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Workplace safety drivers: Strategic insights into communication, procedure, infrastructure, leadership & emergency procedure

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Abstract: Workplace safety is a notion that derives from research on high-reliability organizations. The possibility of physical injury, whether immediate or gradual, to people, property, or the environment while they perform their duties is a feature of work systems. We explained the main strategies and advancements to achieve no accidents in the workplace. It acts as the foundation for building a strong safety structure that protects the health and safety of those engaged in hazardous oil, chemical, and gas industries. Here, our work emphasizes obtaining and maintaining Safety Integrity Level (SIL) ratings in accordance with Indian and international standards to reduce hazardous gas leaks and implement security measures. We also discussed the statistical techniques of workplace safety and its factors, such as strategic insights into communication, procedures, infrastructure, leadership, and emergency procedures. We used five distinct manufacturing and healthcare-based industries for comparison. Company 4 has a high mean in incident awareness and communication (3.46±0.21). Company 5 has a high mean in risk assessment and hazard identification. Company 1 has a high mean in training and competency, including emergency response and incident reporting. It also explains how safety-conscious companies can lower workplace accidents through the use of emergency response, incident communication, and safety management techniques.

Keywords: *Incident prevention, Risk assessment, Safety culture, Safety Integrity level, Workplace safety.*

1. Introduction

Since workplace safety is almost never well-articulated in the administrative sciences, industries, or elsewhere, thus, a conceptual understanding necessitates an explicit justification. The concept of workplace safety is based on the literature on high-reliability organizations [1-3]. It is an attribute of work systems which describe potential of physical harm, whether quick to individuals, assets, or environment as they function. However, here we discuss workplace safety with their determinants include leadership, infrastructure, communication, emergency protocols, and strategic insights into these areas. According to safety research, organizational and managerial factors are the most significant predictors of workplace accidents [4, 5]. Subordinates' safety behaviors have been demonstrated to be impacted by the actions and decisions of leaders, and a variety of leadership styles can be used to develop more sustainable organization [6-9]. Nonetheless, Willis et al. explained that different leadership philosophies may be more successful in situations where people are exposed to risks and safety is a top concern compared to those where risk and hazard perceptions are lower [10]. Safety researchers have thus delved into leadership in both safety-critical and non-critical contexts. Numerous safety outcomes have been found to be predicted by constructive leadership styles like transformational leadership, which emphasizes inspiring and motivating behaviors [7, 11, 12]. Transactional leadership, which includes activities of monitoring, vigilance, and error repair, is another type of constructive

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leadership that pertinent to safety research [7]. Its function in promoting safety behaviors and a safety climate is supported by studies [13, 14]. Despite the potentially disastrous consequences for subordinates, work teams, and organizations as a whole, research on destructive leadership behaviors and their potential negative impact on safety conduct is inadequate [15]. Specifically, laissez-faire, a type of destructive leadership, shows minimal impact on safety practices [15, 16]. The self-regulatory focus theory and self-concept theories of leadership are the backbone of the current study, which links various administrators' safety-specific leadership styles to various employee safety conversation behaviors [17]. It suggests that an administrator's regulatory focus predicts their leadership style, which in turn predicts the behavior of their subordinates.

However, the chemical, oil and gas industries has long been thought to be a very successful one for boosting global economies [18]. Whether onshore or offshore, chemical, oil and gas operations are allegedly extremely difficult and risky worldwide despite safety precautions being in place [19]. This raise worries about extremely dangerous and risky procedures and related activities in the chemical and petrochemical business. With a wide range of strategies and concepts over the years to improve workplace safety and occupational health and safety, the petrochemical oil and gas sector has struggled to reduce a high number of worker fatalities and property damage [20, 21]. In general, hazardous leaks were typically caused by partially sealed equipment, which allows hydrocarbon to be released into the environment and cause several kinds of mishaps or hazardous circumstances. Large amounts of total emissions are caused by fugitive emissions. It typically linked to mishaps or serious mishaps. Large-scale incidents like the 1988 Piper Alpha disaster, which killed 167 lives, Leksikon [22] and the 2010 Deepwater Horizon tragedy, which killed 11 lives and injured 20, Leksikon [23] etc., illustrate the possible scope of significant hazardous gas leaks. According to a investigation on chemical leaks from storage containers in the chemical industry, the organization must manage the risks that could arise in the workplace due to the chemical in the plant, particularly in terms of safety [24]. Additionally, the organization needs to prevent prospective issues that might have an impact on nearby communities. By implementing hazard identification methodologies, the organization must assess the risk of chemical hazards to prevent unintentional activities that could cause direct and indirect damage. Although, ineffective communication and disregard for established laws, regulations, and a dedication to safety are the causes of these mishaps and dangerous situations [25]. These incidents can have catastrophic consequences, resulting in a high rate of occupational injuries and accidents [26, 27]. As a result, developing a safe workplace is crucial. Active communication is linked to workplace safety in order to reduce accident rates and enhance workplace security. Additionally, it is inferred hazardous behavior, which is partially attributed to the organization safety procedures, is the precursor to accidents [28]. Safety communication consequently considered as a key component in lowering human factor-related incidents and enhancing the working environment [29]. Maintaining workplace safety is still difficult, but it is necessary to enhance safety performance and successfully prevent accidents. Although emergency responses are spontaneous, they also necessitate rigorous planning and organization. Being that plan, no matter as well-executed, rarely matches the situation, emergency managers must be creative, flexible, and adept at improvising. Emergency search and rescue, emergency medical assistance, providing temporary shelter, food, and repairing lifelines are few of the tasks that comprise up emergency process. In addition, emergency process encompasses hazard mitigation, which aims to prevent the effects of disasters by constructing barriers or relocating people out of streams; disaster preparation, which includes emergency planning and training; disaster response, which includes search and rescue operations; and disaster recovery, which typically refers to the restoration of lifelines and essential services. Thus, industries should consider HAZOP (Hazard Operability Studies) and HSEIA (Health Safety Environment Impact Assessment) techniques, as follows:

