. In order to reduce occupational risks and guarantee that employers provide safe and healthy working conditions, the Act serves as a core legislative framework. The Minister of Labour has emphasised the need for adherence to prescribed standards and procedures, as well as the need to take a proactive approach to occupational health and safety management by implementing these rules. This legislative action not only reinforces the government's dedication to protecting workers but also delineates the responsibilities of employers in fostering environments that prioritise health and safety. Through these measures, the Act facilitates a comprehensive and structured approach to identifying, evaluating, and mitigating workplace hazards, thereby enhancing the overall safety culture within the South African workforce (SAFCEC, 2023).

2.5.2 The Environmental Protection Agency's (EPA) risk-based process

The Environmental Protection Agency (EPA) is an independent agency of the federal government of the United States. Its mission is to protect human health and the environment by writing and enforcing regulations based on laws passed by Congress. The EPA was established in 1970 and is responsible for implementing and enforcing national environmental policy in areas such as air and water quality, hazardous waste management, and toxic substance control. The EPA also provides technical assistance and funding to states and tribes to help them carry out their environmental programmes.

The Clean Air Act Amendments (CAAA) were passed into law four months after the OSHA publication (EPA, 2011). To prevent the unintentional release of chemicals that endangered workers and the public, the CAAA and the EPA demanded that a chemical process safety standard be established by the OSHA standard (EPA, 2011). This standard includes a list of dangerous chemicals that are extraordinarily flammable, explosive, and poisonous and highly reactive.

Figure 12 illustrates 20 components, including committing to process safety, managing risk, understanding hazards and risk, managing risk, and learning from experience. Although some pieces have different names, it is similar to the OSHA model. Additional features of this model include the conduct of operations, outreach to stakeholders, safe work practices, adherence to standards, process safety competency, management review, and ongoing improvements.

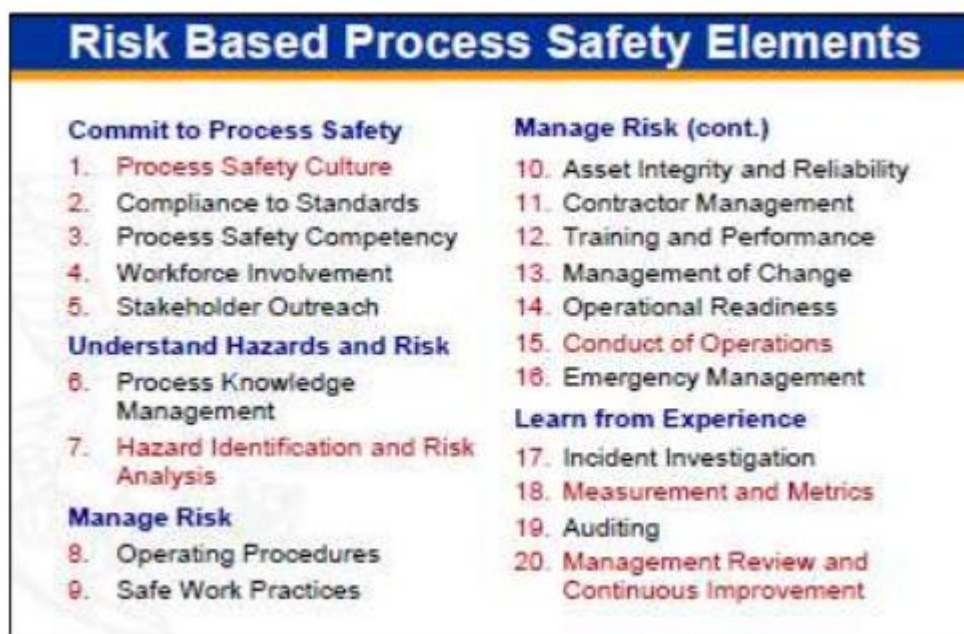


Figure 12: Risk-based PSM framework (Bradshaw, 2012)

Other factors centre on the station employee's competency, training, and procedure adherence. This referred to the focus on human interaction in PSM. The components of workforce involvement, stakeholder outreach, conduct of operations, and contractor management strengthen this. Compliance and operational effectiveness are determined through standards and broad audits.

2.5.3 Centre for Chemical Process Safety (CCPS)

The Centre for Chemical Process Safety (CCPS) is a research centre that forms part of the American Institute of Chemical Engineers (AIChE). It was established in 1985, and its mission is to promote the advancement of chemical process safety and help prevent chemical accidents through the development and dissemination of technical information, guidelines, and best practices. The CCPS provides a forum for industry professionals, researchers, regulators, and others to collaborate on process safety issues and to share their expertise and experiences. The CCPS produces guidelines and tools for the design, operation, and maintenance of safe chemical processes, as well as training programmes and workshops for industry professionals. In Figure 13, the CCPS and PSM model illustrates the different components.

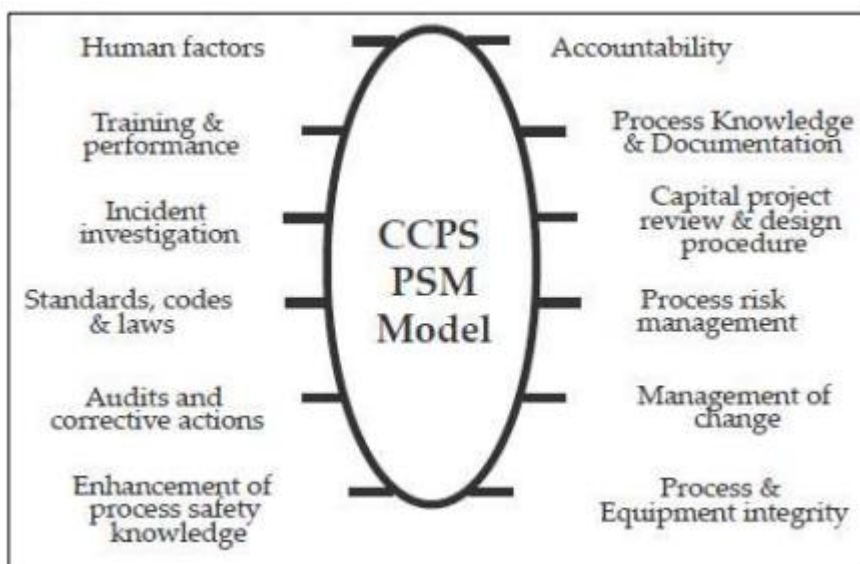


Figure 13: The CCPS model (OSHA, 2012)

Within the first five years of its existence, the CCPS released more than a dozen process safety guideline volumes and procedures (AIChE, 2012). The CCPS concepts were adopted and embraced by several businesses, including the 17 original member companies.

In South Africa, the petrochemical and chemical industries are governed by national regulations and standards that align with international best practices, including those recommended by the CCPS. Companies operating within these sectors often adopt internationally recognised SMSs and models to comply with local regulations, improve safety outcomes, and align with global standards (Naicker, 2022). The oil and gas industry, known for its large-scale operations and the important role in the world's energy supply, involves many complicated processes. These processes require strict safety rules to avoid accidents and protect the environment.

2.5.4 Oil and gas

The International Association of Oil and Gas Producers (OGP) is a global trade association representing the interests of oil and gas producers. It was established in 1948, and its members come from public and private sector organisations and include major international oil companies, national oil companies, and independent oil and gas companies. OGP's mission is to promote safe, environmentally responsible, and economically sustainable exploration and production of oil and gas. It achieves this by developing and promoting industry standards, providing training and educational resources, and facilitating the exchange of best practices and technical knowledge among its members. The OGP also actively engages with regulators and stakeholders to ensure that the oil and gas industry is well-represented in policy and regulatory discussions.

The world's top industry associations and private, publicly traded, and state-owned oil and gas firms comprise the OGP (2013). BP PLC, Chevron Corporation, Exxon Mobil, Conoco Philips, Petróleo Brasileiro SA, Shell International Exploration & Production BV, Statoil, Total, and Schlumberger are all represented on the management committee (OGP, 2013).

Based on this, OGP (2008) released a report on asset integrity that concentrated on the following areas: the asset integrity risk management process, obstacles, innocence throughout an asset's lifecycle, human factors, competencies, and monitoring and review.

2.5.5 The Energy Institute

The Energy Institute (EI) is a professional membership organisation for individuals and companies in the energy industry. It was established in 2001 and is based in the United Kingdom. The EI's mission is to promote safe, sustainable, and efficient energy use. To achieve this, it provides education, training, and technical support to its members and the broader energy industry. The EI develops and publishes guidance and best practice guidelines on a variety of energy-related topics, including health and safety, energy management, and the environment. The EI also conducts research, organises events and conferences, and provides a platform for industry professionals to network and share information. It is a recognised source of expertise and knowledge on energy-related issues and provides a voice for the industry in public policy debates.

The EI is the top chartered professional membership for individuals and organisations in the energy sector. More than 13 500 people and 300 companies from 100 countries are members (EI, 2010). As a Royal Charter organisation, its primary goals are to promote the efficient, safe, and environmentally responsible supply and use of energy for all purposes and in all forms (EI, 2010).

2.5.6 DuPont

In the 1960s, DuPont (2008) invented the ideas and methods that underlie PSM systems. Their working culture was built around strict risk management and process safety for over 200 years. The DuPont system's advantages were recognised by OSHA and the Environmental Protection Agency (EPA) by the late 1980s, and they hired them to help create the PSM laws that now regulate the industry (DuPont, 2008). There are 175 DuPont operations spread across 70 nations (DuPont, 2008). Figure 14 illustrates the DuPont PSM model.



Figure 14: The DuPont PSM model (DuPont, 2008)

The three key components of management, leadership, and commitment form the basis of this approach. Similar to the OSHA model, it is further divided into three broad dimensions, each with 14 sub-elements.

2.6 The OSHA elements

OSHA has established a set of elements for a comprehensive safety and health programme. These elements include:

- Management leadership: commitment from top management to promoting and prioritising workplace safety and health.
- Employee involvement: active participation of employees in identifying and addressing workplace hazards and improving safety and health.
- Hazard identification and assessment: identification and evaluation of workplace hazards to determine their potential effect on workers.

- Hazard prevention and control: implementing measures to eliminate or control workplace hazards, such as engineering controls, administrative controls, and personal protective equipment.
- Safety and health training: education and training of workers on safe work practices and hazards in the workplace.
- Programme evaluation and improvement: ongoing review and evaluation of the safety and health programme to identify areas for improvement and to ensure its effectiveness.
- Communication and coordination: clear and effective communication between management, employees, and relevant stakeholders to promote a culture of safety and health.

Adherence to these elements can help organisations establish a strong safety and health programme, prevent accidents and illnesses, and improve overall worker well-being. These rules integrate several techniques and have led to the institutionalisation of PSM. By deriving its respective components, the minimal specification was incorporated into the PSM standard. These OSHA PSM components are summarised in Table 2, along with the related guidelines (OSHA, 2000).

