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Investigating the relationship between human and organisational factors, maintenance, and accidents. The case of chemical process industry in South Africa

Mashel Gonyora [a,*], Esther Ventura-Medina [a,b]

[a] Department of Chemical and Process Engineering, University of Strathclyde, Scotland, UK
[b] Eindhoven University of Technology, North Brabant, Netherlands

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ABSTRACT

Accidents continue to be a major concern in the production, storage, and use of hazardous substances, and accidents have occurred either during maintenance or lack thereof. However, there is limited academic coverage of the initiatives implemented to prevent such accidents in South Africa. In recognition of this gap, the study explored participants' perceptions on the relationship between human and organisational factors, maintenance, and accidents using a quantitative approach on data analysis. A questionnaire was distributed online and used to collect data from employees of a chemical and process industry company in South Africa, with 247 valid responses out of 316 obtained from 450 participants invited to voluntarily participate in the study.

The findings of the study revealed several noteworthy correlations. Firstly, there were positive and significant relationships between various factors such as procedure implementation, communication accuracy, communication satisfaction, permit to work system, competency level, and risk management. These factors were found to have an impact on the occurrence and frequency of maintenance-related accidents. Specifically, maintenance activities were shown to reduce the likelihood of accidents, while effective risk management practices resulted in a similar outcome. Additionally, communication satisfaction was found to be associated with improved risk management during maintenance operations. The implementation of a permit to work system was also found to reduce the risk during maintenance and contribute to accident reduction. Furthermore, a higher competency level was found to be associated with effective risk management during maintenance and a decrease in accidents. Lastly, communication accuracy was found to be linked to more effective risk management during maintenance, leading to a decrease in accidents.

Based on these findings, it is recommended that companies in the chemical and process industry continue to prioritize human and organization factors as well as maintenance practices to ensure safe and reliable operational performance. By focusing on these aspects, companies can minimize the occurrence of accidents and promote a safe working environment.

1. Introduction

1.1. Background of study

The biggest challenge faced by chemical process industries pertains to the domains of safety and risk management. Despite the prolonged scrutiny of these issues over the last three decades, the trajectory of process safety indicators has not mirrored the noticeable decline observed in well-documented personal safety metric (Lee et al., 2019). The Oil and Gas (O&G) and process industries have been very successful in improving occupational safety, but less successful in improving process safety/major accident performance (Sultana et al., 2019; Pitblado and Nelson, 2013). According to Lee et al., 2019, process safety accidents continue to occur at the same frequency and severity. Renecle et al., 2021 add that despite advancements in technology and safety management systems, organisations operating in high-risk environments continue to face errors and accidents with severe consequences for their workers, customers, and communities.

Process safety incidents continue to occur at an alarming rate, a concerning trend highlighted by SynergenOG. Process Safety Incidents:

* Corresponding author.
E-mail addresses: mashel.gonyora@strath.ac.uk (M. Gonyora), e.ventura.medina@tue.nl (E. Ventura-Medina).

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Causes, Consequences, and Lessons Learned., 2023. These safety events can occur at any stage of operations, including startup, shutdown, process upsets, malfunctions, maintenance activities, product transfer and handling, and emergency response. These incidents result in significant losses due to failures in loss prevention or mitigation barriers, aligning with the accident model known as the 'Swiss Cheese' concept (Reason, 2000). The causes of these incidents are complex and encompass several factors, such as a lack of management commitment to process safety, insufficient employee training in process safety, inadequate execution of process hazard analysis, suboptimal design and operation of equipment and systems, mismanagement of safety hazards, insufficient knowledge and experience in handling hazardous materials, absence of necessary tools, and human errors such as failing to deactivate a valve or leaving a pump operational. Maintenance and inspection are also frequently carried out incorrectly. These factors have been consistently identified as common causes of process safety incidents (Bai, 2023; Walker, 2023; Xiang, 2022; Gil and Atherton, 2008; Reason, 2016). Leveson, 2015 posited that significant incidents are characterized by distinct indicators, although these may solely manifest as meaningful signals retrospectively. Substantially, it is usually the case that notable mishaps encompass a myriad of preliminary factors and subtle hints, signalling the looming probability of an accident.

A recent study by (Bhusari et al., 2021) investigated process safety incidents in 14 different industries, including refining, chemicals, agriculture, pharmaceuticals, and manufacturing. The study analyzed 81 accidents and found that the most common contributing factors to these incidents were the safety culture within the organization, emergency preparedness, and mechanical integrity.

In their study Jarvis and Goddard, 2016 revealed that 51 % of the losses analyzed occurred in refineries, with an additional 28 % occurring in petrochemical plants. Out of the 100 losses scrutinized, 43 % were attributed to failures in mechanical integrity. Additionally, nearly 30 % of the losses classified as Non-Mechanical Integrity Failures occurred during maintenance activities, primarily due to inadequate control measures. Within the subset of losses related to Mechanical Integrity Failure, 39 % of Primary Management System Failures (MSFs) were linked to an inadequate or incomplete inspection program. On the other hand, 37 % of the Primary MSFs for Non-Mechanical Integrity Failure losses were associated with deficiencies in the Control of Work protocols. The study also emphasized that inadequate Process Hazard Analysis (PHA) was cited as a significant factor in contributing to nonmechanical integrity failure losses, accounting for 59 % of such losses. Nekhwevha (Rialivhuwa, 2019) identified operating procedure, process hazard analysis, mechanical integrity, management of change, and training as key contributors to accidents, making up a significant percentage of total process incidents.

Lee et al., 2019 suggested that a thorough analysis of process safety events, such as the BP Deepwater Horizon accident (BP, Deepwater Horizon Accident Investigation Report: Executive Summary, September 8., 2010), indicates that these events arise from a complex interplay of factors. Therefore, ensuring process safety requires collaborative efforts from various disciplines guided by a systems perspective that considers the roles of equipment, personnel, and procedures, along with their significant interactions (Seligmann, 2019; Hassall et al., 2016) . This approach is crucial for addressing the diverse challenges associated with process safety, including human error, process complexity, technological advancements, and the need to cultivate a strong safety culture within organizations (Lee et al., 2019; Walker, 2023) . Recent events have shown that apparently rare or unforeseen scenarios, involving complex interactions between human factors, technologies, and organizations, can trigger major catastrophes (Moura, 2017).

Tragic accidents like the Piper Alpha incident of 1988, which resulted in 167 fatalities, were caused by inadequate maintenance procedures (Reid, 2020). The 1984 Bhopal disaster, on the other hand, was triggered by both inadequate maintenance and operators regularly bypassing critical safety systems (Varma and Varma, 2016). The Buncefield fire in 2005 occurred due to a lack of awareness regarding the malfunction of instrumentation systems and level gauges (Hailwood, 2009). More recently, explosions in chemical industries in Tarragona, Spain in 2020 and Gujarat, India in 2020 have resulted in deaths and injuries. In both cases, issues related to the maintenance of facilities and equipment have been identified as possible causes (Duarte and Santiago Scarpin, 2023).

These examples of major accidents with devastating consequences to personnel, the environment, companies, and local communities highlight the common trends of human and organizational factors (HOF) as contributors. According to Kidam and Hurme, 2013, the majority of accidents (over 95 %) could have been predicted and prevented through the appropriate application of existing knowledge. Likewise, Reddy and Yarrakula, 2016 revealed that countries worldwide have experienced worst-case chemical disasters. The U.S. CSB. CSB Safety Video - Reactive Hazards. U.S. Chemical Safety Board, 2007 emphasized that while we cannot avoid reactive chemical hazards, accidents involving reactive hazards in chemical plants are unacceptable, as there are existing technology and management systems to produce these products safely.

Edmonds, 2016 and the UK HSE. Human factors and ergonomics., 2024 have identified several pertinent human factors topics within the Chemical Process Industries (CPI). These includes managing human failures, maintenance, inspection, and testing (MIT), human factors in design, procedures, organizational culture, organizational change, staffing, training and competence, safety–critical communication, fatigue, and shift work. In a study by Kidam and Hurme, 2013, a frequency analysis classified 156 out of 806 (19 %) CPI-related accidents as being contributed by human and organizational failures. Drogis, 1996, reported similar results, finding that 20 % of accident causes were related to human and organizational faults. Common HOF contributors included failure to follow procedures, faults in the management of maintenance/repair/cleaning work, human faults in line-up/valve setting, and poor training. Kidam and Hurme, 2013, suggested that more research should be conducted on human and organizational factors, analyzing accident cases, publishing lessons learned, and improving the feedback system. Okoh and Haugen, 2013 called for further investigation into the extent to which maintenance causes major accidents, while Holmgren, 2006 identified opportunities for research to support continuous improvement and risk reduction, particularly in the areas of communication and information related to maintenance processes. Furthermore, Reiman, 2011 highlighted the importance of safety management systems and human performance tools in guiding work in maintenance and controlling unwanted performance variability for future research. With accidents continuing to occur, it is clear that more studies should focus on human and organizational factors, analyzing accident cases, publishing lessons learned, and improving the feedback system (Kidam and Hurme, 2013). Past accident analysis is vital in understanding the mechanisms of industrial accidents and providing valuable information for developing accident prevention strategies (Xiang, 2022).

1.2. Overview of the South African chemicals process industry

The South African Chemicals Process Industry (CPI) is one of the pillar industries of the South African's economy, contributing significantly to employment, exports, and gross domestic product (GDP). The CPI sector has supported major investments in South African industries, which shape the economy of the country and produce approximately 600 different types of chemicals. The subsectors include liquid fuels, plastic products, pharmaceuticals, inorganic chemicals, primary polymers and rubber, organic chemicals, consumer chemicals, rubber products, bulk products, pure functional and specialist chemicals, and fine chemicals (Patel, 2022; Majozi and Veldhuizen, 2015) .

Engineering, R.A.o., Global Engineering Capability, 2020 ranked South Africa in 77 out of 99 countries in the category of safety, indicating that there are significant safety concerns related to engineering activities in South Africa. The low ranking in the safety category is concerning because it suggests that there may be significant risks associated with engineering activities in the country. These risks include workplace accidents, infrastructure failures, and other safety-related incidents that could have serious consequences for workers and the public.

Incidence of industrial accidents in South Africa has been decreasing over time; however, accidents still occur (EM-DAT. The International Disaster Database -The Centre for Research on the Epidemiology of Disasters (CRED)., 2023). Hedlund, 2013 argued that studies on occupational accident statistics in South Africa is sparse with the most recent study on manufacturing being published in 1990. He further argues that exhaustive information is available from the insurance system under the Workmen's Compensation Commissioner (WCC), but timely access is difficult.

1.2.1. Reporting of accidents in South Africa

In South Africa, accidents are typically reported to the Department of Employment and Labour (DEL). It is a requirement for companies operating in the country to report accidents to the DEL, as mandated by national policies. However, it is important to note that the availability of information on these accidents to the public is limited. National policies prioritize the confidentiality of accident-related information. Therefore, accessing detailed accident data or information about specific incidents may be challenging for the public and researchers. The primary reason for this limitation is to ensure compliance with privacy regulations and protect the sensitive information of individuals involved in accidents. As a result, conducting studies or research that rely on publicly available accident data in South Africa's chemical process industries can be challenging. For example, only two major accidents in the chemical process industry were reported in the EM-DAT. The International Disaster Database -The Centre for Research on the Epidemiology of Disasters (CRED)., 2023 database for the period 1900 – 2020. Khan and Abbasi, 2002 reported only one major accident in the South African chemical process industry for the period 1970–1979, resulting in seven deaths and seven injuries. Accidents that occur in South Africa are mostly available in newspapers and national television. For example, the incident reported by Firehouse, 2004 in 2004 highlighted a major accident that occurred in South Africa within the chemical process industry. According to the report, approximately 500 employees were engaged in routine maintenance activities at a chemical plant when a blast occurred. Tragically, this incident resulted in five fatalities, leaving over 100 injured individuals. The incident reported by HazardEx. , 2020 described an explosion that occurred at an oil refinery in Cape Town, South Africa. According to the report, this explosion resulted in the tragic loss of two lives, leaving six injured on July 2. According to Welle, 2020, an explosion occurred in South Africa's second-largest oil refinery in 2020, injuring seven people. This incident highlights the ongoing risks and hazards associated with the operation of oil refineries. In addition, according to a report by HazardEx, 2020) an explosion and fire occurred at the Engen-operated refinery in Durban, South Africa on December 4, 2020. As a result of the incident, refinery operations were forced to shut down. HazardEx, 2020 further reported that a fire and several explosions occurred at a chemical factory in Durban, South Africa on December 8, 2020. The incident resulted in 13 people being injured, with two of them reported to have suffered life-threatening injuries. Over 100 workers were evacuated from the factory because of this incident.

The occurrence of these accidents underscores the importance of understanding the perceptions and opinions of employees in the chemical process industries in South Africa. Gaining insights into employees' perspectives can provide valuable information regarding perceptions of safety, risk management practices, and potential areas for improvement.

1.2.2. Investigation of accidents in South Africa

Several studies (Okoh, 2019; Ahmad et al., 2015; Orzáez et al., 2019; Okoh and Haugen, 2014; Nayager, 2015) have pointed to maintenance, inspection, and testing (MIT) as contributing factors to accidents in CPI. In South Africa, there is a significant gap in the literature concerning the study of past accidents. The limited availability of information regarding past accidents can be attributed to several factors. These may include under-reporting of incidents, lack of centralized databases or reporting systems, limited research focus on accident analysis, or challenges in accessing relevant data sources. According to Hedlund, 2013, studies on accident statistics in South Africa were limited at the time of their publication in 2013. They pointed out that the most recent study, specifically focusing on the manufacturing sector, was published in 1990. This suggests a significant gap in the research regarding the safety performance of South African industries.

Countries such as the USA, UK, and Australia have established legal requirements for companies to report incidents and have dedicated bodies responsible for investigating major incidents and accidents. These bodies, such as the Chemical Safety Board (CSB) in the USA, the Health, and Safety Executive (HSE) in the UK, and Safe Work Australia, play crucial roles in investigating incidents, determining their causes, and making recommendations to improve safety practices. A key aspect of these systems is the accessibility of accident reports to the public. Available and accessible accident reports provide a platform for learning from past accidents and help disseminate valuable information that can be used to prevent similar incidents in the future. These reports often contain detailed information on the causes of accidents, contributing factors, and recommendations to improve safety. Access to such reports allows researchers, industry professionals, and the public to study and analyse accident data, identify common patterns, and develop insights that can inform safety measures, regulations, and best practices. It also fosters transparency and accountability, as the public can assess how companies and regulatory bodies handle incidents and take steps to prevent recurrence. To bridge the gap in South Africa, it may be beneficial to consider establishing a similar system that includes mandatory incident reporting requirements, dedicated investigative bodies, and accessibility of accident reports to the public. This can enhance knowledge sharing, encourage continuous improvement in safety practices, and contribute to a safer working environment.