HAZOP: One of the most organised methods for examining risks and operability issues is HAZOP, which investigates the consequences of alterations to design and operational parameters. HAZOP is one in the twelve Process Hazards Analysis (PHA) process, which evaluates operational risks in order to lessen their effects. From discovery to decommissioning, all six phases of process design are covered by

HAZOP [30]. For the purpose of creating safer, more dependable, and more efficient infrastructures, HAZOP has become a standard practice in process system design [31]. It assumes that any malfunction in a system or component of equipment will be the reason in which a variable or parameter in the relevant context deviates from its typical behaviour. For a system to be designed and operated safely at all levels—pilot plant development, executive design, operation, and decommissioning—hazards must be identified. Reducing each risk which leads to significant mishaps, such as fire, explosions, and hazardous discharges, was the ultimate goal.

HSEIA: The HSEIA analysis proves adherence to HSE (health, safety and environment) regulations by proving that all HSE risks, such as significant accident risks, occupational health risks, and environmental impacts, have been recognised, evaluated, and reduced. The environmental impact assessment (EIA), occupational health risk assessment (OHRA), and control of major accident hazards (COMAH) are all included in an HSEIA report [32, 33].

Waste management, physical environmental damage limitation, and anti-pollution measures mandated by national laws, National Oil Companies' (NOC) rules of practice, and environmental authority Health, Safety, Environmental Assessment (HSEIA) instruction. The oil and gas business, regardless of location, should fully aware of these criteria [34].

According to international and Indian standards, our work focusses on achieving and sustaining Safety Integrity Level (SIL) ratings to mitigate dangerous gas leaks and attribute security precautions into place [35-40]. In the current study, we envisioned workplace safety statistics and their determinants, including leadership, infra-structure, communication, procedure, and emergency protocol. Five distinct manufacturing and healthcare-based industries were examined for this study using data from the safety and culture survey. The fundamental elements of workplace safety, such as incident awareness and communication, safety protocols and procedures, infrastructure and equipment, risk assessment and hazard identification, safety culture and leadership, training and competency, emergency response, and incident reporting, should also be highlighted. It also described safety-sensitive organizations that can reduce workplace accidents by implementing safety management strategies, incident communication, and emergency response. Data collected from participants and Likert scales tools were used to measure the safety components. Further, the statistical techniques used for analyzing data with ANOVA and t-tests and comparison between industries described. Also examined, comparison between field-operation-maintenance personnel and managers' safety performance metrics. Among the strengths displayed by both groups, "Emergency Response and Incident Reporting" and "Incident Awareness and Communication," which came in first place, suggesting successful practices in these domains. Since "Equipment and Infrastructure" scored 2.01, both have a persistently low point, suggesting that this area needs to be improved. Field, operation, and maintenance personnel had somewhat higher scores (2.78) in "Risk Assessment and Hazard Identification" than managers (2.64); yet, they have slightly lower scores (2.29) in "Training & Competency" than managers (2.55). Safety compliance in this study refers to actions aimed at fulfilling minimal safety requirements at work, such as paying attention to safety protocols and acquiring the necessary protective gear. Involvement in safety refers to measures that promote workplace safety, like proactively attending safety meetings or aiding colleagues with safety-related concerns.

2. Literature Review

Hazardous substances showed important characteristics like inflammability, explosiveness, toxicity, and corrosiveness [41-43]. Unintentional incidents that happen during the manufacturing, storage, shipping, or other activities of chemicals can have a significant impact on the environment, cause property losses, and result in mass casualties [44]. In terms of risk management and process safety, this type of catastrophe is crucial [45]. Organizations have taken various steps to improve the situation in recent years, including integrating chemical industrial parks, monitoring and controlling operator behavior, revising relevant laws and regulations, and more [46]. People also conducted a great deal of research on the frequency of hazardous chemical accidents [47]. The outcome, nevertheless, is unexpected. Statistics show that at least 1653 hazardous chemical mishaps resulted more than 500 fatalities a year [48]. Although, leak or explosion of a hazardous chemical in production or storage, which was more likely to have serious repercussions [49, 50]. It appears that there is still much work to be done in the field of study on the analysis and prevention of particularly serious hazardous chemical incidents. Determining the different reasons for each accident is crucial so that specific preventive actions can be taken to avoid making the same mistakes twice. Also, large efforts should be made to assist people and organizations in better remembering the incidents and valuable lessons learnt because the process of these accidents occurring and developing is frequently quite complicated and involves many distinct causal elements [51, 52]. Barling et al. explained, the two parts to safety awareness: the behavioral and the cognitive aspects [6] which suggested that the concept encompasses more than just understanding safety hazards and that taking the appropriate action is also crucial [53, 54]. The demands made by the top management also influence how behaviors are modelled in the organizations. Administrators will encourage their staff to enquire about safety and raise their awareness of it by highlighting the significance of health and safety regulations and procedures [55]. In a similar vein, safety leadership involves the health and safety principles to be communicated clearly. Professionals must receive training to raise the awareness of their subordinates. Research indicates that safety behaviors are significantly predicted by consciousness. Preventing workplace accidents, diseases, and fatalities as well as the suffering and financial difficulties that organizations face is the primary objective of safety leadership [56]. The suggested procedures manage workplace health and safety in a proactive manner as opposed to a reactive one, meaning that issues are dealt with only after a worker gets injured. These suggested approaches acknowledge that identifying and addressing risks prior to them result in harm or disease is a much more successful strategy [57].