Table 2: Overview of the OSHA Elements (OSHA, 2012)

Element	Requirement
Employee Participation (EP)	Required Employee involvement in developing and executing as PSM program, particularly in the area of hazard evaluation.
Process Safety Information (PSI)	Required the employer to compile information related to the nature of the chemical (or flammable) hazards involved, process technology, and process equipment.
Process Hazard Analysis (PHA)	Required the employer to conduct a careful analysis of hazards involved with the process. Using one of several formal hazard analysis techniques, a team identified, evaluated, and recommended measures to eliminate, mitigate, or control hazards.
Operation Procedures (OP)	Required the employer to develop and implement written operating procedures for the covered process over all phases of its operation including safe work practices.
Training (TR)	Required employers to train all involved (including contractors) in operating the covered process on the hazards, operating procedures (normal and emergency), and safe work practices. The training was required for each person before they began operating a covered process.
Contractors (CTR)	For all contractors involved directly and in areas adjacent to covered processes, the employers need to evaluate the contractor's capabilities and safety history to assess their suitability for safe performance. In addition, all contractors expected to become involved in operating the covered process must receive training prior to their involvement in operation.
Pre-Start-up Safety Review (PSSR)	Required that employers perform a detailed review of a new or modified (changed) system to ensure the design is appropriate, construction adhered to design specifications, operating procedures were available, training was complete, process hazard analysis was completed, and all process safety information was current.
Mechanical Integrity (MI)	Required that employers develop and implement a methodical program for performing appropriate maintenance and equipment inspection/testing at proper frequencies to uncover equipment deficiencies before they fail.
Hot Work Permit (HWP)	Required that employers develop a formal program to prevent fire and explosions from occurring while conducting hot work (welding, cutting, brazing, grinding, etc.) in and around the covered process.
Management of Change (MOC)	Institute documented procedures aimed at ensuring safe system operation as changes to the system occurred. The management of change process guided updates or development to process safety information, process hazard analyses, operating procedures, and training to ensure all elements of the PSM program are current.

Incident investigation (II)	Required that employers investigated actual incidents or near-misses to understand the factors that contributed to the incident and to develop/resolve recommendations aimed at preventing their future occurrence. A formal incident investigation is needed to begin within 48 hours of an accident.
Emergency Planning and Response (EPR)	Required that employers conduct pre-planning for emergencies that may arise at the facility. At a minimum, the emergency planning needed to include notification procedures, escape routes, alarm systems, and plant-wide training. More intensive efforts were required for situations where employees are expected to actively become involved in mitigating incidents.
Compliance Audits (CA)	Involved in critically evaluating a PSM program and the extent of its implementation at least every three years. The audit must clarify whether the plant was following the standard or identify areas of non-compliance that the plant needed to address to bring the program back into compliance.
Trade Secrets (TS)	This allowed employers to protect those aspects of their covered process considered a trade secret.

Regarding comparative studies, the components of the OSHA mentioned above served as the baseline PSM components. This resulted from OSHA formalising and implementing the initial PSM system.

2.7 Hazard and operability analysis

HAZOP analysis is a risk assessment technique used to identify and evaluate potential hazards and operability problems in complex process systems, such as those found in petrochemicals and other industries. The goal of HAZOP analysis is to identify potential deviations from the normal operating conditions and to assess their impact on safety, health, and the environment. The HAZOP analysis process typically involves a systematic review of the process design and operating conditions, using a standardised set of deviation scenarios to identify potential hazards and operability problems (Crawley *et al.*, 2015).

The HAZOP analysis is typically conducted by a team of experts, including process engineers, safety specialists, and operational personnel, who work together to identify and evaluate potential hazards and operability problems (Rossing *et al.*, 2010:244). The results of a HAZOP analysis are documented and used to develop recommendations for improving the process design and operating procedures to eliminate or mitigate the identified hazards and operability problems.

HAZOP analyses are widely recognised as a best practice for PSM. It is used by organisations around the world to help ensure that their processes are safe and secure. It is a proactive approach that can help organisations identify potential hazards before they become incidents, and it provides a structured and systematic framework for addressing safety and operability issues in the process design and operations (Dunjó *et al.*, 2010:19).

HAZOP analyses are vital for finding and assessing the complex risks in industries like petrochemicals. This detailed risk check prepares the way for the management of change (MoC), which deals with handling and reducing these risks by carefully planning changes to the way things are done, including updates to equipment or systems. By using HAZOP to spot risks early and MoC to make informed changes, companies can improve their safety measures, work more efficiently, and make sure they follow the rules.

2.8 Management of change

Management of change (MoC) can be traced back to the early 20th century when industrial processes became more complex, and organisations started to realise the need for systematic approaches to change management (OSHA, 2000). According to EI (2010), MoC became more formalised in the mid-20th century with the development of total quality management (TQM) and business process reengineering (BPR). In recent years, the increasing pace of technological advancements and globalisation has made MoC an essential component of organisational strategy and management. Today, MoC is widely used across various industries and organisations, including the petrochemical, pharmaceutical, and manufacturing industries to ensure the effective and efficient implementation of changes while minimising risks and maintaining compliance with regulations. MoC refers to planning, documenting, and implementing changes to a company's systems, processes, or equipment in a controlled and systematic manner. The goal is to minimise disruption and ensure the transition is successful and sustainable (EI, 2010).

The projected modifications to a process must be carefully assessed to fully evaluate the effect on the business and employee safety and health (OSHA, 2000). EI (2010) mentioned that with this strategy, every change that would affect the organisation would need to go through a risk assessment to make sure it supported the organisation.

The asset design, operating, and maintenance techniques that form part of a PSI require thorough documentation. It was necessary to complete all operational, maintenance, and testing procedures. More qualified individuals must be found and trained by the TR element. Equipment performance functional testing must be a part of this instruction. OSHA, EI, and OGP were therefore seen to have an aligned strategy.

The requirements for a successful MoC process typically include (Wincek *et al.*, 2015:89).

- Clear definition of the change: The change must be well-defined, including its scope, purpose, and expected outcomes.

- Risk assessment: A thorough assessment of the potential risks associated with the change must be conducted.
- Impact analysis: An analysis of the impact of the change on various stakeholders, such as employees, customers, and suppliers, must be performed.
- Communication plan: A communication plan must be developed to ensure all stakeholders are informed of the change and its implications.
- Stakeholder involvement: Stakeholders must be involved in the MoC process to ensure their buy-in and support.
- Training and support: Employees must be trained on the changes and provided with ongoing support to ensure the transition is successfully implemented.
- Monitoring and review: The change must be monitored and reviewed regularly to ensure that it achieves the desired outcomes and to identify and address any issues that may arise.
- Documentation: The MoC process must be well-documented to ensure its effectiveness and to provide a record of the change for future reference.
- Compliance with regulations: The change must comply with relevant laws, regulations, and industry standards.
- Continuous improvement: The MoC process should be continuously improved to ensure that it remains effective and efficient in supporting organisational change.

2.9 Natural culture and PSM system

PSM is typically seen as a way of thinking that necessitates both sociocultural and psychological change in employees (Stritch *et al.*, 2014:842). It is impossible to overstate how crucial safety is to every element of human life (Hollnagel, 2018:29). Some people view safety as a requirement put on them by their religion, where they are expected to take responsibility for their well-being as well as that of those in their care (Brauer, 2022:19). Legal, societal, and financial considerations are also seen as components of safety (Brauer, 2022:19). Legally, anyone may be held liable for risky actions that result in an accident. Everyone is accountable for avoiding harming themselves

and other people because, socially speaking, everyone lives in a society. Additionally, the financial cost of accidents is equivalent to the economic nature of safety (Brauer, 2022:548).

Companies' basic PSM programmes differ significantly from one another in terms of its features and components, as well as its employees' perceptions of fundamental safety procedures (Bridges *et al.*, 2010:24). The established manner of doing things within a firm or the norms that are regarded as acceptable or forbidden by the organisation as an institution, is one crucial component that could be accountable for variances or similarities between the PSM systems of companies (DeWolf, 2003:192). It is the safety culture. This section examines the safety culture of the petrochemical sectors of South Africa. A strong safety culture is essential and is the root of many human errors. Safety culture must be steered from the top down, not from the based on the administrative pyramid. Senior management must adopt them and urge others to follow suit to make excellent safety practices a culture. Culture is a product of society and has an effect on every enterprise (Block, 2016:72).

2.10 Incident investigation

Incident investigation refers to the systematic process of analysing an event or situation that caused harm, damage, or disruption to determine its root causes and to prevent similar incidents from happening in the future. Incident investigation typically involves collecting and analysing data, interviewing witnesses and involved parties, and identifying corrective actions to prevent recurrence. The goal of an incident investigation is to find out what happened, why it happened, and what can be done in order to avoid it from happening again, thereby improving organisational safety and effectiveness. Incident investigations are common in various industries, including aviation, healthcare, manufacturing, and construction, to ensure that lessons are learned from incidents and that there is continuous improvement in safety and risk management.

Incident investigation is a critical component of many organisational SMSs and is referred to in various regulations and industry standards, including:

- OSHA (Occupational Safety and Health Administration) regulations in the United States
- ISO 45001:2018: Occupational health and SMSs
- The National Safety Council's accident investigation and analysis course
- The Health and Safety Executive (HSE) in the UK

- The International Association of Oil & Gas Producers (IOGP) - Safety Management Standard
- The National Fire Protection Association (NFPA) - Standard for Accident Investigation.

These regulations and standards guide the processes and techniques that should be used in incident investigation and the documentation and reporting requirements that must be followed. Organisations are often required to conduct investigations in accordance with these standards to demonstrate compliance and maintain their operating licenses (OGP, 2008).

2.11 Occupational Health and Safety Act, 85 of 1993

The main law controlling occupational health and safety in South Africa is the Occupational Health and Safety Act, 85 of 1993. This act, which was passed by Parliament and consists of 50 sections, has been implemented to secure people's safety and welfare when using machinery (du Plessis, 2017:5). The legislation includes a thorough framework that details the duties and obligations of employers, workers, manufacturers, suppliers, and anyone else involved in the workplace, highlighting how important it is to ensure a safe and healthy work environment. The Occupational Health and Safety Act seeks to limit risks, decrease workplace hazards, and promote a culture of safety across various industries by establishing standards, specifying procedures, and outlining consequences for non-compliance (du Plessis, 2017:5).

There are several ways in to prevent incidents in the context of PSM models and related approaches discussed above.

2.11.1 Comprehensive PSM models

The guidelines provided by the OSHA, EPA, CCPS, OGP, Energy Institute, and DuPont for comprehensive PSM models should be followed. These models include various elements and recommendations that address essential facets of process safety (Naicker, 2014:22).

Strong management commitment

As emphasised in the OSHA's PSM model, top management should be committed to promoting and prioritising worker safety and health. This dedication establishes the foundation for a corporate culture that prioritises safety (Naicker, 2014:47).

Employee involvement and competency

Training and competency development programmes can help employees develop their understanding of process safety risks and safe work practices. Employees should be actively involved in identifying and addressing workplace hazards (Naicker, 2014:38).

Hazard identification and assessment

Thorough hazard identification and assessment processes should be followed, such as HAZOP analysis, to identify potential deviations from normal operating conditions and to evaluate their effect on safety, health, and the environment (Naicker, 2014:40).

Change management best practices

Best practices for MoC procedures should be observed, such as clearly defining changes, risk assessments, impact studies, stakeholder involvement, training and support, and adherence to legal requirements (Naicker, 2014:47).

Incident investigation and learning

Management should create a structured procedure for incident investigation to identify underlying causes and corrective actions while encouraging a culture of ongoing learning from incidents to stop recurrences (Crowl, 2007:26; Naicker, 2014:48).

Compliance with regulatory standards

A safe working environment should be maintained by adhering to and following all applicable regulatory requirements and industry norms, including those established by OSHA, EPA, and other industry-specific organisations (Crowl, 2007:146; Naicker, 2014:49).

Regular programme evaluation and improvement

To increase overall safety and operational effectiveness, PSM programmes should be continuously evaluated for effectiveness, as stressed in OSHA's PSM model (Naicker, 2014:50).

Stakeholder engagement and outreach

A shared commitment to safety and compliance should be promoted among all stakeholders, including workers, contractors, and pertinent industry groups, through outreach programmes and open communication (Crowl, 2007:114; Naicker, 2014:25).

Documentation and reporting

Compliance with reporting requirements and essential rules and standards should be ensured by maintaining complete documentation of PSM processes, revisions, incident investigations, and safety training (Crowl, 2007:131; Naicker, 2014:40).