The primary objective of this study is to examine the relationship between human and organizational factors, accident occurrence, and accident frequency within the chemical process industries in South Africa. This study aimed to investigate factors such as procedures, communication, permit-to-work systems, and maintenance and risk management practices. The research also seeks to determine the impact of maintenance and risk management on accident occurrence and frequency while exploring their potential role as mediators in the relationship between other factors and accidents. The overarching research question guiding this study is the role of human and Organisational factors in accident frequency and occurrence. By addressing this research question, this study aims to shed light on the influence of human and organizational factors on accidents within the context of chemical process industries in South Africa. The findings contribute to the development of effective strategies and interventions to mitigate accidents and enhance safety within chemical process industries.

2. Theory and hypothesis

2.1. Human and organisational factors theories

Robertson, et al., 2016 cited that human and organizational factor (HOF) remains associated with a wider scope. They necessitate multidisciplinary study of the conditions that foster an efficient and safe human activity (Journé, 2020). Multiple disciplines that have been drawn together to analyse human and organizational factors include ergonomics, psychology, sociology of work, management sciences, sociology of organisations, sociology of professions, and many more. In recent times, focus has shifted from human factors alone to adopting a human and organizational factor approach to safety as the major target for ensuring process safety performance.

2.2. Maintenance management framework

According to the British Standards Institution (BS EN) 13,306 (British Standards, 2010; Blaise, et al., 2017) maintenance can be defined as a combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function. Considering this perspective, it is essential to distinguish between different approaches to maintenance strategies, as illustrated in Fig. 1 of the maintenance literature.

In the era of Industry 4.0, the management of industrial maintenance has assumed heightened significance. Originally, industrial maintenance relied on a corrective or reactive approach, wherein repairs were conducted only after equipment failure occurred, adhering to a "run-to-fail" rationale. However, over time, there has been a paradigm shift towards failure prevention, leading to the introduction of Preventive Maintenance, which encompasses both schedule-based and condition-based maintenance practices. The category of condition-based maintenance encompasses the concept of predictive maintenance, which is considered the most advanced form of industrial maintenance owing to its ability to forecast and anticipate potential failures. This evolution in maintenance activities and methods within maintenance policies signifies a progression from a reactive to a more proactive approach in both addressing and preempting potential failures.

The primary objective of maintenance is to mitigate substantial deterioration or deviation in the functionality of a plant (Hale, 1998), which poses risks not only to production but also to safety. Additionally, its purpose is to restore a plant to its full functioning state following breakdowns or disruptions. Although the goal of maintenance is to ensure plant safety, it is worth noting that maintenance tasks expose maintenance personnel to potential safety hazards. Undoubtedly, the maintenance function exerts a substantial influence on plant safety. Furthermore, maintenance encompasses more than asset retention and restoration; it entails optimizing and managing the operational and production costs of a business.

Maintenance and Abnormality: The need for maintenance often arises because of abnormalities or changes in equipment. This could be due to wear and tear, malfunction, or other factors that may increase the hazard potential of the equipment.

Hazards in Maintenance: The conduct of maintenance work itself can introduce hazards to both the equipment and the personnel involved. It is crucial to carefully control maintenance activities to eliminate or minimize these hazards.

Hazards to Personnel: Maintenance activities can pose risks to personnel involved. Maintenance workers may be exposed to various hazards such as mechanical risks, electrical hazards, exposure to hazardous substances, confined spaces, and other occupational hazards.

Consequences of Poor Maintenance Control: Failure to exercise proper control over maintenance can have serious consequences. The DuPont La Porte Facility Toxic Chemical Release accident in 2014, illustrates the potential risks associated with inadequate maintenance control. The accident resulted in the release of toxic methyl mercaptan, leading to the tragic loss of four workers' lives (Okoh and Haugen, 2013).

Maintenance as a High-Risk Activity: Maintenance work is recognized as a high-risk activity due to the nature of the tasks involved, the variety of sectors where maintenance is performed, and the different working environments. These factors emphasize the importance of comprehensive safety measures and controls in maintenance operations.

2.3. Maintenance safety critical communication

Safety critical communication in industry that are prone to high hazards involves discussions on the probable factors that could go wrong and how the same can be prevented by early adoption of suitable safety measures. A communication error in industrial setting may have far reaching consequences. Thus, safety critical communications have emerged as a mandatory parameter to ensure safe operations (Mitchell, 2016). A safety critical communication is not limited by any time schedules. It can be conducted during any part of the operating cycle both under normal and emergency circumstances. Safety critical communications also involves introspection of the past accidents to extrapolate and discuss the probable gaps and key learnings from the incidents (Mitchell, 2016). Accidents within the chemical process industries can be categorised depending upon the lack in either of the following human and organisation factors, which this study aim to investigate:

2.3.1. Safety critical Communication

Effective communication and clear recording of equipment status are crucial in maintenance operations. The Piper Alpha disaster serves as an example where communication breakdowns between operating shifts and inadequate understanding of equipment status contributed to the catastrophic incident (Marsh, The 100 Largest Losses 4 Harnessing the Power of Data to Prevent Losses 5 Improving Process Safety Performance by Learning from Losses., 2018).

The BP Texas City Refinery Explosion in the year 2005 could be cited as an outcome of lack of safety critical communication. The accident involved 15 fatalities owing to the explosions and fires that has been

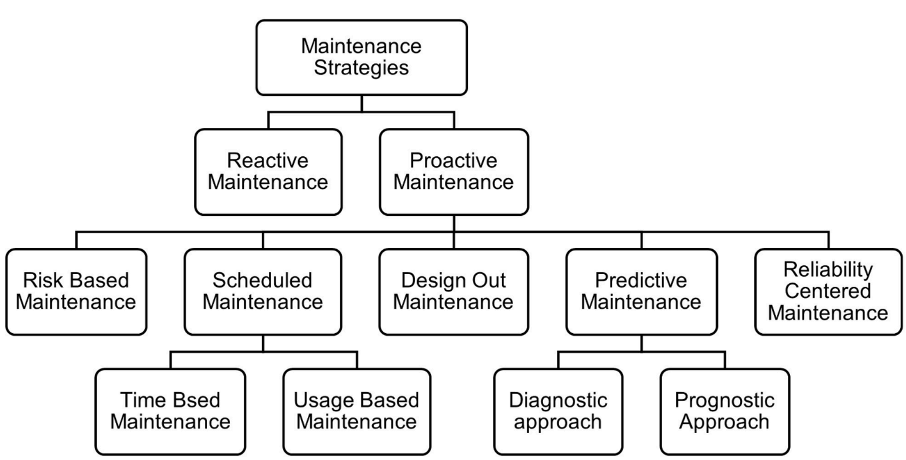

Fig. 1. Types of maintenance strategies (Sambrekar et al., 2018).

anticipated to result from poor shift turnover communications at the BP facility with another 180 injured. The U.S. Chemical Safety and Hazard Investigation Board report found the organization did not practice a shift turnover communication for its operations staff. Supervisors and operators poorly communicated safety critical information regarding the start-up procedure during the shift change. The accident causes financial losses worth of US $1.5 billion (Okoh and Haugen, 2013).

The DuPont La Porte Facility Toxic Chemical Release in 2014 involves release of 24,000 lb of toxic methyl mercaptan. Lack of appropriate shift communication has been cited as one of the major causes for the accident that resulted in 4 casualties. The US chemical safety board reported the errors to initiate five days back to the day of accident (Crocker, 2017).

The BP Deepwater Horizon Oil Spill accident in 2010 also has been cited as an outcome of poor communication. Reports from the BOEMRE and the US Coast Guard revealed the fault on the part of BP to share critical information from their onshore staff as well as reports from Halliburton, their drilling partner, to the Deep-Water Horizon rig crew. The accident involved 11 casualties (Crocker, 2017).

The Kleen Energy Natural Gas Explosion in 2010 has been an example of poor safety communication. According to a report by the U.S. Chemical Safety and Hazard Investigation Board, workers had received mixed communications regarding natural gas blows. The accident due to the breakdown in communication led to 6 casualties and more than 50 people were injured (Crocker, 2017).

2.4. Permit-to-Work

The Permit to Work (PtW) system is an integral part of an organization's effort to maintain a safe system of work. It provides a means to formally authorize plant maintenance, repairs, and modifications, which are tasks that are not part of the normal operational or production routine (IChemE, BP Process Safety Series Control of work., 2007). The HSE, 2005 defined a Permit to Work as "a formal recorded system to control certain types of work that are potentially hazardous". It is also a means of communication between the site/facility supervisor, facility managers and operators, and those performing hazardous work about the work to be performed and the precautions to be taken.

Permit-to-Work are an essential part of safe work systems of work for many maintenance activities. They allow work to start only after safety procedures have been established and provide clear evidence that all foreseeable hazards have been eliminated. A Permit is needed when maintenance work can only be carried out if the usual protective measures/safeguards are removed or if the work creates new hazards.

However, experience has shown that no matter how simple or sophisticated the procedure and work permit forms are, it is the strict application of the procedures and practices associated with the assessment of risk and application of Permit to Work conditions that ensures that work can be carried out. Studies have shown that 30 % of reported incidents in the chemical industry are attributed to maintenance related work, and permit-to-work systems has been implicated in over 20 % of these maintenance incidents (HSE, Dangerous Maintenance: A Study of Maintenance Accidents and How to Prevent Them., 1992). Chemical Safety and Hazard Investigation Board (US), European Major Accident Reporting System and Failure Knowledge Database (Japan) has revealed that Permit to Work has significance contribution to the occurrence of accidents and is worthwhile to be studied in detail. Failure in complying with Permit to Work system has caused major accidents cases, such as Motiva Enterprise LLC in 2001, Phillips Pasadena in 1989 and Piper Alpha Platform in 1988. Inadequate management or control of the Permit to Work (PTW) system resulted in significant losses, as follows:

- In a refinery incident, a fire ensued during hot work in a packed column by a sub-contractor, supervised by the equipment vendor/contractor. Failure to follow the site's hot work permit procedure caused a fire, resulting in major damage and the subsequent collapse of equipment.
- Another refinery incident involved a 'metal fire' during the replacement of internals and packing (hot work) inside a 250ft column, leading to the collapse of the column.
- At a fertilizer plant, a fire spread after welding work by contractors. Combustible materials in the area, including cable trays and conveyor belts, contributed to the fire's escalation (Jarvis and Goddard, 2016; Jarvis et al., 2017)

Despite the availability of information and feedback, the percentage trend in the work injury rate has not decreased over the last two decades. One reason to study permit-to-work is that it may help address this issue (Yan, 2017; Jusoh, 2020) . A survey by the H&SE showed that a third of all accidents in the UK chemical industry were maintenance related, the largest single cause being a lack of, or deficiency in, Permit to Work systems (Atherton, 2008). Failures identified included:

- Not checking systems adequately.
- Not identifying hazards adequately.
- Poor isolation of sources of energy: e.g., plant and electrical systems.
- Unclear on what forms of personal protective equipment were needed.
- Not dealing adequately with formal hand back of plant once maintenance work was completed.

In many cases, little thought had been given to permit form design.

2.5. Accident causation theories vs maintenance

There are multiple theories that explain the basis for accident causation. Some of the notable ones are as follows:

- **The domino theory:** One of the earliest theories for accident causation proposed by Heinrich, the domino theory posits that among the innumerable factors that result in injury, accident is one of them. In the industrial sector the theory is implemented in ten statements that are often referred to as the Axioms of Industrial Safety. The theory states five factors that sequentially results in an accident led injury. The factors are as follows- ancestry/social environment, fault of a person, unsafe act/mechanical or physical hazard, accident, and injury. As per the domino model, prevention of accidents necessitates removal of one of the sequential factors to accident causation. Removal of either of the factors interrupts the knockdown effect. Heinrich proposed unsafe acts/mechanical hazards as the crucial factor with maximum contribution towards accident causation and hence removal of this crucial factor should be targeted to make the preceding factors ineffective (DeCamp and Herskovitz, 2015).
- **The human factor theory:** The theory proposes that the chain of events resulting in accident causation ultimately is caused by certain human error. While addressing the factors that lead to human error the theory proposes three broad and distinct factors as follows- overload, inappropriate response, and inappropriate activities (DeCamp and Herskovitz, 2015).
- **The accident/incident theory:** The theory by Peterson is an adaptation of Ferrell's Human Factor Model that introduces some new elements such as ergonomic traps, the decision to err, and systems failures (DeCamp and Herskovitz, 2015).
- **The systems theory:** While most of the theories focus on human error as the major driver for accidents, it is the system model theory that proposes the relationship between persons and their environment to play a significant role in the accident causation. The system model reviews occurrence of accidents as a system that comprises three components: person (host), machine (agency), and environment. It is the maintenance of harmony between the three

components that provide the shielding effect from any accident causation. Alternatively, it could be stated that while under normal conditions the risk for accidents is low, a disruption in the harmony by changing the status of either of the components substantially increases the risk for accident (DeCamp and Herskovitz, 2015).

- **The combination theory:** The combination theory states that accident causation could not be explained by a single theory. Factors from more than one theory are required to be combined to explain all accidents (DeCamp and Herskovitz, 2015).

Leveson, 2012 posits that accident causation models lie beneath all efforts related with safety engineering, as they serve as basis for accident investigation and analysis, to prevent future accidents in new designs and for the development of risk assessment techniques.

2.6. Incident models

2.6.1. Human factors and the barrier model

The "barrier" or "Swiss Cheese" model, as depicted in Fig. 2, is a commonly accepted accident causation model within the chemical process industry. This model emphasizes the importance of three main barriers: Plant and Equipment, Processes, and People, in order to prevent accidents. When all three barriers are effectively in place, the likelihood of accidents is diminished. However, if any of these barriers have a gap or deficiency, the risk of accidents significantly rises. These gaps in the barriers can be influenced by a range of "human factors" including but not limited to: procedures, training, maintenance, inspection, testing, and safety critical communications.

Hollnagel, 2016 asserts the importance of accurately describing and understanding accidents in order to effectively mitigate their impact. Leveson, 2012 further argues that safety engineering must adapt to the rapid technological advancements that introduce new uncertainties and potential risks. With the progress of technology and society, the causes of accidents also change. In particular, traditional safety engineering techniques, particularly pertaining to digital technology, prove insufficient in controlling accidents involving digital systems and software. Additionally, new hazards, such as manmade chemicals, toxins, and antibiotic misuse, present new risks. The complex interaction between humans and automation has likewise resulted in novel forms of human error, including mode confusion and errors of omission versus commission. Consequently, existing safety engineering approaches are inadequate in addressing these emerging types of errors. Operators of high-tech systems often find themselves subject to the authority of automation design or the social and organizational context. This underscores the immediate necessity of new approaches to enhancing workplace design and automation as a means of minimizing accidents.

The understanding and investigation of accidents have evolved significantly over time, as argued by Lundberg et al., 2009. In our modern world, the complexity of systems demands more advanced accident models. An integral part of safety management systems is the accident investigation manual, which encompasses an accident model that outlines the occurrence of accidents and identifies important factors. These manuals reflect an organization's priorities in investigating accidents and offer guidance on preventing future incidents. They serve various purposes, such as setting standards for investigators, providing guidance for novices, and inspiring new ideas. Due to their multifunctionality, accident manuals are crucial components of safety management systems. While they may not always reflect actual investigative practices, they establish implicit or explicit norms regarding what constitutes a satisfactory investigation. Investigation manuals exert influence at different levels within safety management systems. Many manuals encompass three key aspects of accident investigation: accident models and assumptions regarding the interactions among factors that cause or prevent accidents, factors related to humans, technology, and organizations, and the investigation process or activities. Frequently, these manuals utilize complex linear models, treating identified causes as specific problems that must be addressed when implementing solutions, adhering to the principle of "What-You-Find-Is-What-You-Fix".