Tinmannsvik and Hovden [58] differentiate between general leadership factors, which consist of administrative variables primarily aimed at improving the production system and organization in general, and safety specific elements, which constitute leadership factors primarily aimed at promoting safety [58]. Both safety-specific and other management aspects that may have an impact on safety performance—such as project and staff management are included in this study. According to Clarke and Taylor [13] workplace safety refers to the policies and practices of an organization which have been in place to maintain the health, safety, and well-being of its employees. Theoretical models emphasized leadership as particularly important, even if a variety of situational and individual elements may affect workplace safety Clarke [7]. Bass [59] emphasizing the process of communication between leaders and followers, proposes that leadership can be viewed as a relationship between two or more group members that entails the structuring or restructuring of the situation and the members' corresponding expectations and perceptions [60]. While studies have historically concentrated on the process and impact of positive leadership styles like transformational leadership that explained by Bass [59] authentic leadership explained by Avolio et al., and ethical leadership discussed by Avolio and Gardner [61]; Bass [59] and Kalshoven and Boon [62]. Schyns and Schilling [63] discussed new research that indicated leaders can also engage in destructive behavior which compromises viewers and organization's ability to maintain its objectives [63].

Aasland, et al. [64] explained small number of theoretical models have incorporated the destructive aspects of leadership as antecedents of safety and subordinates' perception of safety at work, despite the relatively high prevalence of both passive and active forms of destructive leadership [64]. Destructive leadership styles could affect different safety aspects, just as constructive leadership styles influence workplace safety. Mackey, et al. [65] explained the meta-analytic studies, according to that destructive leadership has a negative correlation with outcomes that have been shown to be positive correlates of constructive leadership [65]. According to Kelloway, et al. [66] organizational leaders serve as significant role models for safety behavior and convey the value of workplace safety by paying close attention to safety issues [66]. For the purpose to accurately depicting the relationships between leadership and workplace safety, it is necessary to include a wide range of active and passive, as well as constructive and destructive, leadership behaviors. This is because of expertise regarding negative forms of leadership and the consequences of such organizational conduct. Hofmann and Morgeson [67] explained, the available empirical evidence on the relationship between leadership and safety, however, is based exclusively on constructive forms of leadership, with the exception of a few cross-sectional studies that have found a negative relationship between laissez-faire leadership and safety indicators [67]. Resultant, research on the effects of harmful leadership behaviors on workplace safety is conspicuously limited. Although there are compelling theoretical and empirical grounds to believe that both constructive and destructive kinds of leadership related to workplace safety, less exists about the relationship between destructive leadership and safety.

Lyndon, et al. [68] discussed, a variety of communication methods are employed in an organization to raise employee motivation levels in order to preserve workplace safety and behavior development; mutual communication is crucial for these goals in order to modify employee behavior [68]. According to Newnam and Goode [69] earlier research on safety literature, two-way safety communication between managers and safety leaders is crucial as a safety-management strategy to lower occupational accidents and improve workplace safety [69]. To ensure workplace safety, Brown, et al. [70] explained top management in organizations is in charge of defining work standards and rules, as well as allocating safety-related activities and assignments [70]. According to Feng, et al. [71] top management is responsible for accomplishing organizational goals and objectives, even though employees have a significant influence in enhancing workplace safety [71]. According to the analysis of safety-performance research, organizational commitment to safety is crucial [72]. According to a behavioral safety approach, it had a pair of dimensions. On the other hand, volunteer involvement in safety initiatives and promoting safety within the company are referred to as safety participation [73]. Since workplace incidents were frequently investigated because of a lack of safety compliance, the chemical, oil and gas industry placed a great deal of emphasis on safety compliance. Thus, Abu Samah, et al. [74] explained, one of the obstacles to workplace accidents perceived to be inconsistent behavioral safety [74]. Nonetheless, the current study explores into the way safety compliance with safety-management procedures mediates workplace incidents in chemical, oil and gas industries. Numerous industries, including mechanical engineering, automotive, medical, chemical and nuclear power plants etc., use safety-related equipment. According to Kashyap [75] every SIL determination conforms to a specific standard that adheres to IEC 61508 [35]. However, industry E/E/PE SRSs (electrical, electronic, and programmable electronic safety-related systems) were regulated by IEC 61508, the performance-based safety standard [76]. Three components make up a safety-related system: an actuator, a logic solver, and a sensor. Typically, this system is called a safety instrumented system (SIS) [77]. Safety integrity is an assessment of a SIS's safety function. A PFD (probability of failure on demand) that a SIS can effectively carry out the necessary safety function determines the SIL [35].

According to Oyebode, et al. [78] in the oil and gas sector, effective leadership defined as a set of abilities, qualities, and conduct that allow leaders to priorities organizational success, safety, and efficiency while navigating the intricacies of drilling operations [78]. To lead teams through challenging initiatives and unpredictable situations, effective leaders in this context exhibit technical expertise, strategic vision, and good communication abilities. As they support the goals and values of the company, they build trust, encourage teamwork, and enable workers to reach their greatest potential. According to Olowe and Kumarasamy [79] in the oil and gas sector, safety is crucial, and successful executives put safety first [79]. They encourage proactive risk management techniques, establish a safety-first mentality in staff members, and set an example by following safety policies and procedures. Effective leaders have excellent communicators who can clearly and effectively explain goals, expectations, and feedback to staff members at all organizational levels. To increase trust and engagement, they actively listen to employee problems, promote candid communication, and welcome criticism. According to Adekanmbi, et al. [80] proficient leaders put safety first, empower staff, and set an example, fostering an atmosphere where everyone takes responsibility for safety and incidents are reduced by proactive risk management and involvement [80].