Risk management:

Risk management should receive top priority as a crucial element of the PSM framework. Management should determine, evaluate, and prioritise potential risks early on that are unique to the petrochemical sector, including fires, explosions, toxic substance spills, and equipment failures. To reduce these risks and create a safety culture, thorough risk management measures should be implemented (Naicker, 2014:31).

Incorporate inherent safety philosophy

The 'inherent safety' guiding principle should be included while designing petrochemical plants. The value of creating procedures that naturally lower risks and prevent accidents should be stressed. To reduce the possibility of mishaps, safety measures and considerations should be incorporated in the early design (Amyotte *et al.*, 2017:148).

Enhance process safety leadership

Strong leadership should be encouraged for process safety at all organisational levels. Top management should be dedicated, engaged, and leading in fostering a safety-first culture. Clear accountability, excellent communication, and ongoing process safety performance improvement should be fostered by incorporating process safety into the overall management strategy (Crowl, 2007:10).

Address human error and behavioural factors

Human error poses a severe risk to the petrochemical industry and appropriate action should be taken in this regard. Priorities should be set for projects using improved training, SOPs, and technological developments to reduce human error. A culture should be created that prioritises error prevention and learning from mistakes, with a focus on addressing the behavioural elements that contribute to human error (Crowl, 2007:3).

Promote continuous review and improvement

A culture of ongoing evaluation and development in the company should be encouraged. The efficacy and efficiency of systems, processes, and practices should be improved by regularly analysing and adapting them. To consistently improve safety and lower risks, an environment

should be created that values feedback, data analysis, and the discovery of improvement opportunities (Crowl, 2007:25).

Integrate risk identification and assessment

Risk assessment and identification should be included into operational procedures. Various techniques can be used, such as scenario analysis and brainstorming, to thoroughly identify potential risks. Risks should be assessed according to their likelihood and potential impact and the results of the evaluations should guide resource allocation and risk mitigation plans (Crowl, 2007:156).

2.12 Summary of catastrophes in the petrochemical industry and its connected industries

A significant incident may be described as a fire, explosion, or significant release of a hazardous or harmful substance into the environment with serious adverse effects on people's health, the environment, revenue, assets, and the reputation of the company. There have been significant occurrences in the petrochemical sector. These important events have been well documented, allowing for significant learning from past experiences about what strategies are effective and what approaches fail in PSM. Research in this field acknowledges the significance of safety as a critical element in preventing accidents (Michalis & Myrto, 2012). Table 3 gives an overview of the most significant recent disasters in the petrochemical and associated industries.

Table 3: Catastrophic petrochemical accidents outside South Africa (Aljohani, 2021:53)

DATE	COUNTRY	ACCIDENT
June, 2019	Philadelphia Refinery Explosion, USA	The explosion and fire led to minor injuries and was catastrophic to business operations. It destroyed the alkylation unit of the Philadelphia Energy Solutions refinery, where crude is converted to high-octane gas.
July, 2013	Lac-Megantic Derailment Quebec, Canada	47 people were reportedly killed following a derailment of an oil shipment train. The derailment was accompanied by fire and explosion, leading to lost lives and destruction of properties.
October, 2012	Hurricane Sandy Disaster, USA	This caused an explosion at a Consolidated Edison power plant. There were no officially reported casualties and/or injuries.
March, 2011	Tohoku Earthquake and Tsunami, Japan	This caused the Fukushima Daiichi Nuclear Accident in Japan (the largest nuclear disaster after Chernobyl). It resulted in no direct fatalities but some of the plant's workers suffered severe injuries. Another accident that occurred because of the Tohoku Earthquake and Tsunami was the Ichihara gas tank fire, Chiba Prefecture. This was a fire in a natural gas plant at the Ichihara oil refinery. It resulted in fatalities and destruction of properties.
April, 2010	Deepwater Horizon Oil Spill, Gulf of Mexico, USA	11 workers were reported dead because of the oil spillage which was accompanied by an explosion and massive fire in the Gulf of Mexico.
February, 2010	Connecticut Power Plant Explosion, USA	This was a large explosion at the Kleen Energy System in Connecticut. This resulted in 5 deaths and 27 injuries of varied degrees.
August, 2009	Savano-Shushenskava Power Station Accident.	75 people were reported dead, and others were severely injured because of the accident, which was caused by a turbine failure at the hydroelectric power station.
December, 2008	Kingston Fossil Plant Coal Fly Ash Slurry Spill, Tennessee, USA	This resulted in a loss of 1.1 billion gallons of coal ash.
December, 2007	T2 Laboratories Explosion and Fire,	This was caused by an explosion of a runaway reactor used for the production of gasoline additives.

2.13 Previous case studies

PSM is a critical component of overall workplace safety and is essential for several reasons:

- Protection of workers and the public: PSM helps to prevent incidents and accidents that can harm workers and members of the public, and it helps to ensure that all employees and stakeholders are aware of the hazards associated with the workplace and how to avoid them.
- Compliance with regulations: PSM helps organisations to comply with applicable regulations and standards, such as OSHA's PSM standard, which requires employers to establish and implement an effective PSM programme.
- Mitigation of risk: PSM helps to identify and control potential sources of harm, such as toxic releases, fires, and explosions, and it helps to minimise the likelihood and consequences of these events.
- Improved efficiency and productivity: PSM can help organisations identify and eliminate inefficiencies in their processes, which can lead to improved productivity and reduced costs.
- Reputation and brand protection: PSM helps organisations maintain their reputation and brand by ensuring that their operations are safe and responsible and that they are seen as good corporate citizens by the public, stakeholders, and regulators.

In conclusion, PSM is essential to ensuring the health and safety of workers and the public, protecting the environment, and maintaining the viability of organisations in a highly regulated and competitive global marketplace (Behie *et al.*, 2020:9).

Previous studies have investigated these factors and concluded that cultural and leadership commitment are necessary to reach successful outcomes for PSM frameworks and EI models (Naicker, 2014:87). Naicker (2014:87) concludes that the foundation of a successful and long-lasting PSM programme is a safety culture and leadership commitment. The DuPont, CCPS, risk-based PSM framework, and EI models best incorporate these fundamentals. Management should figure out how to integrate these key components into an organisation. Additionally, a brand new PSM programme could be suggested that incorporates these critical components to create a PSM programme that is both effective and long lasting.

Roughton (1993:28) concludes that a comprehensive approach to PSM is the best way for industry to safeguard processes. PSM will also reduce catastrophic events while waste can be reduced, and productivity can be increased. According to Behie *et al.* (2020:9), over the years, companies have effectively implemented PSM programmes to reduce the number of incidents as

well as their severity. According to Rusli and Abidin (2021), human error is continuous. Even though the significant incidents are documented, circulated and shared, failures of a similar nature continue to happen.

This study focuses on the petrochemical industry in South Africa, but the available studies were not on the petrochemical industry nor South Africa. The contribution of PSM in the petrochemical industry in South Africa can include:

- An improved safety culture: PSM helps to promote a culture of safety within the industry by encouraging organisations to focus on safety and to engage employees and stakeholders in the process.
- A reduction in incidents and accidents: PSM helps to identify and control potential sources of harm, such as toxic releases, fires, and explosions, which can reduce the number and severity of incidents and accidents in the industry.
- Compliance with regulations: PSM helps organisations to comply with applicable laws and standards, such as the Occupational Health and Safety Act, 85 of 1993, which requires employers to provide a safe and healthy working environment for employees.
- Environmental protection: PSM can help to minimise the impact of the petrochemical industry on the environment by reducing emissions and waste and by promoting environmentally responsible practices.
- Improved efficiency and productivity: PSM can help organisations identify and eliminate inefficiencies in their processes, which can lead to improved productivity and reduced costs.
- Reputation and brand protection: PSM helps organisations maintain their reputation and brand by ensuring that their operations are safe and responsible and that they are seen as good corporate citizens by the public, stakeholders, and regulators.

In conclusion, PSM is a critical component of the petrochemical industry in South Africa as it helps to ensure the health and safety of workers and the public, protects the environment, and maintains the viability of organisations in a highly regulated and competitive global marketplace.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

Chapter 3 outlines the appropriate research design and methodology for this study. Document analysis was selected as a suitable methodology for this study. This method was chosen to answer the research questions by considering the research problem, which entails a critical evaluation of PSM in the petrochemical industry in South Africa. This chapter explains the methods followed during the study. Additionally, the trustworthiness and the ethical aspects of the research are discussed.

3.1.1 Research objectives

Understanding the research design and methodology is essential to respond to the research questions and achieve the research goals described in Chapter 1. The rules or strategies that must be used to address the study problem are known as a research design (Mouton, 2012:56). Document analysis was used in this study to adhere to the research plan and put the data in a logical arrangement. Labaree (2013) asserts that a research question from the research problem forms the basis of every study.

The study's specified research topic determines the research design used. In contrast, the research methodologies determine how to generate and analyse data and ensure the study results are trustworthy (Creswell & Poth, 2018). Data can be collected using various qualitative, quantitative, or combined methodologies (Joubert *et al.*, 2016:33).

The primary objective of the study, as seen in 1.5.1, is to do a critical evaluation of PSM in the petrochemical industry of South Africa.

The secondary objectives are:

- To create an understanding of PSM in the petrochemical industry in South Africa;
- To determine the PSM elements that significantly contributed to process safety incidents in the petrochemical industry in South Africa; and
- To identify the PSM failures that resulted in process safety incidents in the petrochemical industry in South Africa.

3.1.2 Quantitative research

A quantitative research method uses numerical data to measure a relationship between variables and typically involves experimental or survey-based research (Charles & Mertler 2002:342; Ivankova *et al.*, 2011:257). To comprehend social phenomena, qualitative research, on the other hand, focuses on the participant's perspective and experience from a natural context. This type of research frequently uses standardised tools, such as surveys or questionnaires, to gather information from a sizable sample of individuals. One of its advantages is the potential of quantitative research to generate trustworthy and generalisable results that may be used for a larger population. Also, it enables accurate measurement of variables, which helps determine causal linkages. Quantitative research has drawbacks, such as the possibility of bias in the interpretation of data and a potential lack of depth in understanding complex social processes. Despite these drawbacks, quantitative research is a widely used and productive technique in various disciplines, such as psychology, economics, and public health (Theunissen, 2016:55).

As part of the effect of natural science on information systems, logic and mathematics provide the foundation for quantitative methods in information systems. Handling numerical data during the investigation is the primary characteristic of a quantitative approach. Deductive thinking and a positivist paradigm are also frequently linked to a quantitative approach. The creation of hypotheses usually comes after formulating research questions. Standard quantitative research evaluate the theories using data gathered from community samples, depending on the type of study (Mardiana, 2020:3). Statistical tools are used to analyse the data. Decisions regarding whether to accept or reject the hypotheses are made as the final product of analysis.

3.1.3 Qualitative research

In qualitative research, non-numerical data such as text, photographs, videos, human movements, and gestures, are gathered and analysed (Mardiana, 2020:3). A qualitative study is often carried out in a natural setting, and it takes a discovery-oriented method as the researcher proceeds from facts to theory (inductively). It assumes an all-encompassing viewpoint with dynamic perspectives that change depending on the circumstances. Qualitative data collection indicates that thorough research is being conducted. This method is suitable for the critical evaluation of PSM in the petrochemical industry in South Africa. This study investigates a current problem. According to Hammersley (2013:132), this can only be accomplished through qualitative data. Hence, a qualitative research approach was adopted in this study. Document analysis was used to process and evaluate printed and electronic documents to gather qualitative data (Creswell, 2015:281). This study includes an analysis of printed and digital current events records

(Bowen, 2009). The researcher must compare these documents using the comparative technique to identify best practices.

For this study, the qualitative research method was used to answer the research questions concerning the critical evaluation of PSM in the petrochemical industry in South Africa.