Therefore, this study conducted a thorough examination of these factors in the chemical process industries with the aim of enhancing safety standards. The study suggests that minimizing the impact of human factors can be achieved through effective engineering that eliminates hazards and the implementation of clear and efficient processes and procedures.

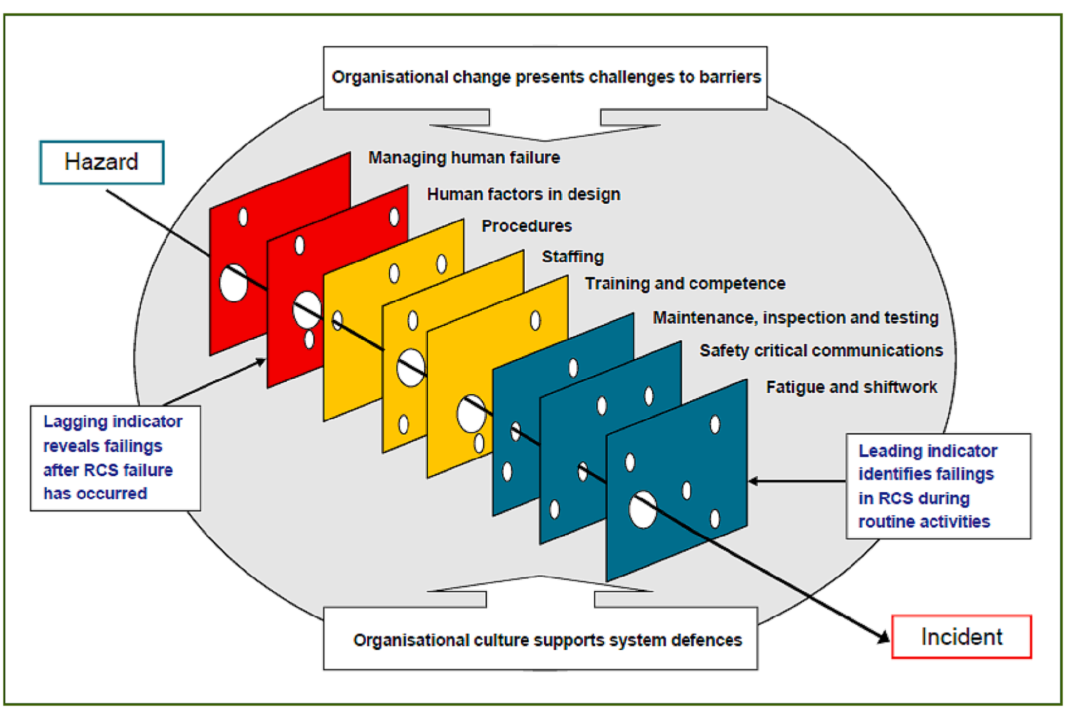

Fig. 2. Swiss Cheese model proposed by Reason considering the different mechanism to manage safety, and how is it possible hazards can lead to some incidents (Reason, 2000; Fitzgerald, et al., 2011) .

2.7. Conceptual framework

The study explore the correlation between different factors and the way they are perceived in regard to risk management and maintenance in the Chemical and Process Industry (CPI) in South Africa. The study also aims to understand how these perceptions affect the occurrence and frequency of accidents. The conceptual framework, as illustrated in Fig. 3, encompasses several factors including procedures, communication accuracy, communication satisfaction, permit to work systems, and competence level. The goal is to assess the extent to which personnel perceive risk management and maintenance to be influenced by these factors. In other words, the effectiveness of risk management and maintenance practices may be impacted by the presence or absence of proper procedures, accurate communication, satisfactory communication, permit to work systems, and the level of competence. Duarte and Santiago Scarpin, 2023 conducted a study examining the relationship between maintenance practices and productive efficiency. While the focus of the research was on the impact of training on maintenance practices, it indirectly highlights the significance of competence in influencing the effectiveness of maintenance.

Furthermore, the study extends its investigation to examine the impact of risk management and maintenance perceptions on accident occurrence and frequency.

The hypothesis posits that if risk management and maintenance practices are perceived positively, there will be a decrease in the number of accidents and their frequency. The anticipated hypotheses are provided in Table 1 which list of all the hypothesis considered in this study.

Hypothesis 1. Procedures, communication accuracy, communication satisfactory, permit to work and competence level will be positively associated with risk management.

The quality, efficiency, and effectiveness of maintenance work are solely dependent on the maintenance worker executing the maintenance tasks. Several factors contribute to the success of maintenance work:

Hypothesis 1. states that procedures, communication accuracy, communication satisfaction, permit to work, and competence level will have a positive association with risk management. The success of maintenance work (quality, efficiency, and effectiveness) relies heavily on the maintenance worker executing the tasks. Several factors contribute to the effectiveness of maintenance work:

- Procedure: The presence of a well-defined and documented procedure is essential for consistent and effective performance of maintenance tasks.
- **Risk Management:** Maintaining overall health and safety in an organization requires effective risk management (Tucci and Stedman, 2023). This involves developing and implementing policies and procedures from a risk management perspective, including identifying, analyzing, prioritizing, implementing solutions, and monitoring risks (Irving, 2014).
- **Competence:** Having a competent maintenance workforce is crucial for safe and effective task execution. Regular training and development of maintenance personnel are necessary for enhancing their skills and competence, ultimately reducing errors and improving overall effectiveness (Shi, 2021).
- **Communication:** Effective communication plays a vital role in ensuring smooth and efficient performance of maintenance tasks. It also contributes to managing the safety climate, as safety communication mediates the relationship between safety climate and safety outcomes (He, 2022).

Hypothesis 2. suggests that procedures, communication accuracy, communication satisfaction, permit to work, and competence level will have a positive association with accident occurrence and frequency. Prior research (Gyekye and Salminen, 2009; Gyekye et al., 2012) has consistently demonstrated that factors such as perceived organizational support, job satisfaction, compliance with safe work practices, safety training, company policy, and communication are correlated with accident frequency (Yeong and Shah Rollah, 2016). Utilizing innovative technologies, such as digital communication tools, can further enhance safety communication and outcomes. Additionally, the implementation of an automated system for assessing employees' professional competencies has been linked to a reduction in accidents and injury rates in the petroleum industry (Glebova et al., 2019).

Hypothesis 3: Procedures, communication accuracy, communication satisfactory, permit to work and competence level will be positively associated with maintenance.

Adherence to procedures is crucial for maintaining effective maintenance tasks, and training plays a significant role in improving maintenance performance. The availability of documentation has also been

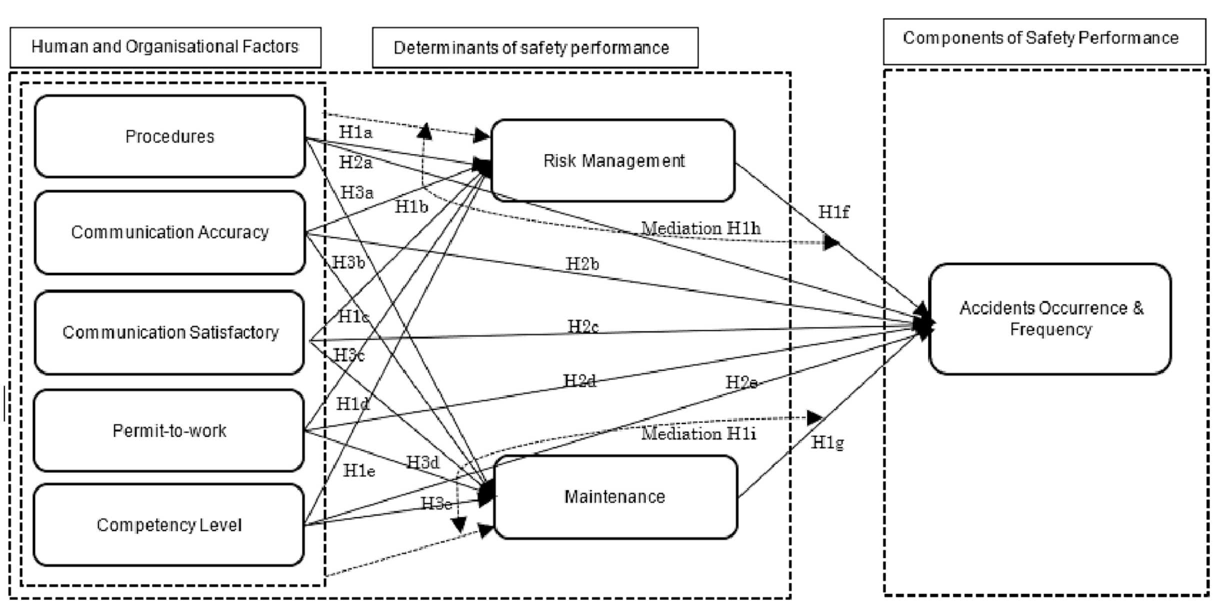

Fig. 3. Conceptual framework and Hypothesis considering human and organisational factors in relation to risk management ($H1_{a,\ b,c,d,e}$), accident occurrence and frequency ($H2_{a,b,c,d,e}$), maintenance ($H3_{a,b,c,d,e}$), and risk management ($H1_f$), and maintenance ($H1_g$) in relation to accident occurrence and accident frequency.

Table 1
This table presents the hypotheses related to organizational factors in relation to risk management (Hypothesis 1), accident occurrence and frequency (Hypothesis 2), maintenance (Hypothesis 3), and risk management (Hypothesis 4), and maintenance (Hypothesis 5) in relation to accident occurrence and accident frequency.

Hypothesis 1.
Hypothesis 1a. Procedure will be positively associated with Risk Management.
Hypothesis 1b. Communication Accuracy will be positively associated with Risk Management.
Hypothesis 1c. Communication Satisfactory will be positively associated with Risk Management.
Hypothesis 1d. Permit to work will be positively associated with Risk Management.
Hypothesis 1e. Competency Level will be positively associated with Risk Management.
Hypothesis 2.
Hypothesis 2a. Procedure will be positively associated with Accident Occurrence & Frequency.
Hypothesis 2b. Communication Accuracy will be positively associated with Accident Occurrence & Frequency.
Hypothesis 2c. Communication Satisfactory will be positively associated with Accident Occurrence & Frequency.
Hypothesis 2d. Permit to work will be positively associated with Accident Occurrence & Frequency.
Hypothesis 2e. Competency Level will be positively associated with Accident Occurrence & Frequency.
Hypothesis 3.
Hypothesis 3a. Procedure will be positively associated with Maintenance.
Hypothesis 3b. Communication Accuracy will be positively associated with Maintenance.
Hypothesis 3c. Communication Satisfactory will be positively associated with Maintenance.
Hypothesis 3d. Permit to work will be positively associated with Maintenance.
Hypothesis 3e. Competency Level will be positively associated with Maintenance.
Hypothesis 4: Risk Management H1f affects accident occurrence and frequency in CPI.
Hypothesis 5: Maintenance H1g affects accident occurrence and frequency in CPI.

found to positively impact the productivity of maintainers.

Research has consistently shown that adherence to procedures is crucial for maintenance tasks (Van Der Schaaf and Kanse, 2004). Training plays a significant role in improving maintenance performance, as it enhances skills and competency (Heryati, 2019). Furthermore, the availability of documentation has been found to positively impact the productivity of maintainers (Leotta, 2013). These findings support the hypothesis that procedures, communication accuracy, communication satisfaction, permit to work, and competence level are positively associated with maintenance.

Hypothesis 4. Risk Management H1f affects accident occurrence and frequency in CPI.

A range of studies have explored the factors influencing accidents in the chemical process industries. An analysis of common causes of 100 major losses from 1996 to 2014, Jarvis et al., 2017 classified them as: In adequate control of processes (15 %), inadequate hazard identification (10 %), Bhattacharjee, 2020 and Soltanzadeh, 2022 both highlight the significant role of human and organizational factors, with the latter specifically identifying risk management as one of the factors. These findings collectively support the hypothesis that risk management (H1f) can indeed affect accident occurrence and frequency in the chemical process industries.

Hypothesis 5. Maintenance H1g affects accident occurrence and frequency in CPI.

Maintenance in the chemical process industry has a significant impact on the occurrence and frequency of accidents. In their study Okoh and Haugen, 2013 revealed that maintenance activities can lead to major accidents. Jarvis et al., 2017 classified them as Mechanical integrity failures (40 to 50 %), failure in operating procedures and practices (20 to 30 %). Okoh and Haugen, 2013 further emphasized the potential negative effects of maintenance on safety barriers. These findings support the hypothesis that maintenance H1g affects accident occurrence and frequency in the chemical process industry.

3. Materials and methods

3.1. Research design and methodology

3.1.1. Target population, sampling, and sample

This study was conducted in the South African chemical and process industries. The target population consisted of employees working at the company. Participation in the study was voluntary. A short presentation letter was distributed by the research team describing the aims of the research. The Participant Information Sheet was provided which gave more details about the study. Participants were invited from various departments within the company, including Mechanical, Electrical, Instrumentation, Civil, Reliability, Production, Safety, Health, and Environment (SHE), as well as other relevant departments. Targeting a random sector of the company's population helped to minimise systematic bias and to ensure that the study results are more representative of the entire population.

3.1.2. Questionnaire design

The Safety Climate tools (Davies and Spencer, 2001; Mearns, 2001; Mearns, 2000; International, 2006) were utilized to design the questionnaire, with selected items customized for the specific study. The questionnaires were categorized as code A to G, as documented in Appendix A. These codes were then used in Appendix B to identify the corresponding questions used. While existing literature questionnaires were applied in various contexts, such as offshore environments, none were specifically tailored for the chemical and process industries. Therefore, the items from these instruments were either adopted or customized in Appendix B to formulate a more comprehensive questionnaire that specifically addressed maintenance operations in the chemical process industries in South Africa. The questionnaire design followed the recommended principles by (Peterson, 2000; Oppenheim, 2000; Olsen, W., Data Collection: Key Debates and Methods in Social Research. Data Collection: Key Debates and Methods in Social Research., 2014) .