According to Ebirim and Odonkor [81] safe work practices, hazard identification, and emergency response are made possible by thorough and well-defined safety rules and procedures. Standardized safety procedures and uniformity across operations are made possible by well specified safety protocols [81]. Although it affects organizational procedures, staff behavior, and decision-making, safety culture has a big impact on incident prevention. An atmosphere where safety is respected, given top priority, and incorporated into all facets of the organization's operations is produced by a positive safety culture. According to Olajiga, et al. [82] the implementation of a robust safety culture promotes increased awareness of potential hazards and risks among employees, empowering them to identify and proactively solve safety concerns [82]. To reduce the possibility of mishaps and injuries, safety culture promotes a methodical approach to risk management, where dangers are recognized, evaluated, and controlled. Positive safety cultures lower the likelihood of regulatory infractions and the fines that come with them by promoting higher levels of adherence to safety standards, laws, and best practices. Workplace safety culture can be instantly assessed, and assistance opportunities can be identified by observing employee behaviors and practices. According to Abrahams, et al. [83] assessing safe and risky behaviors and encouraging the reinforcement of safe practices are the main goals of behavioral observations. In-depth evaluations of safety culture, including leadership commitment, communication, staff involvement, and safety policies and procedures, can be carried out by external consultants or internal safety specialists [83].

3. Methodology

This investigation belongs to an operational research investigation. Here, the specifics of research operation as follows:

3.1. Research Design

The best method for analyzing occurrences in the chemical, petrochemical, and oil and gas processing sectors is quantitative risk analysis, especially when it comes to situations containing toxic discharges, fires, and explosions. It makes it possible to do thorough frequency and consequence analysis, which facilitates precise risk assessment and efficient risk mitigation techniques. This work is ideal for SIL rating assessments for critical infrastructure since it offers thorough scenario modelling that considers human error and equipment failure rates. DNV Safety (Det Norske Veritas - Software for the Assessment of Flammable, Explosive and Toxic Impact) reduces uncertainty by providing data-driven insights as opposed to traditional qualitative methods that depend on subjective assessments. Safety provides integrated risk quantification, cost-benefit comparisons, and spatial analysis, in contrast to more straightforward quantitative approaches, guaranteeing well-informed decision-making.

Implemented as well as recognized essential technique for process safety analysis to assess risks in industrial operations, quantitative risk assessment (QRA) is one of the methodologies for analyzing process hazards. PHA is an analytical tool that uses previous knowledge and experience of a hazard failure to assess the likelihood that a certain activity, facility, product, or system may experience future hazards, hazardous circumstances, or occurrences that could cause injury. It is a crucial requirement of EPA's Risk Management Programme (RMP) Rule, 40 CFR Part 68, and Occupational Safety and Health Administration's (OSHA's) Process Safety Management (PSM) standard, 29 CFR 1910.119. PHS is required under these laws to handle hazardous and fire hazards and their potential effects on workers, the general public, and the environment [84].

In industries like oil, gas, and chemicals, where safety concerns associated with hazardous products and processes are crucial, DNV Safety is a software program that is frequently used for quantitative risk assessment (QRA). By offering comprehensive modelling and simulation of possible incident scenarios, including poisonous gas leaks, fires, and explosions, it enables businesses to evaluate the frequency and impact of such occurrences.

The principal characteristics of DNV Safety are as follows:

- Comprehensive Modelling of Scenarios: By considering variables like material characteristics, meteorological conditions, and equipment arrangement, safety allows users to model intricate incident scenarios.

- Analysis of Frequency and Consequence: The software determines the most probable results (consequences) of incidents, including their effects on the environment, assets, and human health. It also assesses the probability (frequency) of certain occurrence situations.
- Cost-Benefit Assessment: Companies can assess the financial viability of various risk mitigation strategies thanks to the tool's cost-benefit analysis features.
- Safety Integrity Level (SIL) Analysis: Safety facilitates SIL evaluations, which assign a reliability rating to safety systems and parts, including control devices and alarms, based on necessary performance criteria.
- Compliance and Reporting: The application produces reports that assist businesses in meeting regulatory requirements, including COMAH in the United Kingdom and OSHA in the United States of America.

3.2. Advantages Over Alternative Approaches

- Quantitative Depth: Unlike qualitative approaches like HAZOP or FMEA, which rely on expert judgment, Safety provides rigorous, data-driven analysis, reducing uncertainty.
- Integrated Risk Quantification: Safety combines consequence modelling with risk quantification, offering a more comprehensive view than standard quantitative risk assessments.
- Spatial and Graphical Analysis: The software visually represents risk contours and zones, aiding decision-makers in spatial planning and emergency response preparation.
- DNV Safety is highly regarded for its ability to offer comprehensive and precise risk assessments, making it invaluable for industries where accurate, data-based safety planning is essential.

3.3. Sample and Sampling Method

The safety culture survey comprised 5 manufacturing and healthcare-based industries i.e. Hazardous chemicals Methanol and Xylene manufacturing unit; Clethodim manufacturing facility; Solvent recovery plant; Pharmaceutical industry producing active ingredients & intermediates and Neutral spirit producing grain-based distillery. Responses were recorded on the bases of different core components of workplace safety like Incident Awareness and Communication; Safety Procedures and Protocols; Equipment and Infrastructure; Risk Assessment and Hazard Identification; Safety Culture and Leadership; Training & Competency; Emergency Response and Incident Reporting. Table 1 showed the details of companies as follows:

Table 1.
Details of companies used for safety culture survey.

Company	Company name	Sector	Products
C1	Hazardous chemicals methanol and xylene manufacturing unit	Chemical industry	Chemical production
C2	Clethodim manufacturing facility	Chemical industry	Chemical production
C3	Solvent recovery plant	Chemical industry	Chemical solvent recycling
C4	Pharmaceutical industry producing active ingredients & intermediates	Pharmaceutical industry	Pharmaceutical Ingredients Manufacturing
C5	Neutral spirit producing grain-based distillery	Spirit industry	Spirit Distillery

Injuries typically befall within an organisation and influenced by external elements in the complex sociotechnical system. While achieving injury evaluation and prevention, the interconnections between various organisations should be taken into account in an adequate way [48, 85]. Here, National Disaster Management Authority, the Ministry of Environment (NDMA), Forests and Climate Change (MoEFCC), the Directorate General of Factory Advice Service & Labour Institutes (DGFASLI), and the Pollution Control Board are among the investigating agencies that have made their investigation reports accessible. These reports include results induces, accountability, legal infringements, and implied safety improvements. Information collected data from news archives as well. Utilising an online survey platform (Qualtrics, Google Forms, Survey Monkey), quantitative questions are intended to gauge attitudes and satisfaction levels specifically for safety measures on improving techniques.