3.1.4 Research design

The research onion model was used in this mini-dissertation to direct the study design (Mardiana, 2020). The research onion is a well-known conceptual model that offers a systematic approach to study design and allows the researcher to take into account each layer of the onion and its related elements, such as research philosophy, research approach, data collecting, and data analysis methodologies (Saunders *et al.*, 2016). The parts of the research onion model are illustrated below (Mardiana, 2020).

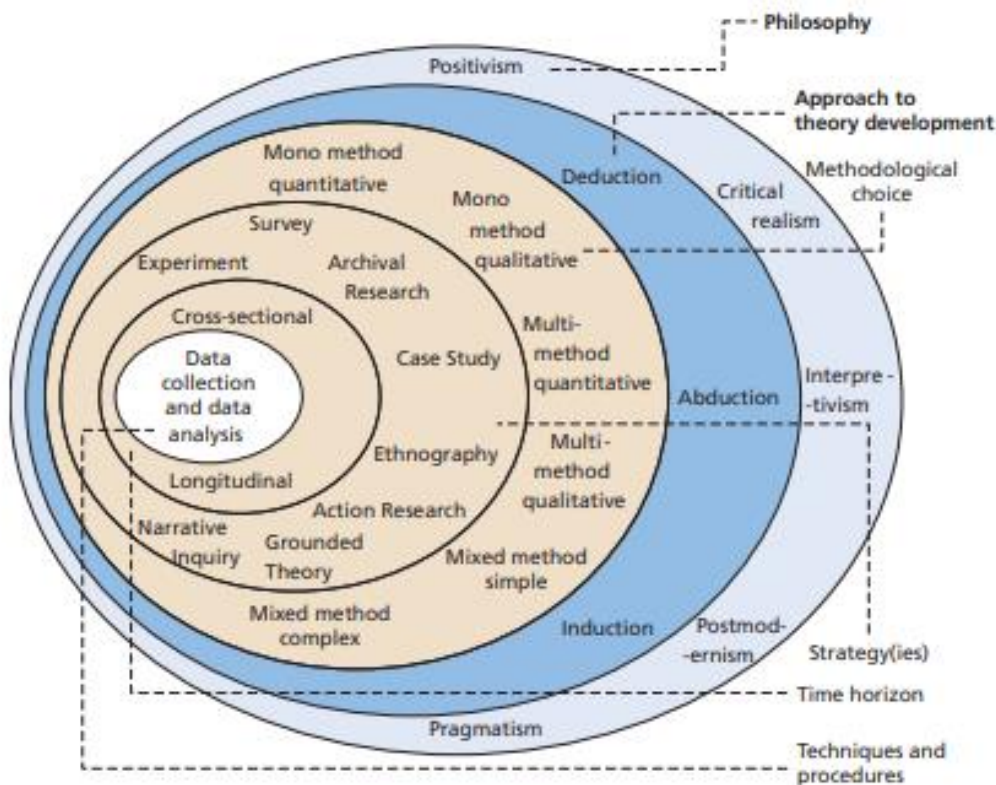


Figure 15: Research onion (Saunders *et al.*, 2016)

3.1.5 Research philosophy

In the Western tradition of science, two main research ideologies have been identified: positivism (also known as scientific) and interpretivism (also known as anti-positivist) (Galliers, 1991: 327). This implies that research is either subjective or objective. When it is interpretivist or more

subjective, the researcher is not excluded from the subject of the inquiry, but when it is scientific or more objective, the researcher is excluded. The research paradigm's ontological dimension, characterised by a blend of qualitative and quantitative methods of inquiry, is represented by the objective-subjective dichotomy. The sociology of radical change or the sociology of regulation stands in for the second dimension, which is epistemological. This refers to the researcher's fundamental assumptions regarding the nature of knowledge and how it might be acquired.

3.1.6 Research paradigm

Since a research study reflects the researcher's worldview. Some authors, like Creswell (2009), have suggested that researchers are positivists, constructivists, advocates, or pragmatists. Their philosophy affects the research design. A philosophical worldview is depicted in four quadrants, with the sociology of regulation on one side and the sociology of radical transformation on the other. Subjectivity and objectivity are opposite extremes of the framework depicting world perspectives, making up the other two contradictions. The researchers that fall into the first of the four quadrants might be summed up as subjectivist pragmatists who subscribe to a sociology of radical transformation. Subjective constructivists in the sociology of social order make up the second category. The sociology of a social order's objective positivists makes up the third type, and the sociology of radical change's object radical humanists round off the list.

Positivism

Suppose researchers adopt a paradigm of functionalism and believe that the best way to study such worlds is through an objective approach (epistemology), independent of the person conducting the observation, such as by using standardised data collection tools like surveys. In such a case, they view the world primarily as consisting of social order (ontology) and seek to study patterns of ordered events or behaviours (Bhattacharjee, 2012:19). Some authors view positive theory as functionalism. Positivism or functionalism has a place in the objective social order. These scientists conduct considerably more systematic studies of reality. The phrase "scientific method" is occasionally used to describe positivism (Mackenzie & Knipe, 2006). The authors say that quantitative data gathering and analysis approaches are typically linked to positivism and positivist research.

Interpretivism

Interpretivism emerged in the nineteenth century to achieve a high level of understanding and the ability to interpret and make sense of data (Maree, 2009:58). The interpretivist research paradigm forces the researcher to think about conducting research outside a defined framework. Such research uses flexible and tailored research frameworks to gather, analyse, and interpret data to

replicate information documents (Edirisingha, 2012). A worldview (paradigm) filters the information to ensure that the researcher can recognise the underlying ideas that should be highlighted in the research and put into practice (Leavy, 2017).

According to De Beer (2017), interpretivism enables the researcher to create, examine, and interpret text data so that the words come to "life" and the data accurately depict the desired reality. According to Maree (2009), interpretivism is a research paradigm that offers the chance to put a specific situation into perspective by looking at and evaluating facts to understand and convey the problem. According to Rubin and Babbie (2010), there are three main principles of interpretivism:

- The researcher is interested in the subject.
- The researcher serves as the core of the collected, analysed and evaluated data.
- A principle exists that a person is an object with a mind, while human behaviour can be influenced by the social world that only comes from relations with man. People form the principle of the social world and understand.

3.2 Research methodology

The research technique was addressed in Chapter 1 to explain how it would be used to investigate the research problem, analyse it, and then assess it to address the problem statement. According to Creswell (2017:32), the research methodology is the general strategy for a study's success. In this study, data were generated by document analysis and then used to examine the data through content analysis.

3.2.1 Data generation through document analysis

Data was generated from documents. According to Flick (2013), data produced in this manner results in generalisations. These generalisations are created using data of different types gathered from various information sources and compared to one another. It includes collecting and comparing any sort of documented material, including written, visual, and electronic data (Nieuwenhuis, 2016). Blaxter *et al.* (2010:186) describe the four forms of sources for document analysis as follows:

- Policy-based document analysis involves investigating and analysing specific and relevant policies and the decisions regarding the policies to support a particular study, for example, the codes of employees' workplace.

- Historically, oriented document analysis includes all archival documents and available sources, such as diaries, bibliographies or recordings of historical events.
- Computer-based document analysis involves data already being analysed, processed, and used for further research.
- Library-based document analysis involves the critical examination of existing research literature.

According to Nieuwenhuis (2016), data comes in two forms, namely primary and secondary data:

- Primary data are a collection of original information obtained using data generation and analysis techniques.
- Data that have already been collected and analysed are considered secondary data. This processed data is priceless because it saves the researcher time and money, according to Blaxter *et al.* (2010:186). The researcher should thoroughly validate secondary data to confirm its accuracy.

3.2.2 Data research

Keywords have been identified to ensure that there is no deviation during the study. The following keywords were used: PSM, petrochemical industry, and South Africa.

The following search engines will be used to find appropriate data, including company documents:

- African Journals
- ERIC
- BASE
- JSTOR
- Google Scholar
- Microsoft Academic

Electronic reports were collected from companies in the petrochemical industry. The researcher received approval to use this data, although the companies will stay anonymous. The types of documents collected include internal reports, safety protocols, process management documents,

and regulatory compliance records. These documents were carefully selected to gain in-depth insight into PSM practices across the sector. Each document underwent an evaluation process to ensure its relevance, timeliness (spanning the years 2009 to 2023), origin verification, and applicability to the study's objectives. The study followed the steps outlined by Nieuwenhuis (2016):

- The primary and secondary documents were examined for relevance and usefulness.
- The publication dates of all data were limited to ensure that they fall within the identified time frame (2009 to 2023) and are relevant to the focus of the study.
- The origin of all the documents was verified to determine their contribution to the study.
- The purpose of each document was established to ensure that the context was indeed applicable to the study.

By applying the above steps, the researcher ensured that the data was correctly categorised. This then leads to the next point of discussion.

3.2.3 Categorisation of data

Data were divided into different categories so that irrelevant information could be removed. The following categories were mainly used:

- Regulatory compliance
- Safety protocols and procedures
- Accident reports and analysis
- Management of change
- Training and personnel

The categorised data were examined and analysed to retain only data that could answer the research question. Flick (2013) describes the following steps as the key to success in categorising data:

- The social phenomenon being studied must be thoroughly investigated and described.
- Differences and similarities must be identified from the data.
- Finally, an explanation must be given of why there are differences in the data.

To simplify analysis, the study's systematic approach involved carefully sorting, coding, and organising data from the petrochemical industry based on predetermined themes relevant to the study's goals. Initial document sorting by category, thematic code application and identification, and thorough sub-categorisation for in-depth study within these themes formed part of this process. The arranged data were then digitally stored using secure cloud storage options and encrypted databases to guarantee confidentiality and accessibility. This allowed for effective data management. The data were methodically prepared for in-depth analysis while upholding integrity and adhering to confidentiality regulations thanks to this expedited procedure.

3.2.4 Method of data storage

The information used during this study is not sensitive. Therefore, all the generated data will only be stored on a hard drive for five years. A passcode will protect this to ensure the petrochemical organisations stay anonymous.

3.2.5 Content analysis

Content analysis is the systematic and detailed examination of content for specific data to identify certain themes (Leedy & Ormrod, 2013:148). Content analysis is performed by various human means of communication, such as newspapers, books, personal journals and legal documents, to be used (De Beer, 2017:41). Neuendorf (2002:10) describes content analysis in the following way:

"Content analysis is a summarising, quantitative analysis of messages that relies on the scientific method (including attention to objectivity, intersubjectivity, a prior design, reliability, generalisability, replicability and hypothesis testing) and is not limited as to the type of variables that may be measured or the context in which messages are created or presented."

However, Nieuwenhuis (2016) believes that content analysis is directly related to qualitative research. This study was completed using qualitative research. As Nieuwenhuis (2016) explained, the end goal of content analysis is to process data from documents systematically.

3.2.6 Objectivity of the researcher

The researcher distanced himself from the research while reflecting on PSM in the petrochemical industry in South Africa. The researcher employed a reflective, analytical stance in presenting the findings from document analysis. By maintaining an objective distance, the focus was on accurately portraying the emotions and experiences conveyed within the documents related to PSM, without personal biases influencing the interpretation. This approach allowed for an understanding of the subject matter, highlighting the complexities and challenges faced in the industry. The analysis aimed to present a balanced view that captures the essence of PSM practices, the emotional and experiential dimensions of those working within the petrochemical sector, and the impact of these practices on safety outcomes. Through this method, the researcher could offer insightful reflections on the data, contributing to a deeper comprehension of the role and effectiveness of PSM in South Africa's petrochemical industry.