The questionnaire consisted of a total of 75 questions, categorized into different sections. The first section comprised seven demographic questions, gathering information on the participants' gender, age, department, job title, years of experience in the chemical processing industry, tenure, and highest level of education. The remaining sections focused on Procedures (8 items), communication accuracy (9 items), communication satisfaction (11 items), permit-to-work (10 items), maintenance (16 items), risk management (8 items), competence level (4 items), and accident occurrence & frequency (2 items). All items were assessed using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

3.1.3. Pilot study

To ensure the questionnaire's effectiveness and clarity, a pilot study was conducted. The questionnaire was sent to selected maintenance staff and representatives from chemical process industries. The respondents were requested to provide feedback on the clarity, suitability, relevance, and flow of the questionnaire. This allowed for the identification of any ambiguities, difficult questions, or structural issues, and enabled adjustments to be made to the questionnaire terminology to ensure familiarity with respondents and ease of data recording. Additionally, respondents were asked to share the time required to complete the questionnaire. This pilot study helped assess the questionnaire's validity, reliability, and content, and facilitated necessary amendments before the official launch in line with Gyekye, 2009. Unintentional mistakes were identified and corrected, and the questionnaire was refined based on the feedback received. The involvement of experts in this process aimed to enhance the quality and relevance of the questionnaire items, ultimately strengthening the overall data collection process Gupta, 2013. This approach aligns with best practices in questionnaire development, emphasizing the importance of pre-testing and refining survey instruments to ensure validity and reliability (Umar, 2010).

3.1.4. Data collection

Data collection was granted ethical approval by the University of Strathclyde Chemical and Process Engineering Departmental Ethics Committee and was in line with the ethical guidelines of the company. Participants were invited to complete the questionnaire once, which served as the initial method of data collection. To ensure data privacy, a link to the questionnaire, hosted on the Qualtrics Strathclyde platform, was sent to participants through their company mail. Participation in the study was voluntary, and a presentation letter was distributed to provide participants with an overview of the research objectives. Additionally, a Participant Information Sheet was provided, offering more detailed information about the study. The survey questionnaire was administered online to employees working in the participating company. Out of a total of 2,834 employees in the company, 450 employees from specific departments were invited to participate. A total of 316 questionnaires were returned, with 247 being valid and 69 being invalid. Invalid questionnaires were discarded after conducting a missing value analysis (MVA), following Hair et al., 2020. Among the 247 valid responses, 221 were completed in their entirety, while 26 had less than 5.3 % missing information. Thus, the final sample size was determined to be 247, which was considered sufficient for a 95 % confidence interval with a 5 % margin of error.

3.1.5. Data analysis methods

The study explored participants' perceptions on the relationship between human and organisational factors, maintenance, and accidents using a quantitative approach on data analysis. Categorical variables were described using frequency and frequency percentages, while continuous variables were described using mean values and standard deviations. The independent *t*-test was used to compare scores between two groups, and the analysis of variance (ANOVA) was used for three groups. Pearson correlations were utilized to determine the correlations between variables, such as maintenance, risk management, procedures, communication accuracy, communication satisfaction, permit to work, and competence level, and perceptions of accident occurrences and frequencies. Significance was determined based on a p-value of less than 0.05. The statistical software SPSS 28 was employed for all calculations and testing.

3.1.6. Constructs internal consistency reliability

To evaluate the reliability of the constructs, Cronbach's alpha coefficients were calculated using SPSS 28. Cronbach's alpha is a measure of internal consistency that indicates how closely related a set of items are as a group, as defined by Hair, 2019. The rule of thumb for interpreting Cronbach's alpha is as follows: values ≥ 0.9 indicate redundancy among indicators, 0.9 to 0.95 suggest somewhat high consistency, 0.8 to < 0.9 indicate excellent consistency, 0.7 to < 0.8 suggest good consistency, 0.6 to < 0.7 are considered acceptable for exploratory research, and values < 0.6 indicate poor consistency. In this study, the reliability coefficients for each construct exceeded 0.6, indicating that the items were acceptable for analysis and could be used in future studies. For data that were not normally distributed, nonparametric tests, including the Mann-Whitney *U* test and Wilcoxon test, were conducted to compare variables between groups. Pearson correlation was used to explore the relationships between variables.

4. Results

4.1. Descriptive statistics and regression results

Descriptive statistics of the variables under review (demographic information of the participants) review are shown in Table 2. The study included demographic questions to ensure that the results were representative of the population being studied and to help to identify any patterns or differences in perceptions based on factors such as age, gender, job role. Results indicates that more males 80.6 % (n = 199). A higher proportion of males in the sample reflects what would be expected in South African companies and specifically in engineering field where in general terms, more males than females are formally employed. The Engineering Council of South Africa Ecsa, 2021 reported in their 2021 annual report that women are severely under-represented. For instance, data indicated that women represent 23 % of candidate engineers also known as Engineers in Training (EITs) and only 5 % of candidate certificated engineers. Among professional engineers and technologists, a similar trend of under-representation in women is also observed. Indeed, only 1 % of professional certificated engineers are women and 6 % of professional engineers are women (Ecsa, 2021). The demographic data unveiled the continuing gaps in poor representation of woman in the engineering industry, and in the participating organisation/company, and area that requires improvement, hence, the government's efforts to empower women in a bid to redress the historic institutionalised preference of males over women in employment. Participants in age groups 31 – 35, (n = 53, 21.5 %) and 36 – 40 years (n = 50, 20.2 %), from the Mechanical department, (n = 92, 37.2 %), with between 6–15 years of experience (n = 65, 40.1 %) with trade qualification/ GCC (n = 79, 32 %) The "other" (n = 70, 28.5 %) category in the current study includes participants from job categories or departments with frequencies less than 10 participants. Some examples of these job categories are scientists (2), supervisors (4), group leaders (1), control officers (3), process controllers (3), QA/QC (6), administrators (3), operators (6), fleet management (1), analyzers (1), communications (1), risk management (1), site services (3), planning (3), lifting operations (1), security (1), condition monitoring (1), admin (1), asset supports (1), and various other roles. These participants were included in the study to provide a comprehensive understanding of the human and organizational factors, maintenance, and accidents in the context of CPIs in South Africa. The inclusion of these job categories allows the study to capture the diverse perspectives and experiences of individuals working in these areas, which can help identify areas for improvement and inform future research and interventions. Lastly Bachelor's degree (n = 49, 19.8 %) levels of education shared their perception in this study.

The study's use of the Pearson Correlation (Table 3) coefficient provides a quantitative measure of the strength of the relationship between the independent variables (procedures, communication accuracy, communication satisfaction, permit to work, and competency level) and accident frequency and occurrence. The results of the study found Hypothesis 5, 4, 1c, 3d, 1e, 1d, 3c, and 1b with beta coefficient (β) values greater than zero suggesting a positive association, and the closer the value is to 1, the stronger the relationship. There were significant positive correlations which supports Hypothesis 5: Maintenance H1g affects accident occurrence and frequency in CPI. ($\beta = 0.736$), Hypothesis 4: Risk Management H1f affects accident occurrence and frequency in CPI. ($\beta = 0.737$), Hypothesis 1c. Communication Satisfactory will be positively associated with Risk Management. ($\beta = 0.659$), Hypothesis 3d.

Table 2
Background information of the sample chemical and process industries workers (n = 247).

	Gender						Age (years)								Years of experience in CPIs							
	Male	Female	Prefer not to say				≤30	31–35	36–40	41–45	46–50	51–55	≥ 55		≤5	6–10	11–15	16–20	≥ 20			
Frequency	199	46	2				20	53	53	50	33	17	21		35	65	65	35	47			
Percentage (%)	80.6 %	18.6 %	0.8 %				8.1 %	21.5 %	21.5 %	20.2 %	13.4 %	6.9 %	8.5 %		14.2 %	26.3 %	26.3 %	14.2 %	19.0 %			
	Tenure (in current role)						**Department**								**Job Title**							
	≤5	6–10	11–15	16–20	≥ 20		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Frequency	90	99	43	10	5		92	17	16	5	9	36	15	57	11	28	13	58	32	21	13	70
Percentage (%)	36.4 %	40.1 %	17.4 %	4.0 %	2.0 %		37.2 %	6.9 %	6.5 %	2.0 %	3.6 %	14.6 %	6.1 %	23.1 %	4.5 %	11.4 %	5.3 %	23.6 %	13 %	8.5 %	5.3 %	28.5 %
	Highest Level of qualification																					
	1	2	3	4	5	6	7	8														
Frequency	36	79	49	10	11	24	1	37														
Percentage (%)	14.6 %	32 %	19.8 %	4 %	4.5 %	0.7 %	0.4 %	15.0 %														

Note: ***N*** = 247;; **Department** Code as: 1 = Mechanical, 2 = Electrical, 3 = Instrumentation, 4 = Civil, 5 = Reliability, 6 = Production, 7 = SHE, 8 = Other; **Job Title** Code as: 1 Senior Manager, 2 = Area Manager, 3 = Engineer, 4 = Artisan, 5 = Technician, 6 = Specialist, 7 = Practitioner, 8 = Other.; **Highest level of education** Code as: 1 = Matric, 2 = Trade qualification/GCC, 3 = Bachelor's Degree, 4 = Honours Degree, 5 = BEng Degree, 6 = Master's Degree, 7 = Doctoral Degree, 8 = Other.

Permit to work will be positively associated with Maintenance. (β = 0.609). Hypothesis 1e. Competency Level will be positively associated with Risk Management. (β = 0.574). Hypothesis 1d. Permit to work will be positively associated with Risk Management. (β = 0.545). Hypothesis 3c. Communication Satisfactory will be positively associated with Maintenance. (β = 0.545). Hypothesis 1b. Communication Accuracy will be positively associated with Risk Management. (β = 0.525). The positive association found between the independent variables and accident frequency and occurrence are significant for several reasons:

- as maintenance practices improve or are conducted more effectively in the CPIs, there is a higher likelihood of a decrease in accidents.
- as risk management practices improve or are implemented more effectively in the CPI, there is a higher likelihood of a decrease in accidents.
- as communication satisfaction improves in the workplace, there is a higher likelihood of an increase in effective risk management practices.
- as the implementation or effectiveness of the permit to work system improves in the workplace, there is a higher likelihood of an increase in maintenance practices.
- as the competency level of individuals in the workplace improves, there is a higher likelihood of an increase in effective risk management practices.
- as communication accuracy increases, Risk Management is expected to increase as well.
- The positive associations suggest that improving the independent variables, such as maintenance, risk management, communication satisfaction, permit to work, and competency level, can lead to a reduction in accident frequency and occurrence. This can help organizations in the CPI to develop targeted interventions to improve safety and prevent accidents.

4.2. *Multiple linear regression models*

The current study employed multiple linear regression models to examine various hypotheses pertaining to risk management and organizational factors. Specifically, Models 1–6 (as presented in Table 4), were utilized to test the relationship between independent variables such as procedure, communication accuracy, communication satisfaction, permit to work, and competency level, and the dependent variable of risk management. Model 1 treated risk management as the dependent variable, while the control variables were considered independent variables. Subsequent models incorporated one independent variable at a time to assess their individual impact on risk management. The regression models were evaluated using the enter method within the SPSS 28 software.

The results of the analysis indicated that hypothesis 1a, which explored the influence of procedure on risk management, failed to garner support as the p-value (0.183) exceeded the threshold of 0.05. This suggests that procedure was not positively associated with risk management at a significant level of 5 %. The questionnaire items encompassed various aspects of procedures, such as clarity, practicality, comprehensiveness, and user-friendliness, which are all critical considerations for effective risk management and accident prevention. They offer valuable insights regarding the alignment between procedures and risk management within the chemical process industry.

One specific item, referred to as Procedure (PRO1), addresses the problem of an excessive number of health and safety procedures/work instructions/rules to follow. It highlights the potential impact of having too many procedures on risk management. This aligns with the findings of Yalcin et al., 2023, who argued that when there is an abundance of procedures, employees may struggle to accurately remember and adhere to them, leading to errors or non-compliance. Another item, Procedure (PRO2), emphasizes the importance of practicality in procedures. Jung et al., 2020, stress that if certain maintenance, health, and safety

Table 3
Relationship Test using Pearson correlation analysis for the variables.

Variable	Procedure	Communication Accuracy	Communication Satisfactory	Permit to Work	Maintenance	Risk Management	Competency Level	Accident Occurrence and Frequency
Procedure	1							
Communication Accuracy	.204**	1						
Communication Satisfactory	.148*	.711**	1					
Permit To Work	.174**	.572**	.609**	1				
Maintenance	.171**	.490**	.545**	.609**	1			
Risk Management	.121	.525**	.659**	.545**	.640**	1		
Competency Level	.090	.582**	.613**	.659**	.457**	.574**	1	
Accident Occurrence and Frequency	.107	.611**	.702**	.613**	.736**	.737**	.600**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
Abbreviations: procedures (PRO); communication accuracy (CA); communication satisfactory (CS), permit-to-work (PTW); maintenance (MAIN); risk management (RM), competence level (CL); accident frequency (AF)

procedures/instructions are not practical to implement, employees may find workarounds or completely disregard them, compromising efforts in risk management. Procedure (PRO3) focuses on the clarity and understandability of safety procedures. Reniers et al. (Reniers, 2006) demonstrate that clear and easily comprehensible procedures are crucial for effective risk management, as employees need to understand and follow them accurately in order to mitigate potential hazards. An additional item, Procedure (PRO4), addresses the issue of confusing procedural instructions. Shimada, 2019, highlight that if instructions are unclear or confusing, employees may misinterpret them, leading to incorrect task execution and potential safety risks. Procedure (PRO5) emphasizes the importance of regularly updating preventive maintenance procedures whenever there are changes in equipment or practices. Shimada, 2019, argue that by keeping these procedures up to date, organizations ensure alignment with evolving equipment or practices, reducing the likelihood of accidents or failures resulting from outdated procedures. Procedure (PRO6) highlights the significance of comprehensive maintenance procedures. Han and Park, 2018 reveal that insufficient content in procedures may hinder the fulfillment of business needs, potentially resulting in incomplete or ineffective maintenance practices and increased safety risks. Procedure (PRO7) focuses on the user-friendliness of procedures. Reniers, 2006 propose that user-friendly procedures facilitate employees' navigation and adherence to safety protocols, ultimately enhancing their ability to manage risks effectively. It is important to note, as emphasized by Jhangiani, 2019, that the absence of evidence for a relationship does not necessarily mean that there is no relationship at all. It simply indicates that there is insufficient statistical evidence, based on the available data and chosen significance level, to confidently support a relationship.

When examining the descriptive statistics for each item in the questionnaire, the mean and standard deviation offer insights into specific elements of procedures that may not effectively support good risk management, as initially expected (see Table 5).

As seen in the values reported in Table 7, the mean values for PRO1, PRO2, PRO3, PRO5, and PRO7 are above 3, suggesting a tendency towards agreement or a positive perception of these items. The mean values for PRO4 and PRO6 fall between 2 and 3, indicating a neutral or slightly leaning towards disagreement stance on these items. It is important to notice that although PRO4 mean's fall in the disagreement category, the results are consistent with PRO3 given the former states that instructions are confusing and the latter that instructions are clearly written.

The means and standard deviation for PRO1 (3.01 and 0.99) and PRO2 (3.08 and 1.20) falling in mostly in the agreement category indicate that there seems to be too many procedures to follow and that their implementation might be at times not entirely feasible to implement.

In light of this, additional research is needed to explore further the reasons why procedures, an in particular aspects associated to number and implementation, may not be seen as positively associated with risk management in the company. This research could delve into factors such as procedures workflows, organizational culture, employee perceptions, and contextual influences that may impact the effectiveness of procedures in managing risk.