3.4. Research endeavours

- Review investigate, and compile information about the use and storage of chemicals in manufacturing.
- Utilise the Walk-Through Survey technique to gather data and document the study in the field. Then, use risk assessment and hazard identification to gather information for hazard identification and to recommend and prevent risks. To accomplish research goals, analyse the chemical process used in the production process to determine its scope.
- Use descriptive analysis to summarise and evaluate the risk assessment data, then interpret the findings to align with the research goals.
- The methodology is regularly evaluated and revalidated via the use of methods like HAZOP, HSEIA, and PHA, which ensures that the facility is improved to effectively manage possible risks.

3.5. Equipment

Hazard identification and risk assessment were major components of research equipment. The Department of Industrial Works' (2000) regulations on risk assessment, hazard identification, and risk management plans were the foundation of their implementation [24]. It is crucial to make sure that these crucial pieces of machinery are sturdy, safe to operate, and meet or beyond the standards of dangerous workplaces.

3.6. Identification of Vulnerabilities

The importance of identifying vulnerable regions that could leak and taking care of them with a methodical assessment. It can be found manually as well as automatically [86].

3.6.1. Automatic identification

The fire and gas system of overseas industries that generates gas and chemicals in leakage process, must be able to identify toxin chemical compounds with set off alarms, and bring about emergency shutdowns and process plant blowdowns. The petroleum-based content might be identified and determined through various techniques [87].

(a) It can be oxidised over a catalyst, and the heat generated measured by catalytic gas detectors [88].
(b) An infra-red (IR) point gas detector measures the amount of chemicals in a continuous throughflow of the surrounding atmosphere with IR light [89].
(c) The average petroleum hydrocarbons content in the area that the beam embraces was determined via an IR line-of-sight gas detector, which employs infrared light across a greater distance [89].

3.6.2. Manual Identification

For manual petroleum hydrocarbons content measurement, a variety of instruments is available. Most of the time, these devices are portable. In addition to metal oxide semiconductor (MOS), IR point, ultrasonic, and electrochemical sensors, standard sensors also have photo-ionising detectors [90]. It is possible to detect tiny hydrocarbon emissions or discharges using an infrared camera and infrared thermography. In order to monitor hydrocarbon systems and trace emission sources, infrared cameras are being used more and more.

3.6.3. Vibration Identification

Weakness and fatigue induced by vibration in a system might result in HC leakage [91]. To stop leaks, systems can visualise vibrations have been developed. The device, which is portable, includes a high-speed camera that amplifies signals to detect tremors. Real-time data collection allows for the observation of vibrations in pipes, for instance, while measurements are being made.

3.6.4. Modern Leak Detection

A wide range of equipment, software, mathematical formulas, and algorithm-based techniques have been put forth to monitor, identify, and stop sinkholes and underground fluid pipeline leaks. For this, traditional methods like acoustic-based approaches have been employed. These methods require for a specialist who checks for leak sounds while scanning a suspicious place. But these techniques take a lot of time, and staff expertise and experience play a big role in how accurate they are [92]. Another common method used to find pipeline breaches is vibration analysis [93]. Nevertheless, hydrophones must be positioned on both sides of the pipeline portion being considered for leak detection in order to use traditional vibration and acoustic-based procedures. For such traditional methods to find a leak precisely, the pipeline's length is necessary. In these situations, the pipeline's length is determined by using the recorded data from maps or by walking while holding a measurement wheel [94]. Sinkholes have been monitored and detected using a variety of techniques. Subterranean pipeline infrastructures have been monitored over time utilising wireless sensor networking (WSN) systems, the Internet of Things (IoT), and image processing technologies that leverage artificial intelligence (AI) [95-97]. In 2004, WSN was initially employed for pipeline leak detection and monitoring [98]. Nonetheless, the majority of WSN, IoT, and image processing techniques primarily concentrate on pipeline monitoring for identifying any flaws like leakage etc.

3.7. Data Analysis

For comparisons between industries, statistical techniques (e.g., ANOVA, t-tests) used for analysing the data. The data analysing process are as follows:

3.7.1. Primary

Using DNV Safety through detailed analysis. DNV Safety simulates possible accident outcomes, calculating both the likelihood (frequency) and impact (consequence) of each scenario chosen. This assisted to assess the effectiveness of their existing safety measures, identify areas of vulnerability, and optimize control measures. By doing so, DNV Safety helps industries make informed decisions to enhance overall safety and compliance with regulatory standards, while ensuring the reliability and safety of equipment and processes as part of robust QRA practices.

3.7.2. Secondary

Considering the hazards and probability of chemical accidents, we develop a strategy and take action to reduce accidents or losses to prevent and resolve the problem. The secondary analysis investigates fundamental elements of workplace safety to ascertain differences across staff categories and organizations. Descriptive statistics revealed strong areas like "Incident Awareness and Communication" and "Emergency Response," while "Equipment and Infrastructure" had significant under-performance. Independent sample t-tests found no significant differences in means between managerial and field staff. However, ANOVA analysis across companies indicated significant variations in components like "Incident Awareness," "Risk Assessment," "Training & Competency," and "Emergency Response," which were company-specific disparities in workplace safety perceptions. This indicates both strengths and areas requiring improvement across different organizational contexts.