3.2.7 Data analysis process

In this study on PSM in the South African petrochemical industry, the researcher followed a systematic approach to qualitative data analysis, as outlined by Elo *et al.* (2014) and further recommended by Rapley (2007) and Bengton (2016). The following steps were undertaken:

Step 1: Defining the research question

The initial step involved pinpointing the central research question to guide the thematic focus of data collection. This question was refined throughout the study to remain aligned with emerging insights.

Step 2: Maintaining a research diary

A research diary was kept for systematic data recording, where observations, methodological notes, and reflections were entered, ensuring a comprehensive account of the research process.

Step 3: Document collection and storage

The researcher sourced relevant documents from a variety of platforms, including online databases, books, and academic journals, as well as company documents. These were digitally stored for efficient access and reference, ensuring a robust foundation for analysis.

Step 4: Transcribing and annotating

All collected documents were transcribed and annotated to highlight significant data points and to facilitate the organisation of information under key themes, employing markers for easy identification of pertinent data.

Step 5: Reviewing and organising data

The transcribed data underwent multiple reviews to grasp the underlying concepts fully, ensuring the researcher's deep familiarity with the content. This phase was critical for accurately categorising and storing information for easy retrieval.

Step 6: Coding

Data were coded according to major themes related to the research question, with flexibility for codes to overlap and evolve as deeper understanding was achieved through continuous data comparison.

Step 7: Data analysis

The researcher analysed the documentation for patterns and variances, forming preliminary conclusions. This iterative process allowed for the development of a grounded theory reflective of the study's findings.

Step 8: Verifying document credibility

To ensure the study's credibility, reliability, and validity, methods such as outlier analysis, comparison with existing literature, and peer consultation were employed, enhancing the research's effectiveness.

Step 9: Compiling the analysis

The final step involved synthesising the findings into a coherent analysis, maintaining objectivity and reflexivity. This comprehensive write-up reflected on the study's contribution with valuable insights into PSM practices.

Throughout the study, the focus was primarily on electronic documents and scholarly articles, allowing for a detailed, document-based exploration of PSM without direct reliance on participant testimonies. This methodological pathway enabled a focused, in-depth analysis consistent with the established steps for qualitative research.

3.2.8 Ethical considerations

Undergraduate students and professional researchers must obey ethical codes. Cohen *et al.* (2007:71) argue that it is the starting point of a good research study. As already mentioned, document analysis was used during this study. Therefore, the study will not use confidential or sensitive information. The researcher adhered to the ethics guidelines of the North-West University. The ethics clearance number was NWU-00579-23A4.

3.2.9 Trustworthiness of the data

According to De Beer (2017), the reliability and validity of a study depend on the quantity and variety of data collected from various documents. To enhance the quality of the data, it is essential to compare and contrast the documents, identifying differences and similarities. Flick (2013) found that crystallisation is the most appropriate way to collect data to ensure that the written and numerical data are not lost during the research's collection process. Nieuwenhuis (2016) explains that crystallisation is how the trustworthiness of a study can be determined. As Nieuwenhuis (2016) describes, crystallisation refers to information related to the same phenomenon, regardless of whether the information is presented numerically or in written form. This study focused on a single social phenomenon, which limited data collection to ensure reliability and validity through cross-referencing with other documents.

3.3 Conclusion

Chapter 3 elaborated on the selected research design and methodology with an emphasis on document analysis for investigating PSM in South Africa's petrochemical sector. It articulated a detailed strategy that aligned the study's aims with qualitative methodologies to facilitate a thorough examination. The chapter delved into research paradigms, ethical considerations, and approaches to data management, establishing a solid groundwork for the intricate analysis of PSM. Such a foundation is geared towards a scholarly, reflective, and systematic investigation, aiming to enhance the comprehension and implementation of process safety measures in South Africa's petrochemical industry.

CHAPTER 4: EMPIRICAL RESEARCH

4.1 Introduction

At the heart of South Africa's economic advancement lies the petrochemical sector, a key driver of GDP growth and a producer of goods fundamental to the South African people's daily lives. Yet, the industry's complex nature and inherent risks pose significant challenges with respect to environmental and public safety. The development of effective PSM strategies is paramount to mitigate hazards, prevent mishaps, and foster the sector's enduring prosperity. Within this context, Chapter 4, emerges as a critical piece in the broader analysis of PSM practices within this dynamic sector. By delving into the empirical data from an in-depth review of these practices, the research aims to shed light on the safety landscape as it currently stands, identify areas ripe for enhancement, and propose actionable insights to refine safety protocols. Through an exploration of select case studies from across South Africa's petrochemical plants, this chapter seeks to weave a narrative that not only portrays the existing conditions but also charts a path forward for safer industry operations.

There are two goals for this chapter:

- To present the findings of the empirical research, including information on safety incidents, close calls, safety culture, adherence to safety standards, and the use of contemporary safety technologies; and
- To critically evaluate the results, making connections, spotting patterns, and making suggestions that will help the South African petrochemical industry better PSM practices.

By filling the gaps and using industry best practices, this study aims to help South Africa's petrochemical industry become safer, more sustainable, and more resilient. This goal is furthered by the study's emphasis on using case studies from the petrochemical sector to examine safety accidents, near-misses, and safety culture carefully. The study seeks to learn essential lessons from actual occurrences and near-misses to have a thorough grasp of the variables that led to them. Additionally, understanding the current safety culture in the sector provides essential knowledge for successfully applying PSM methods. As a result, the safety and resilience of the South African petrochemical industry will be strengthened. The lessons learned from these case studies can lay a solid foundation for improving safety measures, perfecting PSM frameworks, and generating knowledgeable recommendations for future references. (The equipment names have been changed to ensure anonymity of the organisation).

4.2 Participating petrochemical companies in South Africa

In Chapter 4, the focus shifts to incidents that took place within the petrochemical industry in South Africa to better understand the practices of PSM. The incidents examined here were pulled from a variety of sources within the petrochemical industry in South Africa, providing a solid base for analysis. The researcher has sifted through numerous documents, such as internal reports, safety guidelines, accident investigations, and regulatory compliance documents, chosen for their direct relevance to these incidents and their ability to offer a thorough view of the impact of PSM. Documents were collected from various online sources like African Journals, ERIC, BASE, JSTOR, Google Scholar and Microsoft Academic.

The documents were analysed using content analysis, a method that breaks down the complex data from these incidents into understandable themes and identifies patterns in what went wrong or right. This approach helps not just in reporting the incidents but in placing them within the larger context of safety management practices, showing how these specific events reflect broader trends in the industry's approach to safety. Through this process, the researcher aims to provide a detailed picture of how incidents inform and are influenced by the petrochemical sector's safety protocols, leading into a more granular discussion in the subsequent parts of the chapter.

4.2.1 Incident 1: Fire

During November 2022, there was a moderate process safety incident classification at Level 3. The incident was classified as a fire observed at the containment pit during an emergency shutdown.



Figure 16: Fire incident: Image adapted from industry-specific safety incident report documentation

Direct causes: A possible gas breakthrough from the heat recovery steam generator (HRSG) at the petrochemical plant to the industrial drain system and into the containment pit was found.

Pressure exceedance from the industrial drain on the day was observed at 2800kPa. Normal pressure should be less than 400kPa. Nine HRSGs were identified that could potentially have resulted in a gas breakthrough at the Phase 1 containment pit at the time of the incident. A possible ignition source could be identified in the form of open Pratley boxes that were found to be open after the incident. The holding part of the screws inside the Pratley boxes was not found, which might indicate that the boxes had been forced open.

Root cause: Pressure in the HRSG pushed gas into the industrial drain system but no liquid level was available to seal off the industrial drain system effectively, and to subsequently seal the containment pit from the gas.

Failed controls: No liquid level was present in multiple HRSGs at the time of the incident, which resulted in gas leaking into the industrial drain system and subsequently into the containment pit.

Management system failures: None

Immediate actions implemented: Plant structures and equipment were cleaned after the fire. Electrical cable and lights were replaced. Instrument cables were replaced.

Corrective actions: The design philosophy of the containment pits should be reviewed with regard to draining activities and HRSG management. It should be confirmed if the containment pit was originally designed for gas to be present at any given time, and if so, what quantity and frequency. The Hazardous Area Classification (HAC) of the area should be reviewed, depending on the outcome of the design philosophy review.

4.2.2 Incident 2: Liquefied Petroleum Gas (LPG) line leak

During December 2022, the LPG line leaked under a bridge, resulting in a vapour cloud and ice formation, causing production losses. The incident was classified as a minor incident. The failure was due to the sewage line resting on the LPG line. The sewage line was not resting on supports, and when the line expanded and contracted, it rubbed on the LPG line, causing wall loss and a leak.

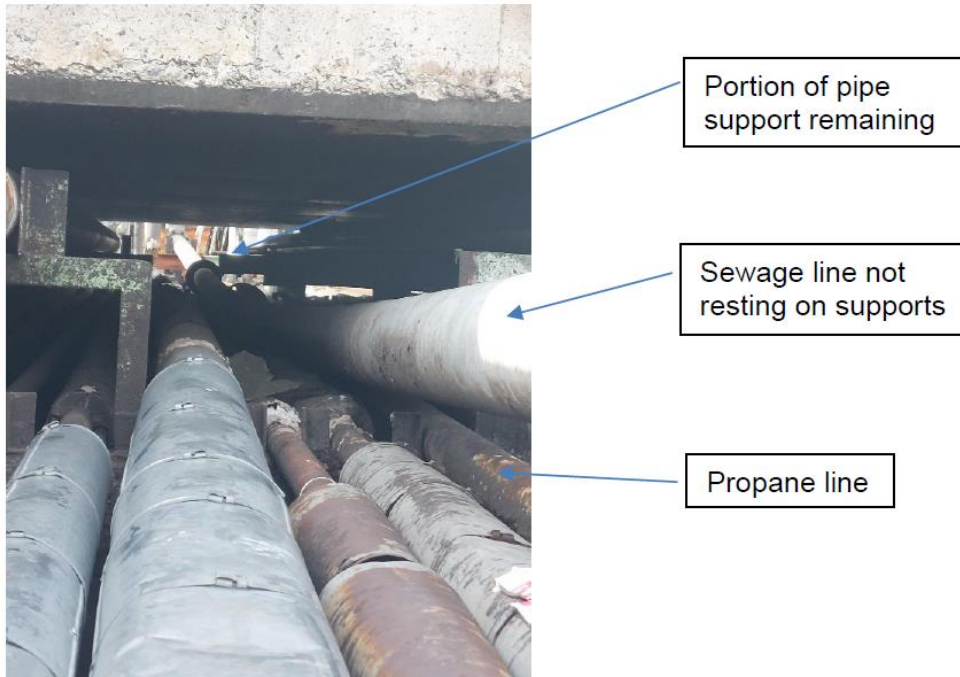


Figure 17: The sewage line resting on the LPG line in the pipe rack. Image used with permission from a source that wishes to remain anonymous.

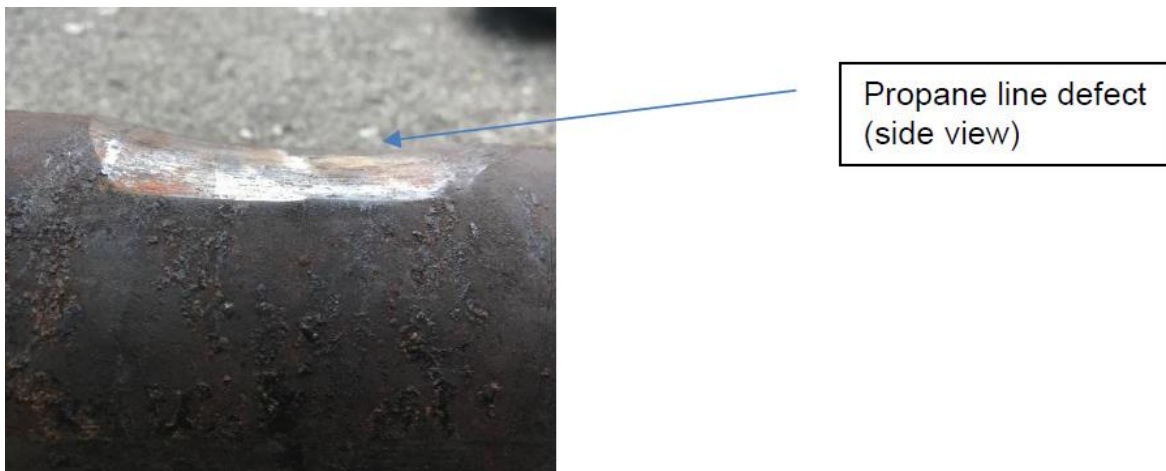


Figure 18: Defect area on the LPG line. Image used with permission from source that wishes to stay anonymous.