Hypothesis 1b. related to communication accuracy and risk management was supported by the results. The significant p-value($p < .001$) which is less than 0.05 and the positive beta coefficient (0.641) indicated that communication accuracy was positively associated with risk management at a 5 % level of significance. Hypothesis 1c related to communication satisfactory and risk management was supported by the results since $p < 0.001$ which is less than 0.005, and the positive beta coefficient (0.622) this shows that communication satisfactory was positively associated with risk management at a 5 % level of significance. Looking at hypothesis 1d permit to work had a p-value $< .001$ which is less than 0.05 and the positive beta coefficient 0.747 which means that permit to work was positively associated with risk management at a 5 % level of significancy, and hypothesis 1e competency level had a p-value < 0.001 which is less than 0.05 and positive beta coefficient 0.506 this showed that, competency level was positively associated with risk management. This concludes communication accuracy, communication satisfactory, permit to work and competency level were positively associated with risk management these are associated with hypothesis 1b-1e.

In summary, the study used multiple linear regression models to investigate the relationship between several independent variables and the dependent variable of risk management. While the hypothesis related to procedure was not supported, as the p-value (0.183) was greater than 0.05, the hypothesis related to communication accuracy, communication satisfaction, permit to work, and competency level was supported, indicating that these variables are positively associated with risk management. The study also highlighted the importance of considering multiple independent variables when examining the relationship between risk management and other factors.

4.3. Accident occurrence and frequency in relation to organisational factors

The study used models 7–14 (Table 6) to test Hypothesis 2a-2e, which examined the relationship between the five independent variables (procedure, communication accuracy, communication satisfaction, permit to work, and competency level) and accident frequency and occurrence. The results showed that all five independent variables were positively associated with accident frequency and occurrence, with p-

Table 4
Results from the linear regression analyses including dependent and independent variables.

Variable	Risk Management						Accident Occurrence & Frequency								Maintenance					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20
	β	β	β	β	β	β	β	β	β	β	β	β	β	β	β	β	β	β	β	β
Gender	−0.066	−0.067	−0.019	0.028	0.050	−0.073	−0.066	−0.066	−0.016	0.024	0.036	−0.072	−0.023	0.025	−0.104	−0.105	−0.072	−0.048	−0.020	−0.108
Age	0.008	0.009	−0.001	−0.010	−0.002	−0.020	−0.009	−0.008	−0.016	−0.025	−0.017	−0.035	−0.014	0.003	−0.013	−0.012	−0.017	−0.023	−0.020	−0.029
Department	−0.035	−0.032	−0.021	−0.027	−0.012	−0.017	−0.029	−0.027	−0.014	−0.021	−0.009	−0.012	−0.006	−0.007	−0.026	−0.022	−0.016	−0.020	−0.009	−0.015
Job Title	0.029	0.028	0.020	0.005	−0.001	0.009	0.045	0.045	0.036	0.022	0.019	0.027	0.026	0.012	0.038	0.037	0.032	0.024	0.017	0.027
Work Experience	0.018	0.022	0.003	0.013	0.026	0.022	−0.042	−0.040	−0.058	−0.047	−0.035	−0.039	−0.054	−0.036	−0.007	−0.003	−0.017	−0.010	−0.001	−0.005
Tenure	−0.023	−0.021	0.002	0.029	0.043	0.033	0.018	0.019	0.044	0.067	0.076	0.070	0.033	0.016	0.002	0.004	0.019	0.033	0.050	0.034
Educational Background	0.009	0.012	0.019	0.011	0.013	0.013	−0.007	−0.006	0.003	−0.006	−0.004	−0.004	−0.013	−0.008	0.001	0.004	0.008	0.002	0.004	0.003
Procedure		0.159						0.091								0.159				
Communication Accuracy			0.641						0.672								0.435			
Communication Satisfactory				0.622						0.588								0.368		
Permit to Work					0.747						0.659								0.538	
Competency Level						0.506						0.474								0.293
Risk Management													0.651							
Maintenance														0.875						
p-value	0.289	0.183	<0.001	<0.001	<0.001	<0.001	0.029*	0.032*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.034*	0.008*	<0.001	<0.001	<0.001	<0.001
F-Statistics	1.227	1.433	12.127	24.531	25.145	15.715	2.280	2.147	21.456	34.628	27.641	20.561	41.385	36.605	2.211	2.647	11.526	14.826	26.422	10.178

N= 247, *p <.05; **p<0.001

Table 5
Descriptive statistics (Mean, Standard deviation) Level of agreement for Procedure items in main questionnaire.

Item	Mean	Standard Deviation
Procedures (PRO1).	3.01	0.99
Procedures (PRO2).	3.08	1.20
Procedures (PRO3).	3.89	0.98
Procedures (PRO4).	2.37	0.99
Procedures (PRO5).	3.73	0.92
Procedures (PRO6).	2.87	0.99
Procedures (PRO7).	3.45	0.95

values less than 0.05 and positive beta coefficients. Therefore, it was concluded that procedures, communication accuracy, communication satisfactory, permit to work, and competency level were all important factors related to accident frequency and occurrence.

The results of the analysis showed that hypothesis 2a related to the influence of procedure on accident frequency and occurrence was supported, as the p-value (0.032) was less than 0.05 and the positive beta coefficient (0.091) indicated that procedures was positively associated with accident frequency and occurrence at a 5 % level of significance. The results of the analysis showed that the hypothesis 2b related to the influence of communication accuracy on accident frequency and occurrence was supported, as the p-value (0.001) was less than 0.05 and a positive beta coefficient 0.672. Therefore, it was concluded that communication accuracy was positively associated with accident frequency and occurrence at a 5 % level of significance. The results of the analysis showed that the hypothesis 2c related to the influence of communication satisfactory on accident frequency and occurrence was supported, as the p-value (0.001) was less than 0.05 and a positive beta of 0.588. Therefore, it was concluded that communication satisfactory was positively associated with accident frequency and occurrence at a 5 % level of significance. The results of the analysis showed that the hypothesis 2d related to the influence of permit to work on accident frequency and occurrence was supported, as the p-value (0.001) was less than 0.05 and a positive beta of 0.659. Therefore, it was concluded that permit to work was positively associated with accident frequency and occurrence at a 5 % level of significance. The results of the analysis showed that the hypothesis 2e related to the influence of competence level on accident frequency and occurrence was also supported, as the p-value (0.001) was less than 0.05 and positive beta 0.474. Therefore, it was concluded that competence level was positively associated with accident frequency and occurrence at a 5 % level of significance.

The results showed that all five independent variables were positively associated with accident frequency and occurrence, with p-values less than 0.05 and positive beta coefficients. Therefore, it was concluded that procedures, communication accuracy, communication satisfactory, permit to work, and competency level were all important factors related to accident frequency and occurrence. These are associated with Hypothesis 2 (2a- 2e). Studies (Sadeghi, 2020) and (Zahiri Harsini, 2020) support the findings that procedures, communication accuracy, communication satisfaction, permit to work, and competency level are important factors associated with accident frequency and occurrence in CPIs. They highlight the significance of considering both individual and organizational factors in promoting workplace safety and preventing accidents.

4.4. *Maintenance*

Models 15 – 20 (Table 6) were used to test Hypothesis 3a – 3e. Hypothesis 3a related to procedures and maintenance was supported by the results. The significant p-value($p < .008$) which is less than 0.05 and the positive beta coefficient (0.159) indicated that procedures was positively associated with maintenance at a 5 % level of significance. Hypothesis 3b related to communication accuracy and maintenance was supported by the results. The significant p-value($p < .001$) which is less than 0.05 and the positive beta coefficient (0.435) indicated that communication accuracy was positively associated with maintenance at a 5 % level of significance. Hypothesis 3c related to communication satisfactory and maintenance was supported by the results since $p < 0.001$ and the positive beta coefficient (0.368) this shows that communication satisfactory was positively associated with maintenance at a 5 % level of significance. Looking at hypothesis 3d permit to work had a p-value < 0.001 which is less than 0.05 and the positive beta coefficient (0.538) which means that permit to work was positively associated with maintenance and hypothesis 3e competency level had a p-value < 0.001 which is less than 0.05 and the positive beta coefficient (0.293) this showed that, competency level was positively associated with maintenance. Therefore, it can be concluded that procedures, communication accuracy, communication satisfactory, permit to work and competency level were positively associated with maintenance as these are associated with **Hypothesis 3** (3a −3e). The study (Sadeghi, 2020) supports the notion that multiple variables, including procedures, communication accuracy, communication satisfaction, permit to work, and competency level, are important factors related to accident frequency and occurrence.

Models 13 and 14 were used to test hypotheses 4 (1f) related to the relationship between risk management and accidents frequency and occurrence. The results of the analysis showed that hypothesis 4 (1f) was supported, as the as the p-value (0.001) was less than 0.05 and positive beta 0.651. Therefore, it was concluded that risk management was positively associated with accident frequency and occurrence at a 5 % level of significance. The results of the analysis showed that the hypothesis 1f related to the influence of maintenance on accident frequency and occurrence was support (Wiatrowski, 2013; Zarei et al., 2021) .

Model 14 was used to test hypothesis 5 (1 g) which was supported since the p-value (0.001) was less than 0.05 and positive beta 0.875. Therefore, it was concluded that maintenance was positively associated with accident frequency and occurrence at a 5 % level of significance. This indicates that there is positive association between maintenance and accident occurrence and frequency. Therefore, the analysis suggests that risk management and maintenance are both positively associated with accidents frequency and occurrence.

This study (Kidam and Hurme, 2013) examines the role of equipment failures in chemical process accidents. While it does not specifically focus on maintenance, it provides insights into the factors contributing to accidents in CPIs, which can indirectly relate to maintenance practices.

These findings can have important implications for organizations that are interested in improving safety and reducing accidents. Specifically, the results suggest that focusing on risk management or maintenance may effectively reduce the frequency and occurrence of accidents. However, it is important to note that the specific context of Chemical Process Industries (CPIs) in South Africa is not well-documented in the available literature. The South African chemicals industry, like other small, second-tier chemicals economies globally, is vulnerable and faces challenges (Barnes and White, 2020). The literature highlights the importance of risk management in preventing both occupational accidents and major accidents in manufacturing environments where hazardous materials are used (Brocal, et al., 2018; Manuwa, 2008) . It emphasizes the need for effective risk management procedures and the integration of scientific data with broader concerns in regulatory decision-making (Manuwa, 2008). In the context of South Africa, there is a lack of information available specifically for CPIs to learn from local incidents and prevent them from happening (Barnes and White, 2020).

This indicates a research gap and the need for further studies that focus on the South African chemical industry. Conducting further research in this context would provide valuable insights into the specific challenges, risks, and effective risk management strategies unique to the South African CPIs. Therefore, while the general importance of risk management and maintenance in reducing accidents is known, the specific application and effectiveness of these measures in the South African chemical industry, particularly in CPIs, remain relatively unexplored. Further research in this area would contribute to the understanding of the unique challenges and opportunities for risk management in the South African context, providing valuable insights and guidance for industry stakeholders and policymakers. Organizations need to consider these human and organisational factors could be contributing to accidents, to effectively reduce accidents and promote safety.

Overall, the study's findings offer new and valuable insights into the specific factors that contribute to accidents in CPIs in South Africa and, highlight the importance of risk management and maintenance practices in preventing accidents. By considering these factors, organizations can improve safety and reduce accidents in CPIs, ultimately promoting a safer and healthier workplace for employees.

5. Limitations of the study

The majority of respondents were males, making up 80.6 % of the total sample size (n = 199). Females accounted for 18.6 % of the respondents (n = 46), indicating a ratio of approximately 4 males to every 1 female. It is worth noting that a small percentage of respondents, 0.80 % (n = 2), chose not to disclose their gender or preferred not to state it. The results indicate a significant imbalance in the gender distribution among the respondents, with a higher proportion of males compared to females. This gender disparity raises concerns about potential bias in the survey results however the gender split is representative of the company population and in the CPIs sector. Most respondents in the study have less than 10 years of experience in the company which could potentially affect their perceptions about safety. Employees with less tenure in a company may have limited exposure to the organization's safety culture, practices, and historical safety incidents.

Lundberg et al., 2010 conducted a study on the factors that influence accident investigation and the recommendations for remedial actions. One of the key findings of their study was the importance of data availability for investigation. The authors stated that "what you find is not always what you fix" The availability of data can indeed be a factor that contributes to accidents, as limited data can lead to incomplete or incorrect conclusions. The literature on past accidents in South Africa is limited, with a particular gap in the study of occupational accidents (Hedlund, 2013). This is due to challenges in accessing data, including data inaccuracies and a lack of comparable data from different systems (Hedlund, 2013). Similarly, the survey was voluntary, some participants were not available and did not choose to participate on the survey. A total of 316 questionnaires were returned, with 247 valid and 69 invalid questionnaires, which were discarded after performing missing value analysis (MVA), as proposed by Hair, 2019. The availability of data can be influenced by various factors, such as the voluntary nature of participation in surveys, missing data, and limited resources for investigation. This can lead to incomplete or biased conclusions, which in turn can influence the behavior of individuals involved in accident investigation and the subsequent decision-making processes.

Correlating employees' perceived accident frequency with actual occurrences is crucial for assessing safety awareness within a company. However, due to confidentiality it was not possible to publish the number of accidents occurring in the company as the data is treated as sensitive information for various reasons, including legal considerations, employee privacy, and the potential impact on the company's reputation. Despite this, the study utilized anonymous surveys to assess safety perceptions, comparing them with industry accident trends to glean an insight into safety culture effectiveness while maintaining confidentiality.

A limitation of the current study in relation to competence assessment is that it focuses solely on procedure writing excluding the evaluation of practical execution of work and examination of maintenance incidents. It can be argued that sufficient and effective competence in executing procedures should result in a reduction of incidents. Nonetheless, it is imperative to conduct further research on competence as it relates to work performance and incident management. By incorporating a more comprehensive assessment that encompasses both procedural knowledge and practical application, a more complete understanding of competence in maintenance tasks can be achieved. This approach has the potential to enhance practices and outcomes. Employing a reflective approach to integrating feedback would demonstrate a commitment to improving the effectiveness of the questionnaire and advancing knowledge in this area of study.

Furthermore, a limitation in the lack of regular critical control monitoring and performance verifications, could be addressed in future studies. Regular critical control monitoring and performance verifications plays a critical role in tracking the operation, identifying trends that suggest a loss of control, detecting deviations, and providing written documentation for verification purposes. Nonetheless, the questionnaire used in this study does not explicitly inquire about the regularity of monitoring and performance verifications as standard practices. Consequently, this research gap presents a valuable opportunity for future investigation to enhance effectiveness and compliance in the Chemical Process industries.

Furthermore, it is imperative to acknowledge that there are numerous factors that can impede effective communication. The decision to emphasize "excessive noise" as a hindrance to good communication, despite the presence of other inhibiting factors, is based on the significant impact it has on disrupting the communication process. The interference caused by excessive noise poses an immediate obstacle to the transmission and reception of messages. By highlighting the importance of noise as a barrier to communication, it emphasizes the necessity of clear and uninterrupted channels of communication to facilitate effective workplace interactions. Future research endeavours can enrich the existing body of knowledge by investigating additional factors such as leadership, unclear objectives, disengaged employees, and management styles, and how they also hinder communication in the workplace.