3.8. Ethical Consideration

However, no special approval needed because the data is publicly accessible, it has been collected and used in compliance with all relevant legal and ethical requirements. Some company's names and private data have been anonymised and handled in a discrete manner. The only academic objective of this data analysis is to identify suitable control strategies to improve industry safety standards. The study and suggestions were intended to have a beneficial effect on the occupational safety sector. Techniques were used to confirm that data interpretation remained neutral and objective, using statistical methods and standards for choosing suitable control measures. This analysis made use of publicly available data from websites run by government authorities. Every use of data complies with ethical norms and institutional policies while maintaining confidentiality and privacy.

3.9. Results

The present investigation employs risk assessment to identify the potentially harmful substances, safety procedures and protocols, equipment and infrastructure, emergency response etc, that can have an impact on the environment and the health of local residents by evaluating the potential of hazardous chemical leaks. Table 2 showed that the descriptive statistics for the study factors.

Table 2.
Descriptive statistics.

Core components of workplace safety	Incident awareness and communication (H1)	Safety procedures and protocols (H2)	Equipment and infrastructure (H3)	Risk assessment and hazard identification (H4)	Safety culture and leadership(H5)	Training & competency (H6)	Emergency response and incident reporting (H7)
Count	104	104	104	104	104	104	104
Mean	3.225	2.503205	**2.007813**	2.755769	2.966783	2.325721	3.114011
SD	0.294529	0.314878	0.18262	0.377736	0.264227	0.562107	0.35296
Max	3.8	3.4	2.8125	3.7	3.454545	3.5	3.857143
Min	2.6	1.8	1.5	1.8	2.272727	1.375	2.285714
25%	3	2.333333	1.9375	2.5	2.727273	1.875	2.857143
50%	3.2	2.466667	2	2.8	3	2.125	3.142857
75%	3.4	2.733333	2.0625	3	3.181818	2.875	3.428571

The data shows that "Incident Awareness and Communication (H1)" is perceived most positively with the highest mean score of 3.225 and the lowest variability (SD = 0.295). Next is "Emergency Response and Incident Reporting (H7)" with a mean of 3.114 and slightly higher variability (SD = 0.353). "Safety Culture and Leadership (H5)" follows with a mean of 2.967 and low variability (SD = 0.264). In the middle range, "Risk Assessment and Hazard Identification (H4)" has a mean of 2.756 and higher variability (SD = 0.378), while "Safety Procedures and Protocols (H2)" scores a mean of 2.503 with moderate variability. Lower satisfaction is noted in "Training & Competency (H6)" which has a mean of 2.326 and the highest variability (SD = 0.562). The least favourable perception is of "Equipment and Infrastructure (H3)" with the lowest mean score of 2.008 and minimal variability (SD = 0.183). This overall pattern highlights strong perceptions in some areas and significant dissatisfaction, particularly with "Equipment and Infrastructure." Figure 1 showed that the average scores for the various workplace safety management components.

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Figure 1.
Mean scores for different components of workplace safety management.

Table 3.
Difference in mean study variables between different designations using independent sample t-test.

Core components of workplace safety	**Managerial staff (Operations, & support functions)**	**Field staff (Operations, & support functions)**	**t-value**	**p-value**
	Mean±SD			
Incident awareness and communication (H1)	3.12± 0.30	3.24±0.29	-1.48	0.14
Safety procedures and protocols (H2)	2.60±0.25	2.49±0.322	1.28	0.20
Equipment and infrastructure (H3)	2.01±0.28	2.01±0.16	0.09	0.93
Risk Assessment and hazard identification (H4)	2.64±0.48	2.78±0.35	-1.29	0.20
Safety culture and leadership (H5)	2.92±0.25	2.97±0.27	-0.67	0.50
Training & competency (H6)	2.54±0.56	2.28±0.56	1.73	0.09
Emergency response and incident reporting (H7)	3.11±0.38	3.11±0.35	-0.084	0.93

Table 3 showed that the difference in mean study factors between managerial staff (Operations, & Support functions) and field staff (Operations, & Support functions) using independent sample t-test. Since p-values are greater than 0.05 hence there is no significance difference in mean Equipment and Infrastructure, Emergency Response and Incident Reporting, Incident Awareness and Communication, Safety Procedures and Protocols, Risk Assessment and Hazard Identification, and Safety Culture and Leadership between managerial staff and field staff.

Table 4.
Difference in mean study variables between different companies using one-way ANOVA.

Core components	Companies					F-value	p-value
	C1	C2	C3	C4	C5		
	Mean±SD						
Incident awareness and communication (H1)	3.16±0.26	3.27±0.34	3.10±0.19	3.46±0.21	3.12±0.27	7.885	**0.001******
Safety procedures and protocols (H2)	2.54±0.23	2.46±0.34	2.45±0.20	2.5±0.37	2.50±0.32	0.272	0.896
Equipment and infrastructure (H3)	2.04±0.21	2.05±0.19	1.97±0.18	2.03±0.16	1.97±0.18	0.857	0.493
Risk assessment and hazard Identification (H4)	2.54±0.35	2.58±0.38	2.58±0.35	2.66±0.29	3.02±0.28	11.909	**0.001******
Safety culture and leadership (H5)	2.87±0.25	2.97±0.28	3.02±0.14	2.96±0.29	2.99±0.27	0.588	0.672
Training & competency (H6)	3.15±0.22	2.91±0.20	2.77±0.32	1.93±0.21	1.95±0.27	105.740	**0.001******
Emergency Response and incident reporting(H7)	3.53±0.18	2.99±0.36	3.05±0.38	3.10±0.27	3.03±0.34	7.354	**0.001******

Note: ***p<0.001.