Direct causes: The LPG line leaked because the sewage line rested on the line and not on supports, causing friction that formed a vapour cloud and ice build-up. The culvert space was congested with limited access. The sewage line does not have a technical identification number.

Root causes: The sewage line support was not re-instated in 2005 when the line was modified, and the line was left to rest on the LPG line. Visual inspections were done at the market and process integration (MPI) section of trench, with no defects reported. No inspections were done on the tank farm side of the culvert. Sewage lines are excluded from risk-based inspections (RBIs); however, they should be maintained. The MOC procedure was not followed as there were

inadequate inspections of the culvert (MPI & Tankfarm). The sewage line was not maintained. The strategy for all sewage lines is run-to-failure.

Corrective actions:

- The area of responsibility for tank farm and MPI should be distributed.
- Sewage pipe (material changed to HDPE) should be re-routed.
- A production checklist should be developed for the tank farm to incorporate the inspection of supports.
- Hydrocarbon lines in culvert areas should have fixed gas detectors installed.
- Inspections should be done on all the culverts (consider including in corrosion loop inspections).
- The viability of creating technical IDs for sewage lines in SAP should be investigated.
- There should be production re-training on visual inspections.
- There should be production training on visual inspections as per the revised checklist.
- There should be communication with civil maintenance to ensure that when a repair or change is made in the vicinity of other pipelines, the scope of work is discussed at the MPI MOC meeting.

Lessons learned: An agreement on the area of responsibility agreement and alignment is crucial between different business units. The quality of visual inspections in culverts is important.

4.2.3 Incident 3: Fire

During February 2023, while preparing for hot work activities on a cooling tower cable rack, a fire occurred while testing for power using a grinder. The source of hydrocarbons was identified as a leaking heat exchanger. The hydrocarbons leaked from the heat exchanger via the cooling water return line to the cooling towers.

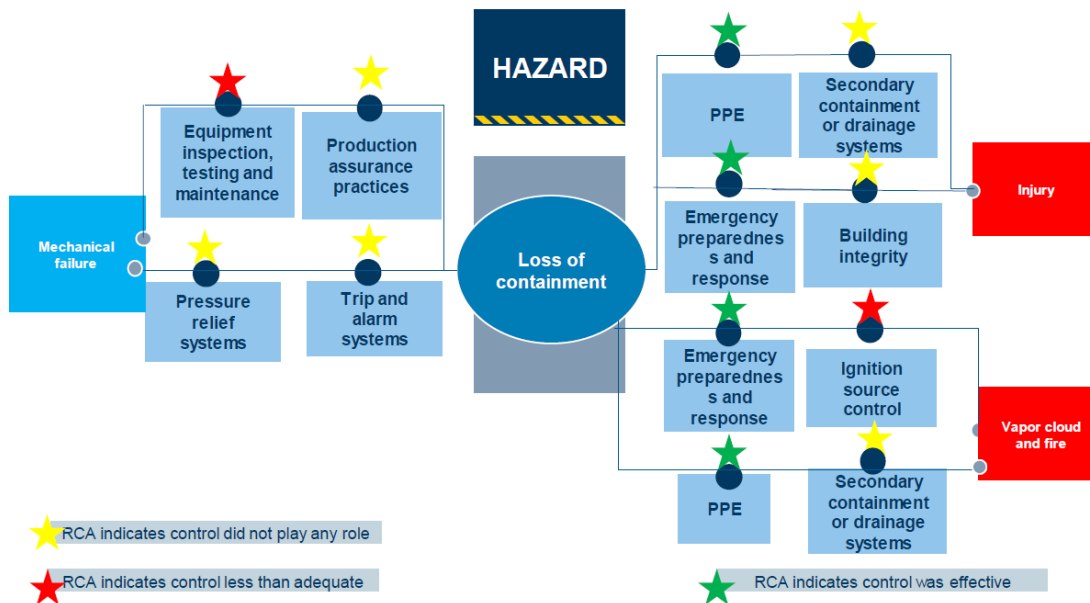


Figure 19: Bow tie for loss of containment. Image used with permission from a source that wishes to stay anonymous.

Direct causes: There was a heat exchanger tube failure: Two tubes were identified to be leaking after the incident. The failure mechanism of the tubes should to be determined by either removing the tubes or by using relevant inspection techniques and conducting metallurgical tests to determine the failure mechanism. This can only be done at the next opportunity or during the September 2024 shutdown due to operational demands.

Probable root causes: There is corrosion due to the presence of corrosive species in the cooling water system (Process waste liquor (PWL) chlorides, sulphates, dissolved oxygen, suspended solids). There is erosion due to the presence of solid particles in the cooling water stream. Manufacturing defects led to premature failure of tubes.

Corrective action: A project should be initiated to install permanent gas detectors in the cooling tower vicinity to enable real-time gas detection (general specification for plant fire and gas systems). There is a possibility that cooling water may have played a role in the failure of the tubes due to its quality, i.e., phosphates, suspended solids, etc. The possibility of a cooling water treatment programme should be investigated to address the water quality and verify the PWL quality. The RBI should be reviewed for the condensers. The failure mechanism on the tubes should be investigated and an RCA session should be arranged once the failure mechanism has been identified. There should be an effective system to manage gas meters and permits. EM should be requested to conduct Flair hydrocarbon detection frequently until permanent gas detectors are installed. All hot work activities in the cooling tower vicinity should be conducted under continuous monitoring conditions until permanent gas detectors are installed. Four-hourly

plant inspections for gas monitoring should be conducted until permanent gas detectors are installed.

Lessons learned: Always ensure that there is a functioning system in place for the control and management of permits and gas meters. Always consider the possibility of having hazardous substances present when working in cooling tower areas. Controls to mitigate the risks associated with the presence of hydrocarbons around cooling towers should be in place.

4.2.4 Incident 4: Process liquor release

During September 2022, process liquor was released from a drain line after removing blanks, resulting in three employees being sprayed. The blank was completely removed when the process liquor started pouring. The nature of the injuries, two first aid cases and a restricted workday made it a moderate process safety incident.



Figure 20: The area where the blank was removed for box-up. The red marking is on the drain line flange. Image used with permission from source that wishes to stay anonymous.

Direct causes: There was an unforeseen blockage in the line.

Underlying causes: Safe-making conditions were not re-evaluated for the blank removal after the cleaning was done in the tank using the gas liquor. After washing the tank with the gas liquor, not all the liquid drained due to the unforeseen blockages.

Contributing causes: None.

Root causes: There was a sudden dislodgement of the blockage in the line, resulting in process liquor spraying onto personnel.

Control failure analysis, administrative control: Safe-making conditions were not re-evaluated for the blank removal after the cleaning was done in the tank using the gas liquor. Cleaning was inadequate. After washing the tank with the gas liquor, not all the liquid drained due to the unforeseen blockages.

Lessons learned: Vacuuming should be incorporated into the cleaning procedure after the washing activities take place on the tank to clear possible blockages and liquid accumulation.

4.2.5 Conclusion on incidents

The detailed case studies, ranging from fires and gas leaks to process liquor releases, not only highlight the diverse challenges the sector faces but also reveal common themes in the root causes and management system failures. These incidents serve as a stark reminder of the potential hazards inherent in petrochemical operations and the need for continuous vigilance, improvement of safety protocols, and adherence to best practices. From the analysis, it is evident that there are significant opportunities to enhance PSM practices with better design considerations, regular and thorough maintenance checks, more rigorous training for employees, and the implementation of advanced safety technologies. The lessons learned from these incidents, particularly the importance of re-evaluating safety procedures post-maintenance and ensuring clear communication among all levels of operation, are invaluable for guiding future safety improvements.

4.3 Challenges of PSM

Organisations face various difficulties in the field of PSM. These are problems that, if left unresolved, could have a significant effect on the operation's safety, integrity, and sustainability. The firm names have been omitted from this discussion on the case studies in the petrochemical industry to emphasise the general lessons and insights that cut beyond organisational boundaries. These occurrences served as crucial turning points where process safety controls were put to the test and, occasionally, showed weaknesses. By maintaining the confidentiality of the involved organisations, the attention remains on examining the more significant systemic problems that necessitate proactive, sector-wide remedies. To create a future that is safer and more robust, it is essential to focus on critical lessons learned and to encourage a group commitment to bolstering process safety procedures. The following sections evaluate the incidents that can occur in the petrochemical Industry.

4.3.1 Incident 1: Fire

Direct causes: There was a possible gas breakthrough from HRSG and open Pratley boxes.

Root cause: There was a low liquid level in HRSGs, allowing gas to enter the industrial drain system and containment pit.

Challenges identified: There was inadequate monitoring and maintenance of HRSGs and a lack of safeguards to prevent gas breakthrough. There was also insufficient inspection and control of Pratley boxes.

4.3.2 Incident 2: LPG line leak

Direct causes: There was friction between the sewage and LPG lines due to lack of proper supports.

Root causes: There was inadequate maintenance of sewage line supports and lack of inspections.

Challenges identified: There was poor infrastructure maintenance and a lack of technical identification for sewage lines. There were also insufficient inspections and failure to follow management of change (MoC) procedures.

4.3.3 Incident 3: Fire

Direct causes: There was a flash fire during hot work due to a leaking heat exchanger.

Root causes: The heat exchanger tube failed, possibly due to by corrosion, erosion, or manufacturing defects.

Challenges identified: There was inadequate real-time gas detection and a lack of water quality control in cooling water. There is a need for tube failure mechanism investigation into the absence of an effective gas meter and permit management.

4.3.4 Incident 4: Process liquor release

Direct causes: There was an unforeseen blockage in a drain line during the removal of a blank.

Root causes: There was a failure to re-evaluate safe-making conditions and inadequate cleaning procedure.

Challenges identified: Safety conditions should be re-evaluated. Liquid drainage procedures are incomplete, and there is a need for improved cleaning and blockage prevention measures.

The above descriptions of the occurrences are reminders of the complex issues inherent to PSM. These incidents shed light on the dense network of intricacies organisations must navigate to guarantee the safety and integrity of their operations. In summary, the research provides insights into various crucial aspects that require attention and the collective endeavours to improve process safety.

4.3.5 Maintenance practice recommendations

The instances highlight the need to implement thorough and proactive maintenance practices. A recurring theme was the insufficient inspection, maintenance, and monitoring of critical equipment, including HRSGs, heat exchangers, and drain lines. The failure to adhere to proper maintenance practices has the potential to lead to disastrous outcomes. Organisations must embrace a culture centred around preventative maintenance, carry out routine equipment inspections, and establish comprehensive maintenance processes to guarantee the dependability and operational effectiveness of essential components.

Safety evaluations have frequently been shown to be the underlying causes of these occurrences, as they have been found to exhibit deficiencies. Insufficient risk assessments and safety studies may result in the oversight of marginal vulnerabilities. Therefore, organisations must strengthen their dedication to conducting thorough safety evaluations, risk assessments, and hazard identification processes. Systematic evaluations of safety policies and procedures on a regular basis can play a crucial role in the detection and resolution of possible risks before they escalate into significant accidents.