6. Discussion

Despite significant investments in safety management, safety incidents with various consequences continue to occur worldwide (Drupsteen and Guldenmund, 2014; Drupsteen and Wybo, 2015) . Maintenance is widely recognized as a crucial component of the business process that adds value to organizations (Peach, 2021). While many empirical studies have examined human and organizational factors contributing to workplace accidents in industries such as oil and gas industries (Jarvis and Goddard, 2016; Marsh, The 100 Largest Losses 4 Harnessing the Power of Data to Prevent Losses 5 Improving Process Safety Performance by Learning from Losses., 2018; Glebova et al., 2019; Marsh and McLennan, 2020; Marsh and McLennan, 2023) , marine safety (Berg, 2013), food industry (Jacinto et al., 2009), offshore oil industry (Jarvis et al., 2017; Umar, 2010; Sneddon et al., 2013) , chemical and process industries (Reddy and Yarrakula, 2016; Leotta, 2013; Bhattacharjee and Das, 2020; Chen, 2022; Chin, 2020; Lees, 2012; Al-Shanini et al., 2014) , process industries (Al-Shanini et al., 2014) and manufacturing industries (Reiman, 2011; Zakaria, 2020; Urbani, 2020; Lee et al., 2022; Nenonen, 2011) , financial performance (Bautista-Bernal et al., 2024), aviation (Adjekum and Tous, 2020), are mostly contextualised in the USA, European and Asian countries. Although there have been studies Mabele and Hoque (Mabele, S.E. and M.E. Hoque, Investigating Workplace Safety Programs in a Chemical Industry in Africa. Journal of Medical Clinical Research 5 (9): 211, 2020), Seeme, 2019, conducted in South Africa relating to workplace safety programs in the chemical industry and human error in maintenance of mechanical systems, their objectives differed from the focus of this study. This suggests that there is a dearth of empirical research on organizational and workplace factors in Africa, including South Africa.

The research expands on the limited academic coverage of the relationship between human and organizational factors (HOF) and accidents by explored participants' perceptions on the relationship between human and organisational factors, maintenance, and accidents using a quantitative approach on data analysis.

The present study contributes to the existing body of knowledge by exploring participants' perceptions regarding the influence of human and organizational factors, as well as the role of maintenance in accidents. The results of the survey of participants' perceptions regarding the influence of human and organizational factors, as well as the role of maintenance in accidents, aligns with previous studies (IChemE, E-Book: Learning Lessons from Major Incidents. Rev.11 (21-July-, 2023; Okoh and Haugen, 2013; Jarvis and Goddard, 2016; Amyotte, 2016; Qian et al., 2023; Davidson, 2018; Chen and Reniers, 2020; Badri et al., 2018; Xiang, 2022; Kidam and Hurme, 2013) which revealed that human and organizational reasons are most common accident contributors for storage tanks, piping and heat transfer equipment. It also adds to the growing body of literature in this area. Organizational factors, such as management commitment, participation, and safety culture, are recognized as influential in occupational accidents. Understanding the interactions between human and organizational factors is crucial for preventing major accidents, as suggested by previous research (Robertson, et al., 2016; Eskandari, 2017; Luo and Liu, 2022) .

The results of this study demonstrate a positive association between independent variables such as procedures, communication accuracy, communication satisfaction, permit to work, and competency level, and accident frequency and occurrence. The results show a positive correlation between Risk management and Accident Occurrence and Frequency with the HOF: Communication Accuracy, Communication Satisfactory, maintenance, permit-to-work, and competency level.

Communication accuracy, encompassing active listening and alignment, is crucial for the Chemical Process Industries (CPI) to enhance operations, safety, and minimize accidents. In South Africa's chemical industry, digital transformation using predictive maintenance, real-time monitoring, and data analytics aims to improve safety. These technologies prevent breakdowns, reduce machine changeover times, and avert safety incidents through effective data usage. Aligned with Industry 4.0, analyzing maintenance data enhances operational and maintenance efficiency. Communication accuracy's significance persists in South Africa's chemical process industries, offering potential improvements in safety, streamlined operations, and sector resilience. Addressing comprehension gaps, adopting digital tools, and nurturing accurate communication culture are vital. These findings align with studies in European, American, or Australian contexts. These insights parallel studies conducted in European, American, or Australian contexts (Kidam and Hurme, 2013; Hollnagel, 2016; Klei, 2017; Stefan Van, 2016; Dalvie et al., 2014; Barnes and White, 2020) .

These results suggest that as maintenance practices improve or are conducted more effectively in the CPIs, there is a higher likelihood of decreasing accidents (Kidam and Hurme, 2013). However, while procedures were not positively related to risk management, they did have a positive impact on accident occurrence and frequency. Issues related to the use of written procedures in high-risk industries have been identified, such as outdated and overwhelming procedures Sasangohar, 2018. Incidents like the BP Texas City refinery highlight the problems associated with inconsistent, inappropriate, or voluminous procedures, leading to non-conformance and deviation from established procedures (Sasangohar, 2018; Bullemer and Hajdukiewicz, 2004). Therefore, it is necessary to improve and further understand the elements of procedures to make them effective for risk management.

In the case under study there are some elements of procedures that need to be improved and further understood in order to make these effective for risk management. Furthermore, this study emphasizes the importance of a clear and concise standard operating procedure (SOP) for communication during routine operations and maintenance activities. Regular review and updates of SOPs with consultation and participation of line managers, artisan, first line supervisors and users are essential to reflect best practices and lessons learned. Maintenance procedures should not have too much information. Digitalization and leveraging digital-enabled approaches can enhance business processes, operational efficiency, and maintenance effectiveness. Establishing and maintaining clear operating procedures and fostering a strong safety culture are vital in ensuring process safety and preventing accidents in the CPI (Praino and Sharit, 2016). The risks associated with written work procedures have been highlighted, and the need for context-specific and continuously improved risk management procedures has been recognized (Praino and Sharit, 2016).

Therefore, further investigation is necessary in particular in relation to number of procedures, feasibility for implementation and possibly procedures workflow. Effective risk management practices, including self-regulation programs like Responsible Care (RC), have been shown to reduce the likelihood of accidents in the CPI (Finger and Gamper-Rabindran, 2011). However, technical and engineering failures remain the primary causes of accidents in the industry (Kidam et al., 2010). Therefore, self-regulation programs should be complemented by a focus on technical and engineering aspects to further decrease accident rates. The implementation of process safety management (PSM) regulations has also proven effective in reducing accident rates (Kwon, 2006).

Improving communication satisfaction and the implementation or effectiveness of the permit to work system are also associated with the increase in effective risk management practices and maintenance practices, respectively (Mousavi, 2020). The Permit to Work system has been found to improve workplace safety and maintenance practices, although areas such as hazard identification and risk assessment may require improvement (Mousavi, 2020). Practical steps proposed by Sinha, 2015 can enhance maintenance effectiveness in conjunction with a well-functioning PTW system. The value of the Permit to Work system in maintaining standards and communication during maintenance work has been emphasized (Fauziningrum, 2020).

Maintenance practices can effectively contribute to increasing the overall equipment effectiveness in CPI. Research has consistently shown that maintenance practices, particularly Total Productive Maintenance (TPM), can significantly enhance Overall Equipment Effectiveness (OEE) in the Chemical Process Industry (CPI). Fam, et al., 2018 found that TPM pillars such as planned maintenance, autonomous maintenance, and focused maintenance were instrumental in improving OEE in the semiconductor industry. Similarly, Nallusamy and Majumdar, 2017 reported a 15 % increase in OEE in a manufacturing industry after the implementation of TPM. Nallusamy, 2016 also observed a 5–7 % improvement in OEE in a small-scale industry through the application of TPM techniques. Jantunen, et al., 2009 further emphasized the role of efficient maintenance, including Condition Based Maintenance (CBM) and e-Maintenance, in maximizing OEE. These studies collectively underscore the importance of maintenance practices in enhancing OEE in the CPI.

The quality, efficiency, and effectiveness of maintenance work are solely dependent on the maintenance worker executing the maintenance tasks. The competency level of individuals in the workplace is linked to a higher likelihood of an increase in effective risk management practices. Finally, as communication accuracy increases, Risk Management is expected to increase as well.

Human factors are significant determinants of safety and performance across all types of businesses, including small and medium enterprises (SMEs). SMEs face similar challenges as larger organizations, such as managing human resources, training, and maintaining safety protocols. Workplace accidents can occur in any setting and addressing them is essential for all businesses. Addressing workplace accidents is essential for all businesses, regardless of their size.

7. Conclusion

This study investigates the intricate connection between human and organizational factors, maintenance practices, and accidents within the context of the Chemical Process Industry in South Africa. The objective of this research was to propose measures that aim to enhance safety levels in this industry. The Chemical Process Industry is well-known for its complex operations and potential hazards, thus making it crucial to understand the role of human factors in accidents. These human factors include maintenance, risk management, communication, procedures, decision-making, and training, which significantly impact the safety and reliability of the Chemical Process Industry. By investigating the relationship between human and organizational factors, maintenance, and accidents in the Chemical Process Industry in South Africa, this study provides valuable insights on how to improve safety measures and prevent accidents in this sector.

The findings from this study indicate that mitigating the impact of human factors can be achieved through the implementation of robust engineering practices that eliminate potential hazards. Additionally, the establishment of explicit and streamlined processes and procedures is vital in ensuring the achievement of safety objectives. Notably, this study emphasizes the importance of effective risk management procedures and the integration of scientific data with broader concerns in regulatory decision-making to prevent maintenance related accidents in chemical process industries.

This study contributes to the South African chemical industry by highlighting the significance of effective risk management procedures, the integration of scientific data, and the role of human factors in safety and performance. The study provides valuable insights for industry stakeholders, policymakers, researchers, and emphasizes the critical role of human and organizational factors in maintenance, safety, and performance, including the competency level of individuals in the workplace, communication accuracy, and effective risk management practices. Moreover, the challenges faced by small and medium enterprises (SMEs) in managing human resources, training, and maintaining safety protocols, emphases the universal importance of addressing workplace accidents across all business sizes.

Furthermore, this study identifies a significant gap in the literature regarding the study of past accidents in the Chemical Process Industries in South Africa. Factors contributing to this gap include under-reporting of incidents, lack of centralized databases, limited research focus on accident analysis, and difficulties in accessing relevant data sources. The study proposed solutions, such as establishing dedicated investigative bodies such as the U.S. Chemical Safety and Hazard Investigation Board, and improving accessibility to accident reports, which will contribute to knowledge sharing, transparency, and accident prevention in the South African context. The study also emphasizes the need for research institutions, universities, and relevant organizations to prioritize accident analysis and prevention to bridge this gap in the literature.

Further studies focusing on the South African chemical process industries are necessary to provide insights into the specific challenges, risks, and effective risk management strategies unique to this industry. Finally, the study's contribution extends to promoting safety, mitigating accidents, and enhancing risk management practices within the chemical process industries.

CRediT authorship contribution statement

Mashel Gonyora: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Esther Ventura-Medina:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interest/personal relationship which may be considered as potential competing interests: Mashel Gonyora reports a relationship within the process chemical process industry that includes: employment.

Data availability

The data that has been used is confidential.

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APPENDIX a

Table A1. Questionnaires, labeled A to G, from which the study items were selected and listed in Appendix B.

Code	Questionnaire	Reference
A	Health and Safety Climate Survey Tool [HSCST] (Davies and Spencer, 2001)	Davies, Fiona., Spencer, Rachael., Dooley, Karen: Summary guide to safety climate tools. Health, and Safety Executive (2001) Offshore technology report 1999/063
B	Offshore Safety Questionnaire [OSQv1] (Mearns, 2001)	Mearns, K, Flin, R, Fleming, M, and Gordon, R. Human, and organisational factors in offshore safety. United Kingdom: N. p., 1998. Web.
C	Offshore Safety Climate Questionnaire [OSQ99] (Davies and Spencer, 2001)	Davies, Fiona., Spencer, Rachael., Dooley, Karen: Summary guide to safety climate tools. Health, and Safety Executive (2001) Offshore technology report 1999/063
D	Computerised Safety Climate Questionnaire [CSCQ] (Davies and Spencer, 2001)	Davies, Fiona., Spencer, Rachael., Dooley, Karen: Summary guide to safety climate tools. Health, and Safety Executive (2001) Offshore technology report 1999/063
E	Loughborough Safety Climate Assessment Toolkit [LSCAT] (Davies and Spencer, 2001)	Davies, Fiona., Spencer, Rachael., Dooley, Karen: Summary guide to safety climate tools. Health, and Safety Executive (2001) Offshore technology report 1999/063
F	Quest Safety Climate Questionnaire [QSCQ] (Davies and Spencer, 2001)	Davies, Fiona., Spencer, Rachael., Dooley, Karen: Summary guide to safety climate tools. Health, and Safety Executive (2001) Offshore technology report 1999/063
G	Maintenance Assessment Questionnaire (International, 2006)	Manufacturing Solutions International Chattanooga Office 7704 Royal Harbour Circle Ooltewah, TN 37363

APPENDIX B

Table B1. Individual items selected from the validated questionnaires, along with their corresponding item reference codes from the instrument Source.