Table 4 showed that the difference in mean study factors between different companies. The p-value for Incident Awareness and Communication, Risk Assessment and Hazard Identification, Training & Competency, and Emergency Response and Incident Reporting with p-values of 0.001, hence there is significant difference in mean Incident Awareness and Communication, Risk Assessment and Hazard Identification, Training & Competency, and Emergency Response and Incident Reporting between different companies. In Incident Awareness and Communication, the company 4 has high mean 3.46±0.21 when compared to other companies. In Risk Assessment and Hazard Identification the company 5 has high mean when compared to other companies. In Training & Competency the company 1 has high mean when compared to other companies. In Emergency Response and Incident Reporting the company 1 has high mean compared to other companies. In contrast, Safety Procedures and Protocols, Equipment and Infrastructure, and Safety Culture and Leadership show no significant differences, since p>0.05. Thus, we can say uniformity of P value in these three components respondents may perceived similarly and might require equal emphasis, attention in enhancement of overall effectiveness.

Table 5.
Company crosstabulation.

			Company					Total
			1	2	3	4	5	
Category	Managerial staff (Operations, & Support functions)	Count	3	3	3	3	4	16
		% within Category	18.8%	18.8%	18.8%	18.8%	25.0%	100.0%
		% within Company	21.4%	20.0%	30.0%	12.0%	10.0%	15.4%
	Field staff (Operations, & Support functions)	Count	11	12	7	22	36	88
		% within Category	12.5%	13.6%	8.0%	25.0%	40.9%	100.0%
		% within Company	78.6%	80.0%	70.0%	88.0%	90.0%	84.6%
Total		Count	14	14	15	10	25	40
		% within Category	13.50%	13.5%	14.4%	9.6%	24.0%	38.5%
		% within Company	100.00%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5 showed that the association between designation and companies. Field staff constitutes a larger portion of the company's workforce, representing 84.6% of the total, with higher percentages in the lower satisfaction ratings, while managerial staff makes up 15.4% and shows more balanced satisfaction distribution.

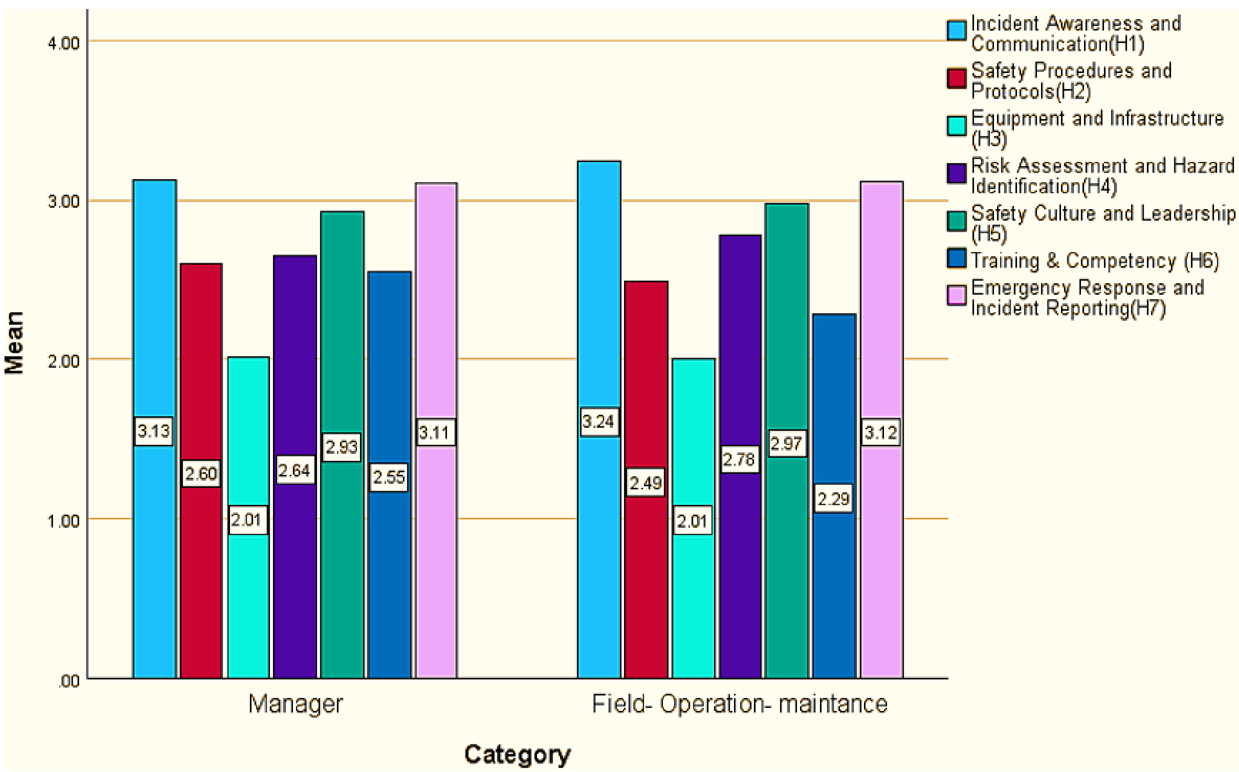

Figure 2.
Cluster bar chart for study variables between managerial staff (Operations, & Support functions) and field staff (Operations, & Support functions).

According to Figure 2, data cluster bar chart which had both management and field-operation maintenance have their strongest area, "Incident Awareness and Communication", with mean scores 3.13 and 3.24 respectively. Conversely, "Equipment and Infrastructure" has the lowest mean score of 2.01 for both groups thus it needs improvement tremendously. Notably, even though "Emergency

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Response and Incident Reporting" mean scores are also high as they stand at 3.11 (for managers) and 3.12 (for field-operation-maintenance), thus showing a good performance by both groups in responding to emergencies; other areas like "Safety Procedures and Protocols" plus "Training & Competency" recorded lower ratings which point to some deficits that exist within the realm of safety protocols as well as training that should be dealt with.