When successfully implemented, a strong PSM culture can significantly change incidents such as those mentioned above in the petrochemical industry. These accidents can be significantly reduced, if not eliminated, by incorporating PSM principles into the very fabric of organisational operations. A solid basis to protecting procedures and facilities is established with regulatory compliance and the safety standards directed by a proactive safety approach. Historical occurrences serve as sober reminders, highlighting the value of a strong PSM culture in averting the repetition of previous accidents. Additionally, by accepting and incorporating technological innovations, as well as by ensuring that the workforce is continuously educated, workers are given the tools they need to recognise and deal with any hazards (Al Mazrouei *et al.*, 2019:3238). By highlighting the importance of safety and establishing the tone for the entire organisation, leadership commitment further solidifies this culture. A continuous drive for improvement is ensured through regular assessments of the safety culture and benchmarking against best

practices in the industry. Effective communication channels make it easier to provide vital safety information, promoting an open and informed workplace. A resilient PSM culture emerges, prioritising the well-being of employees, the community, and the environment, ultimately promoting a safer and more sustainable petrochemical sector when businesses fully commit to proactive safety measures, invest in their workforce, and adapt to changing conditions (Naicker, 2022:23).

4.3.6 Monitoring processes

Implementing effective monitoring practices plays a crucial role in ensuring process safety. The cases illustrate how deficiencies in the oversight procedures can result in unforeseen events. The comprehensive scope of monitoring systems should include not only the evaluation of equipment performance but also the assessment of ambient conditions and process factors. The implementation of robust monitoring procedures, which encompass real-time gas detection, is necessary to detect any deviations from safe operating conditions promptly.

4.3.7 Control systems

The issues clarified by looking at adverse events emphasise the imperative nature of implementing robust control systems. The lack of reassessment of safety conditions and inadequate controls during maintenance tasks highlight the significance of clearly defined and consistently adhered protocols. Organisations must ensure that their control systems are not only thoroughly documented, but also strictly adhered to in practical implementation.

In summary, these occurrences serve as a reminder that PSM is a fluid and progressive field that requires ongoing attentiveness and enhancement. Recognising and addressing the concerns highlighted by these occurrences is not only recommended but also a moral and practical need. In doing this, organisations can strengthen their safety protocols, improve their risk mitigation strategies, and substantially decrease the probability of similar incidents transpiring in subsequent instances. Process safety is a fundamental and steadfast dedication propelled by a culture that prioritises safety excellence, to safeguard both individuals and the environment while ensuring the uninterrupted continuation of operations.

4.4 The way forward: Recommendations

Given the knowledge gained from the accidents above, it is imperative to establish a thorough strategy for augmenting PSM in an organisation. This proposed "way forward" outlines a strategy designed to enhance safety protocols and reduce the likelihood of similar disasters occurring in the future.

4.4.1 Enhancing maintenance practices

It is imperative to establish and execute a comprehensive preventive maintenance programme that includes systematic equipment inspections, maintenance assessments, and testing processes. It is essential to establish a robust system of responsibility for maintenance duties, so ensuring that maintenance teams are equipped with the requisite training and resources. This paper aims to propose the implementation of condition-based monitoring systems as a means to identify initial indications of equipment deterioration or malfunction.

4.4.2 Improving safety assessments

It is imperative to carry out thorough and regular safety evaluations, including the identification of hazards, analysis of risks, and conducting process safety reviews. Organisations should foster a culture of perpetual enhancement by actively promoting staff engagement in the reporting of near-miss incidents and potential risks. They should enhance the accuracy and efficiency of safety evaluations by employing modern technologies, such as process hazard analysis (PHA) software. Implementing robust monitoring processes is essential in ensuring the effectiveness and reliability of a system. It is advisable to allocate resources towards acquiring real-time monitoring systems for critical equipment and processes, as this would facilitate prompt identification of abnormal conditions.

It is imperative to establish unambiguous processes for promptly addressing alarms and deviations while also ensuring that workers have comprehensive training in emergency procedures. It is essential to consistently evaluate and revise monitoring systems to include the most up-to-date technology and adhere to the most effective methodologies. One area of focus that might enhance organisational effectiveness is the implementation of robust control mechanisms. The objective is to establish and disseminate standardised protocols for all maintenance operations, specifically ensuring safety measures are implemented. To provide the effective assessment and mitigation of risks related to operational modifications or changes, it is imperative to establish a comprehensive and resilient MoC process.

Organisations should promote the development of a corporate environment that prioritises the observance of established protocols and regulatory measures, with a particular focus on instilling a sense of commitment to compliance across the whole workforce. Continuous improvement and learning are essential components of any successful organisation. By consistently striving to enhance processes, products, and services, organisations can stay competitive in a rapidly changing business environment. Additionally, fostering a culture of continuous learning enables employees to acquire new knowledge and promote a proactive stance towards safety by engaging in post-incident investigations and root cause analysis for all occurrences, irrespective of their

severity. Management should facilitate the dissemination of valuable insights and experiences throughout the entire organisation, cultivating an environment that prioritises ongoing enhancement and the exchange of knowledge.

It is imperative to evaluate and revise safety standards consistently, integrating industry-leading methodologies and innovative technologies. The topic of engagement and training is important in academic discourse. Organisations should encourage the active participation of employees across all hierarchical levels within the organisation by involving them in safety initiatives, thereby seeking their valuable feedback and fostering their engagement in safety programmes. It is imperative to offer continuous training and development prospects to guarantee that all personnel possess the requisite information and competencies to preserve safety standards.

4.4.3 The examination of adherence to regulations and compliance standards

It is imperative to consistently evaluate and revise safety protocols to conform to prevailing industry norms and regulatory mandates. It is advisable to engage in collaboration with regulatory agencies to remain updated on the dynamic nature of safety regulations and guarantee adherence to them. Developing key performance indicators (KPIs) is essential for monitoring and evaluating the efficacy of PSM activities. To enhance organisational safety, it is imperative to establish a comprehensive event reporting and investigation framework that effectively monitors occurrences, near-misses, and subsequent remedial measures.

Through the implementation of this complete strategy to expand PSM, the organisation can cultivate a safety culture that is characterised by increased safety measures, enhanced resilience, and a proactive approach, this approach not only reduces the potential dangers linked to future accidents but also strengthens the organisation's dedication to the welfare of its workers, preservation of the environment, and sustainability of its operation.

4.5 Conceptualisation and comparison with literature

The petrochemical industry is likely one of the first globalised sectors where safety issues were taken seriously, yet different countries have different ideas about process safety. It is essential to realise that the lack of a PSM system in any petrochemical industry raises the potential of casualties, both human and material. Whether due to explosions, spills of harmful and dangerous materials, and putting the environment in jeopardy, pollution harms the ecosystem (Flynn & Theodor, 2019). Failure to consider this poses a significant risk to humanity and the environment. Therefore, this part covers the understanding and attributed meanings expressed by PSM responders. These opinions are also consistent with the National Research Council's (1999) definition of PSM, which roughly describes it as *“the process of enabling the systematic*

identification, analysis and management of critical business risks". In the petrochemical sector, damage is frequently linked to risks like pollution, harm to resources, stoppage of business, destruction of properties, and injuries to people. Any PSM system in the petrochemical industry is required to have the following primary goals:

- To avoid a fire, an explosion, or the release of hazardous substances that could expose substantial risks to workers and others (Kletz, 2009);
- A systematic evaluation of the entire chemical process inside the industry;
- Implementing a hazard identification strategy at work; and
- PSM must also participate in the workplace with all parties involved (Kletz, 2009).

PSM is the use of management and systems to recognise, comprehend, and manage process hazards to prevent injuries and mishaps in the petrochemical sector. Twelve important PSM components are listed by Kletz (2009) as essential to avoiding risks in petrochemical facilities, including the handling and storage of hazardous materials. To find potential flaws in procedures and processes, tools like HAZOP, LOPA, hazard identification, and failure mode and effect analysis (HFMEA) are used (Knegting & Pasman, 2009).

4.6 PSM procedure and incident reporting system

The variety of PSM tasks in the petrochemical industry includes everything from predicting the flare system's capacity to standardising routine operator rounds. However, if done correctly, these actions can contribute to incident prevention. If they are not completed, they may also result in accidents. According to research in the petrochemical sector, catastrophic incidents can cause more damage or injuries in a short period than what has been prevented by safety initiatives in more than ten years (Michalis & Myrto, 2012). Major incidents frequently have underlying causes related to PSM process breakdowns or reporting system failures in the sector (Kerin, 2017). The tremendous effects of catastrophic events are highlighted through research conducted in the South African petrochemical industry. Such occurrences have the potential to result in significant harm and injuries in a very brief amount of time, frequently exceeding the cumulative benefits of safety interventions over a decade. This alarming fact highlights the critical need for thorough and effective PSM practices.

It is critical to understand that significant events within the South African petrochemical sector frequently have underlying causes connected to PSM process breakdowns or shortcomings in incident reporting systems. Defects in risk assessments, safety protocols, equipment maintenance, and employee training might be examples of such breakdowns (Popoola, 2007).

The lack of a well-organised incident reporting system might exacerbate these problems since it may make it more challenging to identify and address potential risks and safety concerns promptly. Improving their PSM processes and event reporting, systems must take priority for South African petrochemical industries, considering all these challenges. Comprehensive risk assessments, strict adherence to safety procedures, preventative maintenance techniques, and ongoing staff training, and development are required. It also calls for developing effective incident reporting processes that enable staff members at all levels to report safety-related issues, near-misses, and occurrences swiftly.

The South African petrochemical industries can proactively reduce risks, prevent accidents, and promote a safety culture by taking care of these crucial PSM and incident reporting aspects. This safeguards not only their operations but also the health of their workforce and the environment. A robust PSM framework and a watchful incident reporting system are essential cornerstones for long-term safety and operational excellence in the industry (Naicker, 2022).

4.7 Factors that shape PSM culture in South Africa

Several interrelated elements have a significant effect on the PSM culture in the petrochemical sector in South Africa. The regulatory environment lays the groundwork for safety standards, and historical occurrences serve as sharp reminders of the significance of PSM. Accepting technical developments, workforce education, and leadership commitment all play crucial roles in forming a safety culture. The growth of a strong PSM culture is also aided by safety culture evaluations, benchmarking against industry best practices, and efficient communication channels. External pressures like stakeholder expectations and the state of the economy only emphasise how important it is for enterprises to put safety first (Naicker, 2022). A strong PSM culture develops in this dynamic interplay of forces when firms commit to proactive safety. The need for enterprises to emphasise safety is further underlined by external factors like stakeholder expectations and economic situations. A strong PSM culture develops in this dynamic interplay of forces when firms commit to proactive safety procedures, invest in their workforce, and stay flexible to changing conditions, eventually assuring the well-being of their people and the preservation of the environment (Naicker, 2022).

4.8 Challenges of process safety

The petrochemical companies in South Africa have a wide range of difficulties related to regulations, resources, and culture (Naicker, 2022). Compliance with intricate safety rules still presents a challenge, especially in a changing regulatory environment. Moreover, the implementation of solid SMSs and infrastructure modifications is hampered by a lack of experienced workers and resource limitations. It is a constant struggle to create a safety culture

that transcends productivity issues. Their already complex safety situation is further complicated by problems growing like cybersecurity threats and community environmental concerns (Kohn, 2014). To meet these difficulties, industry and regulatory organisations must work together to prioritise safety, make investments in education and training, and promote a collaborative approach to risk reduction and the creation of a safety culture. Another obstacle is ineffective communication, particularly between those from various ethnic and cultural backgrounds (Phua *et al.*, 2011). While there are ways to get around these obstacles, such as multilingual signs, safety gear, and appropriate and protective work attire, it is crucial to find ways to safeguard employees from harm or injuries that result from them (Phua, 2011).