Variable	Item Code	Item	Question item from instruments
Procedure	PRO1	Health and safety procedures /work instructions/ rules are too many to follow. (modified)	Reference A28
	PRO2	Some maintenance, health and safety procedures / instructions are not practical to implement. (modified)	A14
	PRO3	Safety procedures and instructions are written in clear language and easy for people to understand. (modified)	C43
	PRO4	Procedural instructions are confusing potentially leading to wrong task execution. (modified)	B98/ D50
	PRO5	Preventive maintenance procedures are updated when there are changes in equipment or practices (modified)	F3
	PRO6	The content of maintenance procedures is less than adequate to address all the needs of the business. (modified)	F151
	PRO7	Procedures are user friendly (modified)	C43
	PRO8	Some health and safety procedures / instructions/ rules are difficult to follow. (adopted)	A28
Communication Accuracy	CA1	Maintenance procedures have enough information for the user to perform the task safely. (modified)	F202
	CA2	Maintenance procedures have enough information for the user to perform the task correctly. (modified)	F202
	CA3	Information on recurring causes of accidents/incidents is effectively disseminated to all personnel. (adapted)	F258
	CA4	Where calculations are required, the provided methods are clear and understandable (modified)	F151
	CA5	Maintenance procedures are written in clear unambiguous language appropriate to the needs of the user. (modified)	F151
	CA6	The maintenance personnel are always given feedback on accidents/incidents that occur on the site. (modified)	B131/D56
	CA7	Communication failure on equipment tagging system exits which results in working on the wrong equipment. (modified)	F192
	CA8	Maintenance procedures are technically accurate. (modified)	F148
	CA9	During maintenance, there is in general a lot of noise which sometimes obstructs communication efforts during task performance. (modified)	F95
Communication Satisfactory	CS1.	There is good communication here about safety issues which affect me. (Adapted)	E13
	CS2.	I am satisfied with the way I am kept informed about what takes place on this site during maintenance work. (Adapted)	B31/C11

(continued on next page)

(*continued*)

Variable	Item Code	Item	Question item from instruments
	CS3.	I am always informed about the outcome of meetings which address maintenance health and safety issues. (Adapted)	A21
	CS4.	I receive on-time information needed to do my job. (modified)	B22
	CS5.	Communication of critical task is adequate to prevent maintenance accidents (modified)	F31
	CS6.	Changes to maintenance procedures are communicated to the users.	F159/F161
	CS7.	Communication in Permit-to-work is clear.	F6
	CS8.	There is good communication between maintenance and production personnel. (modified)	B32
	CS9.	Communication is done in the right language at the appropriate level. (Modified)	F151
	CS10.	Maintenance safety information is always brought to my attention by my line manager/ supervisor (Adapted)	E34
	CS11.	There is good communication at shift handover (Adapted)	C17
Permit-to-Work	PW1.	A discussion about hazards between the Recipient / task Executor/s and the Issuer takes place as part of the permit-to-work process. (Modified)	F7
	PW2.	Correct and clear identification of equipment and locations on permit-to-work is done by walking the line. (Modified)	B127
	PW3.	The permit issuer understands the hazards/risk when issuing the permit. (Modified)	B127
	PW4.	Permits are cross-referenced where there is interaction between jobs, including isolations if they are common to more than one job. (Modified)	F8
	PW5.	Communication of permit conditions and requirements is done when there is shift handover. (Modified)	F8
	PW6.	If the work is stopped "not to resume" then the "Cancellation" in section 10 of the PTW is filled in. (Modified)	F8
	PW7.	The permit cancellation and reason for cancellation is recorded on the relevant section on the work permit by the issuer. (Modified)	F8
	PW8.	If the conditions to ensure a safe working environment as specified on the work permit change, the work permit is withdrawn and re-issued after the desired conditions are reinstated. (Modified)	F8
	PW9.	When a permit is cancelled all persons working on the task in the work area are informed and withdrawn. (Modified)	F8
	PW10.	Permit to work and task risk assessment is a lot of tick box exercise. (Modified)	A29
Maintenance	MAIN1.	Reviewing of effectiveness of corrective actions is done to ensure implemented corrective actions adequately control the root cause(s). (Modified)	B79/C24
	MAIN2.	Maintenance accidents root cause analysis allows for the exploration of all possible factors associated with incidents. (Modified)	F261
	MAIN3.	Closure of root cause analysis next steps is adequately done. (Modified)	B79/C24
	MAIN4.	Equipment task sheets are completed for plant inspections with enough detail about equipment defects. (Modified)	F300
	MAIN5.	Equipment risk study is always conducted and adhered to before cancellation/deferred of maintenance strategies. (Modified)	F297
	MAIN6.	Maintenance strategies has been developed for all equipment and civil structures. (Modified)	3
	MAIN7.	Clearance for operation is always complied with by all relevant departments. (modified)	F8
	MAIN8.	The requirements for deferral of maintenance strategies on statutory equipment is adhere with to ensure legal compliance. (Modified)	5
	MAIN9.	Statutory inspection regime is followed for all identified critical equipment.	
	MAIN10	Maintenance accidents root cause analysis is done objectively (without taking sides). (modified)	F264
	MAINDATA11	Reasons for scheduled work not getting done are reviewed and discussed in the maintenance-scheduling meeting (PDR). (Modified)	11
	MAINDATA12	Work orders are always completed with all relevant actual information to allow analysis for recurring problems. (Modified)	6/2/17
	MAINDATA13	Maintenance data is analysed and is used to implement improvement opportunities. (Modified)	6
	MAINTOOL14	The right tools are used during maintenance. (Modified)	E46
	MAINTOOL15	The use of home-made tools is common during maintenance. (Modified)	E46
	MAINTOOL16	Home-made tools are used with good intention as alternative to correct tools. (Modified)	E46
Risk Management	RM1.	The communication of risks ensures risks are understood during maintenance. (Modified)	B102
	RM2.	Critical control failures are investigated for root causes. (Modified)	F261
	RM3.	The communication of risk is understood at the appropriate level. (Modified)	C79
	RM4.	Risk assessments are done at appropriate level for critical dangerous maintenance. (Modified)	F23
	RM5.	Key undesirable events (KUE) deviations next steps address critical control failures. (Modified)	F268
	RM6.	Special risk assessment is conducted for critical dangerous maintenance. (Modified)	C79
	RM7.	Communication of risk during maintenance is satisfactory for new employees. (Modified)	A40
	RM8.	Risk assessments involve personnel performing the maintenance work. (Modified)	A17
Competence Level	CL1.	Procedures are written by personnel who understands the process and task. (modified)	A16
	CL2.	Procedures are written with the participation of workers performing the task. (modified)	A16
	CL3.	The level of detail in procedures considers the training, experience and capabilities of the users. (modified)	F154
	CL4.	Maintenance incident investigation are conducted by technical competent personnel. (Modified)	F264
Accident Occurrence & frequency	AF1.	Accidents have occurred as a result of one or more of the above Human and organisational factors. (Modified)	B131
	AF2.	How frequently does accidents occur due to one or more of the above Human and organisational factors. (Modified)	F258

References

Adjekum, D.K., Tous, M.F., 2020. Assessing the relationship between organizational management factors and a resilient safety culture in a collegiate aviation program with safety Management systems (SMS). Saf. Sci. 131, 104909.

Ahmad, M., M. Pontiggia, and M.C. Leva, *Integration of human and organizational factors with quantitative risk assessment based on accident investigation.* 2015.

Al-Shanini, A., Ahmad, A., Khan, F., 2014. Accident modelling and analysis in process industries. J. Loss Prev. Process Ind. 32, 319–334.

Amyotte, P.R., et al., 2016. Why major accidents are still occurring. Curr. Opin. Chem. Eng. 14, 1–8.

Atherton, J., 2008. and F. Incidents That Define Process Safety, Gil, p. 352.

Badri, A., Boudreau-Trudel, B., Souissi, A.S., 2018. Occupational health and safety in the industry 4.0 era: a cause for major concern? Saf. Sci. 109, 403–411.

Bai, M., et al., 2023. Why do major chemical accidents still happen in China: analysis from a process safety management perspective. Process Saf. Environ. Prot. 176, 411–420.

Barnes, J., White, J., 2020. Repositioning the future of the south african chemicals industry. Digital Industrial Policy Brief 5.

Bautista-Bernal, I., Quintana-García, C., Marchante-Lara, M., 2024. Safety culture, safety performance and financial performance. *A Longitudinal Study.* Safety Science 172, 106409.

Berg, H., 2013. Human factors and safety culture in maritime safety. Marine navigation and safety of sea transportation: STCW, Maritime education and training (MET). Human Resources and Crew Manning, Maritime Policy, Logistics and Economic Matters 107, 107–115.

Bhattacharjee, G. and S.K. Das, *Effects of Human Factors in Process Safety: Analyses of Chemical Industrial Case Studies*, in *Safety and Security Issues in Technical Infrastructures*. 2020, IGI Global. p. 173-202.

Bhusari, A., et al., 2021. Process safety incidents across 14 industries. Process Saf. Prog. 40 (1), e12158.

Blaise, J.-C., et al., *Why is maintenance a high risk activity?* 2017.

BP, *Deepwater Horizon Accident Investigation Report: Executive Summary, September 8*. 2010.

British Standards, I., *Maintenance-Maintenance terminology*. 2010, BSI Standards Publication. p. 98.

Brocal, F., et al., *Risk management of hazardous materials in manufacturing processes: links and transitional spaces between occupational accidents and major accidents.* materials, 2018. **11**(10): p. 1915.

Bullemer, P.T. and J.R. Hajdukiewicz. *A study of effective procedural practices in refining and chemical operations*. in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting.* 2004. SAGE Publications Sage CA: Los Angeles, CA.

Chen, Y., 2022. The development and validation of a human factors analysis and classification system for the construction industry. Int. J. Occup. Saf. Ergon. 28 (1), 479–493.

Chen, C., Reniers, G., 2020. Chemical industry in China: the current status, safety problems, and pathways for future sustainable development. Saf. Sci. 128, 104741.

Chin, H.H., et al., 2020. Asset maintenance optimisation approaches in the chemical and process industries–a review. Chem. Eng. Res. Des. 164, 162–194.

Crocker, N. *Workplace Accidents Caused By Poor Shift Communications.* 2017 [cited 11-03-2023; Available from: https://trylogbook.com/workplace-accidents-caused-by-poor-shift-communications/.

CSB. *CSB Safety Video - Reactive Hazards*. U.S. Chemical Safety Board 2007 [cited 12-11-2022]; Available from: https://www.youtube.com/watch?v=gafDmL5bIC0.

Dalvie, M.A., Rother, H.-A., London, L., 2014. Chemical hazard communication comprehensibility in South Africa: safety implications for the adoption of the globally harmonised system of classification and labelling of chemicals. Saf. Sci. 61, 51–58.

Davidson, R.S., 2018. Safety awareness: a chemical engineering imperative. AIChE J 64 (3), 798–809.

Davies, F., Spencer, R., 2001. and K. Dooley, Summary guide to safety climate tools.

DeCamp, W., Herskovitz, K., 2015. The theories of accident causation. In: Security Supervision and Management. Elsevier, pp. 71–78.

Drogaris, G., *Major-accident-reporting-system-Lessons-learned-from-accidents.* 1994(14): p. 219-224.

Drupsteen, L., Guldenmund, F.W., 2014. What is learning? a review of the safety literature to define learning from incidents, accidents and disasters. J. Conting. Crisis Manag. 22 (2), 81–96.

Drupsteen, L., Wybo, J.-L., 2015. Assessing propensity to learn from safety-related events. Saf. Sci. 71, 28–38.

Duarte, A.L.C.M., Santiago Scarpin, M.R.S., 2023. Maintenance practices and overall equipment effectiveness: testing the moderating effect of training. J. Qual. Maint. Eng. 29 (2), 442–459.

ECSA, 2021 Female Engineers Digital Book. 2021: Engineering Council Of South Africa.

Edmonds, J., *Review of common human vulnerabilities and contributions to past accidents*. 2016.

EM-DAT. *The International Disaster Database -The Centre for Research on the Epidemiology of Disasters (CRED)*. 2023 [cited 04-03-2024; Available from: https://www.emdat.be/.

Engineering, R.A.o., Global Engineering Capability Review. 2020.

Eskandari, D., et al., 2017. A qualitative study on organizational factors affecting occupational accidents. Iran. J. Public Health 46 (3), 380–388.

Fam, S.-F., et al. *Overall equipment efficiency (OEE) enhancement in manufacture of electronic components & boards industry through total productive maintenance practices*. in *MATEC Web of Conferences*. 2018. EDP Sciences.

Fauziningrum, E., 2020. PERMIT TO WORK SYSTEM (a Familiarization on safe working on Board of a Ship). JURNAL SAINS DAN TEKNOLOGI MARITIM 20 (2), 111–118.

Finger, S.R. and S. Gamper-Rabindran, *Does industry self-regulation reduce accidents? Responsible Care in the chemical sector.* Responsible Care in the Chemical Sector (November 18, 2011), 2011.

Firehouse. *South African Chemical Plant Explosion Kills 5, Injures Over 100*. 2004 [cited 03-03-2024; Available from: https://www.firehouse.com/home/news/10511112/south-african-chemical-plant-explosion-kills-5-injures-over-100.

Fitzgerald, K., et al. *Key performance measures for human factors in major hazard industries*. in *IChemE Hazards. XXII symposium, Liverpool, UK*. 2011.

Gil, F. and J. Atherton. *Can we still use learnings from past major incidents in non-process industries?* in *Institution of chemical engineers symposium series*. 2008. Institution of Chemical Engineers; 1999.

Glebova, E., Volokhina, A., Vikhrov, A., 2019. Accidents and injury rates reduction in petroleum industry based on the development and implementation of the automated complex for the employees' professional competences assessment. IOP Conference Series: Earth and Environmental Science. IOP Publishing.

Gupta, U.C., 2013. Informed consent in clinical research: revisiting few concepts and areas. Perspect. Clin. Res. 4 (1), 26–32.

Gyekye, S.A., Salminen, S., 2009. Age and workers' perceptions of workplace safety: a comparative study. Int. J. Aging Hum. Dev. 68 (2), 171–184.

Gyekye, S.A., Salminen, S., Ojajarvi, A., 2012. A theoretical model to ascertain determinates of occupational accidents among ghanaian industrial workers. Int. J. Ind. Ergon. 42 (2), 233–240.

Hailwood, M., et al., 2009. Conclusions drawn from the buncefield and Naples incidents regarding the utilization of consequence models. Chemical Engineering & Technology: Industrial Chemistry-Plant Equipment-Process Engineering-Biotechnology 32 (2), 207–231.

Hair, J.F., et al., 2019. Multivariate data analysis. Eighth Ed.

Hair, J.F., Page, M., Brunsveld, N., 2020. *Essentials of Business Research Methods.* Fourth Ed.

Hale, A.R., et al., 1998. Evaluating safety in the management of maintenance activities in the chemical process industry. Saf. Sci. 28 (1), 21–44.

Han, D.-H., Park, M.S., 2018. Survey of awareness about hazardous chemicals of residents living near chemical plants in South Korea. Ind. Health 56 (4), 285–291.

Hassall, M.E., Sanderson, P.M., Cameron, I.T., 2016. Incident analysis: a case study comparison of traditional and SAfER methods. Journal of Cognitive Engineering and Decision Making 10 (2), 197–221.

HazardEx. *Fire and explosion forces South Africa's second largest refinery to shutdown*. 2020 [cited 10-09-2023; Available from: https://www.hazardexonthenet.net/article/182475/Fire-and-explosion-forces-South-Africa-s-second-largest-refinery-to-shutdown.aspx.

HazardEx. *Oil refinery explosion in South Africa kills two, injures six*. 2020 [cited 06-12-2023; Available from: https://www.hazardexonthenet.net/article/179461/Oil-refinery-explosion-in-South-Africa-kills-two–injures-six.aspx.

HazardEx. *South Africa chemical factory explosions injure 13, two critically*. 2020 [cited 01-05-2023; Available from: https://www.hazardexonthenet.net/article/182590/South-Africa-chemical-factory-explosions-injure-13–two-critically.aspx.

He, Y., et al., 2022. Agile incident response (AIR): improving the incident response process in healthcare. Int. J. Inf. Manag. 62, 102435.

Hedlund, F.H., 2013. Recorded fatal and permanently disabling injuries in south african manufacturing industry–overview, analysis and reflection. Saf. Sci. 55, 149–159.

Heryati, A.N., et al., 2019. Effect of safety climate on safety behavior in employees: the mediation of safety motivation. Psikohumaniora: Jurnal Penelitian Psikologi 4 (2), 191–200.

Hollnagel, E., *Barriers and accident prevention*. 2016: Routledge.

Holmgren, M., *Maintenance-related incidents and accidents: aspects of hazard identification*. 2006, Luleå tekniska universitet.

HSE, *Guidance on permit-to-work systems: A guide for the petroleum, chemical and allied industries*. 1st ed. 2005: Health and Safety Executive. 40.

HSE, *Dangerous Maintenance: A Study of Maintenance Accidents and How to Prevent Them.* 1992, United Kingdom: HSE.

HSE. *Human factors and ergonomics*. 2024 [cited 03-08-2023; Available from: https://www.hse.gov.uk/humanfactors/top-ten.htm.

IChemE, *BP Process Safety Series Control of work*. 2007. 86-86.

IChemE, *E-Book: Learning Lessons from Major Incidents. Rev.11 (21-July-2023)*. Rev.11 ed. 2023: P. Marsh-XBP Refining Consultants Ltd.

International, M.S., *Maintenance Assessment Questionnaire*. 2006, Manufacturing Solutions International.

Irving, A.V. *Policies and Procedures for Healthcare Organizations: A Risk Management Perspective*. 2014 [cited 12-06-2023; Available from: https://www.psqh.com/analysis/policies-and-procedures-for-healthcare-organizations-a-risk-management-perspective/.

Jacinto, C., Canoa, M., Soares, C.G., 2009. Workplace and organisational factors in accident analysis within the food industry. Saf. Sci. 47 (5), 626–635.

Jantunen, E., et al. *e-Maintenance: a means to high overall efficiency*. in *Engineering Asset Lifecycle Management: Proceedings of the 4th World Congress on Engineering Asset Management (WCEAM 2009), 28-30 September 2009*. 2010. Springer.

Jarvis, R. and A. Goddard, *An Analysis of Common Causes of Major Losses in the Onshore Oil, Gas & Petrochemical Industries.* Loss Prevention Bulletin, 2017. **1.0**(255): p. 1-12.

Jarvis, R., Goddard, A., 2016. An analysis of common causes of major losses in the Onshore oil gas & Petrochemical Industries. Loss Prevention Bulletin 1, 36.

Jhangiani, R.S., et al., 2019. Research methods in psychology. Kwantlen Polytechnic University.

Journé, B., et al., 2020. Human and organisational factors: practices and strategies for a changing world. Springer Nature.

Jung, S., Woo, J., Kang, C., 2020. Analysis of severe industrial accidents caused by hazardous chemicals in South Korea from January 2008 to june 2018. Saf. Sci. 124, 104580.

Jusoh, N., et al., 2020. The permit to work in relation with occupational accident at petrochemical plant. IOP Conference Series: Materials Science and Engineering. IOP Publishing.

Khan, F.I., Abbasi, S.A., 2002. Accident Hazard index. Process Saf. Environ. Prot.

Kidam, K., Hurme, M., 2013. Statistical analysis of contributors to chemical process accidents. Chem. Eng. Technol. 36 (1), 167–176.

Kidam, K., Hurme, M., 2013. Analysis of equipment failures as contributors to chemical process accidents. Process Saf. Environ. Prot. 91 (1–2), 61–78.

Kidam, K., Hurme, M., Hassim, M.H., 2010. Technical analysis of accident in chemical process industry and lessons learnt. Chem. Eng. Trans. 19, 451–456.

Klei, A., et al., 2017. Digital in chemicals: from technology to impact. McKinsey & Company.

Kwon, H.-M., 2006. The effectiveness of process safety management (PSM) regulation for chemical industry in Korea. J. Loss Prev. Process Ind. 19 (1), 13–16.

Lee, J., Cameron, I., Hassall, M., 2019. Improving process safety: what roles for digitalization and industry 4.0? Process Saf. Environ. Prot. 132, 325–339.

Lee, J., Phillips, I., Lynch, Z., 2022. Causes and prevention of mobile crane-related accidents in South Korea. Int. J. Occup. Saf. Ergon. 28 (1), 469–478.

Lees, F., 2012. Lees' loss prevention in the process industries: Hazard identification, assessment and control. Butterworth-Heinemann.

Leotta, M., et al., 2013. A Pilot Experiment to Quantify the Effect of Documentation Accuracy on Maintenance Tasks. IEEE.

Leveson, N., 2015. A systems approach to risk management through leading safety indicators. Reliab. Eng. Syst. Saf. 136, 17–34.

Leveson, N., *Engineering a safer world systems thinking applied to safety*. 2012: The MIT Press.

Lundberg, J., Rollenhagen, C., Hollnagel, E., 2009. What-you-look-for-is-what-you-find–the consequences of underlying accident models in eight accident investigation manuals. Saf. Sci. 47 (10), 1297–1311.

Lundberg, J., Rollenhagen, C., Hollnagel, E., 2010. What you find is not always what you fix—How other aspects than causes of accidents decide recommendations for remedial actions. Accid. Anal. Prev. 42 (6), 2132–2139.

Luo, X., Liu, Q., 2022. The influence of human-organizational factors on falling accidents from historical text data. Front. Public Health 9, 783537.

Mabele, S.E. and M.E. Hoque, *Investigating Workplace Safety Programs in a Chemical Industry in Africa.* Journal of Medical & Clinical Research 5 (9): 211, 2020. **218**.

Majozi, T., Veldhuizen, P., 2015. The chemicals industry in South Africa. American Institute of Chemical Engineers (AIChE) 46–51.

Manuwa, K., 2008. Step change towards zero incidents in the chemical industry: managing the human factor. North-West University.

Marsh and McLennan, 2023. The global risks report 2023, 18th Edition. Zurich Insurance, Group.

Marsh and McLennan, *Risk Engineering Position Paper-04. Process Safety Performance Indicators - PSIs*. 2020.

Marsh, *The 100 Largest Losses 4 Harnessing the Power of Data to Prevent Losses 5 Improving Process Safety Performance by Learning from Losses*. 2018.

Mearns, K., et al., 2000. Factoring the human into safety: translating research into practice. Industrial Psychological Group 1–158.

Mearns, K., et al., 2001. Human and organizational factors in offshore safety. Work Stress. 15 (2), 144–160.

Mitchell, J., 2016. Safety critical communication. In: Human Factors in the Chemical and Process Industries. Elsevier, pp. 417–434.

Moura, R., et al., 2017. Learning from accidents: Interactions between human factors, technology and organisations as a central element to validate risk studies. Saf. Sci. 99, 196–214.

Mousavi, S.M., et al., 2020. Factors affecting performance of permit to work system: a case study in an oil refinery. Archives of Occupational Health 4 (4), 863–869.

Nallusamy, S., 2016. Enhancement of productivity and efficiency of CNC machines in a small scale industry using total productive maintenance. Int. J. Eng. Res. Afr. 25, 119–126.

Nallusamy, S., Majumdar, G., 2017. Enhancement of overall equipment effectiveness using Total productive maintenance in a Manufacturing industry. Int J Performability Eng 13 (2), 173–188.

Nayager, D., *Causes of near miss and minor operating incidents at selected chemical organisations in Durban and their impact on key functional areas*. 2015.

Nenonen, S., 2011. Fatal workplace accidents in outsourced operations in the manufacturing industry. Saf. Sci. 49 (10), 1394–1403.

Okoh, P., Haugen, S., 2013. Maintenance-related major accidents: classification of causes and case study. J. Loss Prev. Process Ind. 26 (6), 1060–1070.

Okoh, P., Haugen, S., 2013. *The influence of maintenance on some selected major accidents.* CEt chemical. Eng. Trans. 31.

Okoh, P., Haugen, S., 2014. A study of maintenance-related major accident cases in the 21st century. Process Saf. Environ. Prot. 92 (4), 346–356.

Okoh, P., *Maintenance-related major accidents in the metal industry: The combustible dust challenge.* Loss Prevention Bulletin 268, 2019.

Olsen, W., *Data Collection: Key Debates and Methods in Social Research*. Data Collection: Key Debates and Methods in Social Research. 2014: SAGE Publications Ltd.

Oppenheim, A.N., *Questionnaire design, interviewing and attitude measurement*. 2000: Bloomsbury Publishing.

Orzáez, F., Domingo, R., Marín, M., 2019. Considerations for the development of a human reliability analysis (HRA) model oriented to the maintenance work safety. Procedia Manuf. 41, 185–192.

Patel, M., *Mitigation options for South Africa's petrochemical value chain.* 2022.

Peach, R.H., 2021. *Maintenance human factors in the south african electricity transmission industry*, in *faculty of engineering, built environment and information technology*. University of Pretoria (South Africa), p. 419.

Peterson, R., *Constructing Effective Questionnaires*. Constructing Effective Questionnaires. 2000: SAGE Publications, Inc.

Pitblado, R., Nelson, B., 2013. Advanced safety Barrier Management with inclusion of human and organizational aspects. Chem. Eng. Trans. 31.

Praino, G., Sharit, J., 2016. Written work procedures: identifying and understanding their risks and a proposed framework for modeling procedure risk. Saf. Sci. 82, 382–392.

Qian, Y., Vaddiraju, S., Khan, F., 2023. Safety education 4.0–A critical review and a response to the process industry 4.0 need in chemical engineering curriculum. Saf. Sci. 161, 106069.

Reason, J., 2000. Human error: models and management. BMJ 320 (7237), 768–770.

Reason, J., 2016. Managing the risks of organizational accidents. Routledge.

Reddy, K., Yarrakula, K., 2016. Analysis of accidents in chemical process industries in the period 1998–2015. Int. J. ChemTech Res. 9 (4), 177–191.

Reid, M., 2020. The Piper alpha Disaster: a personal perspective with transferrable lessons on the long-term Moral impact of safety failures. In: ACS Chemical Health and Safety. American Chemical Society, pp. 88–95.

Reiman, T., 2011. Understanding maintenance work in safety-critical organisations–managing the performance variability. Theor. Issues Ergon. Sci. 12 (4), 339–366.

Renecle, M., et al., 2021. Enhancing safety in high-risk operations: a multilevel analysis of the role of mindful organising in translating safety climate into individual safety behaviours. Saf. Sci. 138.

Reniers, G.L., et al., 2006. Decision support systems for major accident prevention in the chemical process industry: a developers' survey. J. Loss Prev. Process Ind. 19 (6), 604–620.

Rialivhuwa, N., *Analysis of key contributors to process safety incidents in chemical process industry*, in *FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT*. 2019, UNIVERSITY of JOHANNESBURG. p. 80.

Robertson, K., et al., *Human and Organisational Factors in Major Accident Prevention: A Snapshot of the Academic Landscape*. 2016.

Sadeghi, F., et al., 2020. Effective Parameters on chemical accidents occurrence: findings from a systematic review. J. Fail. Anal. Prev. 20, 1184–1191.

Sambrekar, A., Vishnu, C., Sridharan, R., 2018. *Maintenance strategies for realizing industry 4.0: an overview.* Emerging trends in engineering, science and Technology for Society. Energy Environ. 365–374.

Sasangohar, F., et al., 2018. Investigating written procedures in process safety: qualitative data analysis of interviews from high risk facilities. Process Saf. Environ. Prot. 113, 30–39.

Seeme, L.R., 2019. Human factors consideration in the automation design of a safety-critical installation. University of Johannesburg (South Africa).

Seligmann, B.J., et al., 2019. Comparing capability of scenario hazard identification methods by the PIC (plant-people-procedure Interaction contribution) network metric. Saf. Sci. 112, 116–129.

Shi, C., et al., 2021. Perceptions and experiences of risk management by managers of residential aged care facilities: a qualitative study from Hunan Province, China. Int. J. Qual. Stud. Health Well Being 16 (1), 1978724.

Shimada, Y., et al., 2019. *Risk assessment for process accident prevention using screening questionnaire.* CET journal-chemical. Eng. Trans. 77.

Sinha, P., 2015. Towards higher maintenance effectiveness: integrating maintenance management with reliability engineering. International Journal of Quality & Reliability Management 32 (7), 754–762.

Sneddon, A., Mearns, K., Flin, R., 2013. Stress, fatigue, situation awareness and safety in offshore drilling crews. Saf. Sci. 56, 80–88.

Soltanzadeh, A., Mohammadfam, I., 2022. *Cause-consequence modeling of occupational accidents in construction sites: a retrospective study in Iran.* journal of Health & Safety at. Work 12 (3).

Stefan Van, T., et al., 2016. Industry 4.0 and the chemicals industry. Catalyzing Transformation through Operations Improvement and Business Growth.

Sultana, S., Andersen, B.S., Haugen, S., 2019. Identifying safety indicators for safety performance measurement using a system engineering approach. Process Saf. Environ. Prot. 128, 107–120.

SynergenOG. *Process Safety Incidents: Causes, Consequences, and Lessons Learned*. 2023 [cited 3-07-2024; Available from: https://synergenog.com/process-safety-incidents/ .

Linda Tucci and Craig Stedman. *What is risk management and why is it important?* 2023 [cited 02-09-2023; Available from: https://www.techtarget.com/searchsecurity/definition/What-is-risk-management-and-why-is-it-important.

Umar, A.A., *Design for safety framework for offshore oil and gas platforms*. 2010, University of Birmingham.

Urbani, M., et al., 2020. *Maintenance-management in light of manufacturing 4.0.* technical, economic and societal effects of Manufacturing 4.0: automation. Adaption and Manufacturing in Finland and beyond 97–111.

Van Der Schaaf, T., Kanse, L., 2004. Biases in incident reporting databases: an empirical study in the chemical process industry. Saf. Sci. 42 (1), 57–67.

Varma, R., Varma, D.R., 2016. The Bhopal Disaster of 1984. Bull. Sci. Technol. Soc. 25 (1), 37–45.

Walker, L.M. *The Current Challenges of Process Safety Management*. 2023 [cited 09-09-2023; Available from: https://ei1.com/2023/09/14/the-current-challenges-of-process-safety-management/.

Welle, D. *South Africa: Seven injured in Durban oil refinery explosion*. 2020 [cited 11-06-2023; Available from: https://www.dw.com/en/south-africa-seven-injured-in-durban-oil-refinery-explosion/a-55819337.

Wiatrowski, W.J., 2013. "Using workplace safety and health data for injury prevention," monthly labor review, U.S. Bureau of Labor. Statistics [cited 10–11-2023; Available from: 10.21916/mlr.2013.34.
Xiang, Y., et al., 2022. Statistical analysis of major industrial accidents in China from 2000 to 2020. Eng. Fail. Anal. 141, 106632.
Yalcin, E., Ciftcioglu, G., Guzel, B., 2023. Human factors analysis by classifying chemical accidents into operations. Sustainability 15 (8129).
Yan, C., et al., 2017. Contribution of permit to work to process safety accident in the chemical process industry. Chem. Eng. Trans. 56, 883–888.
Yeong, S.S., Shah Rollah, A.W., 2016. *The mediating effect of safety culture on safety communication and human factor accident at the workplace.* asian. Soc. Sci. 12 (12), 127.
Zahiri Harsini, A., et al., 2020. Factors associated with unsafe work behaviours in an iranian petrochemical company: perspectives of workers, supervisors, and safety managers. BMC Public Health 20, 1–13.
Zakaria, J., et al., 2020. Safety climate factors at selected chemical manufacturing plant in Malaysia. Process Saf. Prog. 39 (1), e12096.
Zarei, E., Khan, F., Abbassi, R., 2021. Importance of human reliability in process operation: a critical analysis. Reliab. Eng. Syst. Saf. 211, 107607.