4.9 Conclusion

The themes explored in this study revolve around the contextual meanings and understandings of PSM systems in South Africa. The national culture refers to the shared values, beliefs, and practices that shape the behaviour and decision-making processes in a country. The PSM system, on the other hand, encompasses the policies, procedures, and structures that govern the public sector and its management. An organisation should understand the relationship between a country's national culture. The course of action be determined in accordance with the identified results.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Introduction

The findings from the previous chapter were addressed, and particular factors that contributed to process safety events were examined to determine which PSM principles should be given more consideration to prevent occurrences. This chapter presents conclusions, suggestions, and a discussion of the extent to which the research objectives have been. This study aimed to delve into the PSM procedures within the petrochemical industry in South Africa. As detailed in Chapter 4, this research has unveiled noteworthy findings applicable to South African contexts. This chapter defines the contributions of this study to the broader academic research community in this field. Additionally, based on the findings, it offers a set of recommendations primarily tailored to the South African context but with potential applicability to the global community. These recommendations can serve as valuable insights for policymakers seeking to fortify PSM procedures in the petrochemical sector. The research's limitations are acknowledged, and avenues for future research are suggested.

5.2 Contribution of the study

The research findings have bearing on PSM and the safety management process in the petrochemical industry in terms of theory (conceptual), knowledge, and practice. This paragraph investigates and discusses the contribution of the research.

Contribution to theory and concept in South African context: A thorough understanding of PSM in the South African petrochemical industry has emerged from this research. This study has discovered significant differences by examining and highlighting the differences in the South African PSM system. In particular, it finds that the South African system tends to follow a specific paradigm, which implies fewer event reports, limited recognition of mistakes, minimal post-incident investigation, and a predominately silent culture surrounding such occurrences. Such a strategy might make it more challenging to deploy PSM procedures successfully in the South African petrochemical environment. The investigation of these characteristics and their potential effect on PSM in South Africa is a theoretical contribution of this study.

Contribution to knowledge in the South African context: This study significantly contributes to our understanding of PSM by focusing on the South African petrochemical industry. It highlights a crucial aspect known as "institutional thickness" within this specific context. The concept of institutional thickness, as defined by Amin and Thrift (1994), refers to the degree of collectivisation and corporation of economic life fostered by institutional and cultural traditions. This research extends to the South African context, emphasising substantial differences in institutional thickness

within the country. South Africa maintains a unique balance between state involvement in the petrochemical industry and private enterprise. This research also raises pertinent questions about the effectiveness of state control in both business and regulatory capacities. Findings indicate disparities in the commitment, including political will, legislation, and monitoring, to safety management procedures within the South African petrochemical industry. The research recommends that South Africa should develop and implement procedures to empower petrochemical industry workers to report incidents without fear, with an emphasis on unbiased handling of reported cases.

This research underscores a critical gap in the existing literature, particularly regarding safety management procedures in the South African petrochemical industry. This study addresses this gap, enriching the existing body of knowledge by providing updated information on current safety management procedures in the South African petrochemical industry.

Contribution to practice in South Africa: It becomes evident that the existing safety policies and procedures primarily cater to a male-dominated workforce, potentially neglecting the unique needs and considerations of female employees. This finding underscores the importance of considering gender as a significant factor in developing future safety policies and procedures in South Africa's petrochemical industry. Mainly, as there is a growing emphasis on encouraging more women to join the workforce, it is imperative to ensure that safety measures are inclusive and responsive to the diverse workforce.

Given the substantial socio-cultural differences in the workforce in South Africa, it is crucial to adapt safety procedures to be more inclusive and accommodating. For example, South Africa may need to consider integrating the needs of women into the current process safety procedures, especially in light of initiatives like 'Vision 2030,' which aims to bridge societal divides and promote gender parity in the workforce. This research emphasises the necessity of aligning safety practices with evolving socio-cultural dynamics, ultimately fostering a more inclusive and equitable petrochemical industry in South Africa (Kinninmont, 2017).

5.3 Limitations and recommendations for future work

This research has effectively accomplished its intended goals, but it is essential to recognise its inherent limits. These restrictions are described in this section, along with some promising directions for further investigation:

The selection of cases to use were subject to the permission by the companies where the research was done, and only cases were selected that would not directly reveal the companies identity, on request of the companies. This limited the number of cases that could be studied in

depth to four specific cases. However, as is the case in case study research, the learning points from these four cases are sufficient to draw conclusions and make recommendations.

The biggest drawback of this study is its scope, which affects how broadly applicable it is. Due to time restrictions and limited access to documents and incident reports, the study was limited to only South African petrochemical businesses. Therefore, this study can provide a starting point for future research that aims to analyse and contrast a broader range of petrochemical businesses in these or other nations.

Despite these drawbacks, this study represents a substantial advancement in the researcher knowledge of and ability to enhance safety management in the petrochemical industry. For academics and practitioners looking to improve safety procedures and policies in this crucial industry, the discovered flaws and research priorities provide helpful direction.

5.4 Study conclusion

In conclusion, the critical assessment of PSM in the South African petrochemical industry shows the sector's dedication to improving safety procedures while underlining ongoing issues that demand ongoing attention. Collaboration between business stakeholders, government agencies, and the workforce is essential to furthering PSM. Investments in education and training, the promotion of a safety-first culture, and ongoing evaluation and enhancement of safety procedures are all part of this. The South African petrochemical sector can grow further by confronting these difficulties while placing a high priority on everyone's safety.

5.5 Recommendations

In South Africa, it is crucial to support local companies in crafting comprehensive SMSs that encourage a culture where everyone feels accountable for safety. While PSM is still relatively new in this context, the emphasis often skews towards occupational safety. A significant hurdle is the complexity of safety programmes, making it challenging for workers to grasp their implications fully. There's a need to shift this mindset, ensuring that all employees, not just managers, consider safety their responsibility. How workplace accidents are documented in South Africa should evolve to promote learning and minimise future incidents. Furthermore, individuals responsible for safety breaches should face appropriate consequences, sending a clear message to others. The current system for recording accidents, especially near misses, has room for improvement. Introducing mandatory reporting laws, with company owners taking responsibility, could significantly enhance safety practices.

In establishing new safety departments, it is vital to create signage that transcends language and educational barriers. The direct translation of international safety standards into local languages

can distort their meaning, causing difficulties for workers in understanding and relating to them. Addressing language barriers, particularly in environments like plant sites where effective communication is paramount, is essential to ensure a safer workplace.

For an organisation to successfully implement a strong PSM culture in the petrochemical industry, a systematic strategy that incorporates the many factors indicated in the mentioned occurrences is needed. The following steps can be taken to improve the PSM culture in South Africa:

5.5.1 Understand regulatory standards and historical incidents

Organisations should begin by comprehensively understanding the regulatory environment and safety standards applicable to the petrochemical industry. They should analyse historical incidents to identify common patterns and lessons learned.

5.5.2 Leadership dedication and workforce training

Leadership should ensure that the personnel receive proper training and education so they are aware of the value of safety and their contributions to keeping it that way (Blasé *et al.*, 2003:81).

5.5.3 Accept technological progress

Organisations should accept and incorporate technological developments pertinent to the petrochemical industry to improve safety precautions. This can involve cutting-edge monitoring tools, preventative maintenance technologies, or safety gear (Olive *et al.*, 2006:138).

5.5.4 Evaluation of safety culture and benchmarking

To determine how well the organisation's current safety measures are working, they should conduct routine safety culture evaluations. They should pinpoint opportunities for improvement and harmonise your safety procedures with industry standards, benchmark against industry best practices.

5.5.5 Communication and openness

Leadership should create effective communication channels to notify all employees about safety policies, procedures, and updates. They should promote an open safety culture by encouraging open discussion about safety issues and accidents (Olive *et al.*, 2006:138).

5.5.6 Preventative safety measures

Organisations should implement preventative safety measures, such as regular inspections, equipment upkeep, and hazard analyses. They should encourage staff members to anticipate potential dangers and report them right away (Olive *et al.*, 2006:138).

5.5.7 Workforce and adaptability investments

Organisations should invest in the workforce's continual training and skill development to improve their capacity to recognise, and address safety hazards. They should promote flexibility to changing circumstances by promoting ongoing improvement and taking lessons from mistakes (Olive *et al.*, 2006:133).

5.5.8 Stakeholder participation

Organisations should engage stakeholders, such as the community, the workforce, and the appropriate authorities, to learn what they expect of safety. They should use their suggestions to enhance safety procedures and show a dedication to safety (Olive *et al.*, 2006:138)

5.5.9 Encourage a "safety first" mentality

Organisations should encourage a culture where safety is prioritised in all decisions and actions. Employees who strongly commit to safety should be honoured and rewarded (Roughton *et al.*, 2019:242).

5.6 Meeting research objectives

The study conducted an investigation of PSM in the petrochemical sector in South Africa to accomplish its main objectives. The first goal was to identify the PSM components that had a significant impact on the incidence of these occurrences. This resulted from a careful inspection and analysis of numerous instances, which helped to spot recurring patterns and pertinent PSM components.

In answer to the study's second objective, faults within the PSM components directly contributing to process safety incidents were carefully studied and identified. Each incident's root causes, and immediate causes were examined, giving essential insights into the PSM components that failed and caused events to occur.

The study aimed to understand the PSM components in the context of the petrochemical industry in South Africa to achieve the third objective. Specific PSM components that were significant in the occurrence of incidents were identified through a thorough study of incident reports and the

data that was available. Furthermore, by connecting the detected PSM components to the circumstances, the study successfully achieved the fourth objective. After carefully analysing each event, it was apparent how deficiencies in PSM components contributed to incident occurrences.

Overall, the study offered a thorough examination of various PSM components and their contributions to process safety incidents in the South African petrochemical sector. It provided valuable insights that could help enhance safety measures and PSM processes within the industry by methodically identifying shortcomings in these elements and connecting them to adverse events.

5.7 Concluding remark

This study combined an in-depth investigation of empirical research and relevant literature to fully comprehend the crucial significance of PSM aspects in the incidence of process safety events within the petrochemical industry in South Africa. The empirical research comprised a thorough analysis of certain situations, covering both their immediate and underlying causes, to pinpoint the PSM components that significantly influenced these accidents. Additionally, a thorough examination of the results of prior research gave rise to a more comprehensive theoretical framework and recommended methods for PSM.

The empirical research highlighted deficiencies in PSM components, such as insufficient maintenance procedures, inadequate monitoring, and a lack of thorough safety evaluations, shedding light on real-life circumstances within the petrochemical industry. These shortcomings were discovered to be prevalent causes of several events, highlighting the necessity of preventative actions and improved safety practices.

The literature review, on the other hand, provided a theoretical basis by offering a thorough overview of PSM and its key components. It also stressed how crucial it is for the petrochemical industry to have a strong safety culture, conduct comprehensive risk assessments, and implement efficient monitoring procedures. The available literature gave valuable insights into internationally recognised best practices, safety standards, and PSM-related principles. The results of the empirical investigation and the conclusions drawn from the literature review were compared, and it became clear that there is a considerable alignment between theoretical ideas and actual events. The critical role that PSM components play in preventing process safety events was emphasised in both sources, as well as the requirement for an integrated safety culture that penetrates all facets of organisational operations.

Combining empirical research findings with insights from the literature improved our understanding of PSM components and their function in process safety incidents in the petrochemical industry. This strategy lays the groundwork for enhancing PSM procedures, encouraging a strong safety culture, and eventually providing a safer and more sustainable working environment for the South African petrochemical industry. The goal of future initiatives should be to continue closing the knowledge gap between theory and practice to increase process safety within the sector.

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