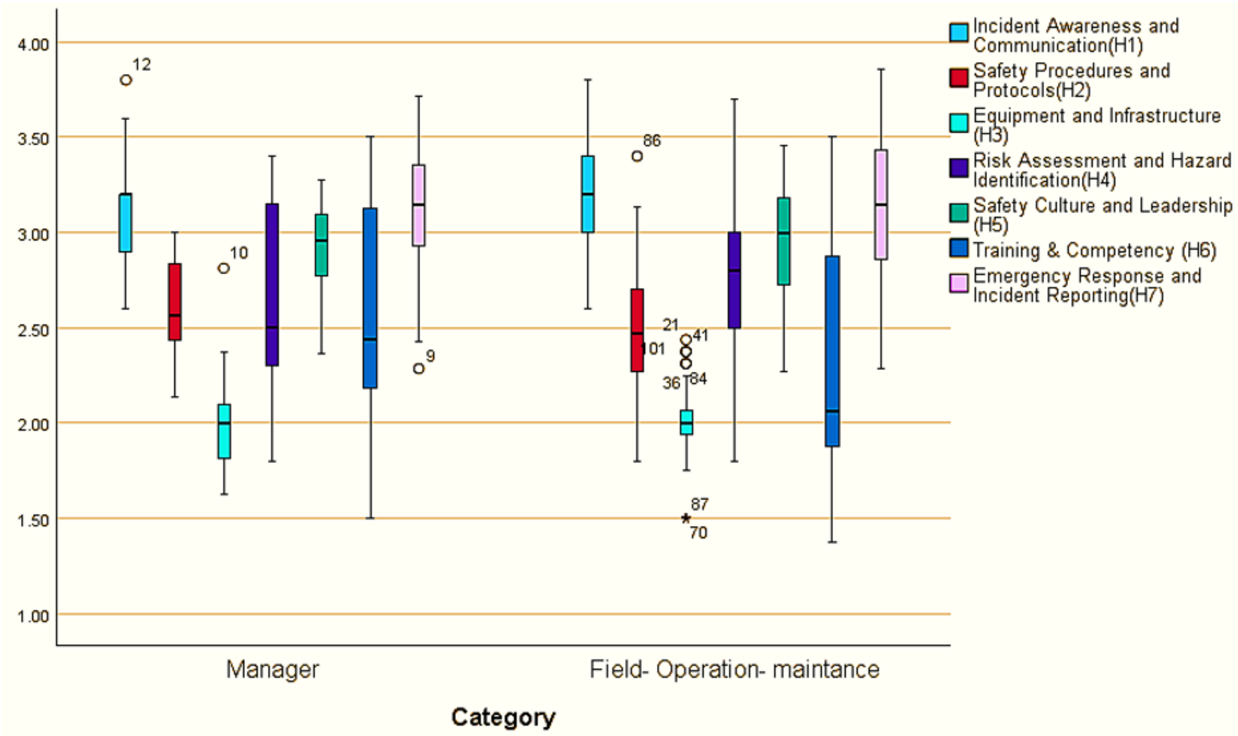

Figure 3.
Box plot for study variables between managerial staff (Operations, & Support functions) and field staff (Operations, & Support functions).

According to Figure 3, the data from the Box plot shows that the strongest category for both managers and field-operation-maintenance staff is "Incident Awareness and Communication" with scores of 3.13 and 3.24 respectively. This means that both groups do well in this aspect. On the other hand, "Equipment and Infrastructure", is consistently at the bottom for both groups, a sign that it is an important area for improvement, with both groups scoring 2.01. Other categories display moderate variability; "Safety Procedures and Protocols" and "Training & Competency" have relatively lower scores particularly when considering field-operation-maintenance staff, implying that these are areas of concern too. Generally speaking, however, although both groups are good in terms of incident awareness and emergency response there are notable weaknesses in equipment infrastructure and training which need to be dealt with.

4. Discussion

As workplace accidents have significant financial and human implications, it is important to research the factors that contribute to a decrease in incidents [99]. The structure of this study is tested by considering some of factors. The findings indicate that workplace safety awareness and safety leadership are positively correlated. It was suggested that leadership strategies and workplace accidents would be mediated by safety compliance. The study's findings demonstrated, as expected, safety procedures and

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protocols, equipment and infrastructure, incident awareness and communication, risk assessment and hazard identification, safety culture and leaderships, training and competence, emergency response and incident reporting. The results of previous research are supported by this study [100]. Employees must work in a safer manner so as not to endanger themselves or their colleagues [101]. Developing a work plan, reporting all potential hazards, receiving safety training, reporting all actual hazards during the work, taking responsibility for any misconduct and taking steps to prevent it in the future, and teaching ourselves and our coworkers methods to prevent accidents are all ways to increase this awareness [102]. Employes can stay safe and steer clear of hazardous circumstances due to the organization enforcement of safety standards and procedures [103]. Safety policies, which are a component of the safety atmosphere, can help make safety management more effective. The need of staff training in preventing any unfavorable circumstances at work is another crucial aspect of safety leadership. To increase safety consciousness, it becomes vital to steer clear of hazardous situations and to enforce people to be safe on their own and to keep others safe while working [104]. People aim to increase their safety consciousness by learning as much as they can to prevent mishaps. Organizations need to communicate about the hazards that come with working there. Regular communication can be beneficial in two ways. Employees are made aware of the risks involved in their line of work in the first place, and in the event that something goes wrong, it will be promptly reported to minimize the damage [105]. The ideas and guidelines are often communicated by improved safety management. This raises awareness of safety. Another method to include prompt emergency preparations that can lower the potential level of hazard at work is through preventive planning. Employees can become more aware of their safety by thinking about it and participating in the creation of preventive plans. In summary, preventive planning, communication, training, and policies all work together to encourage workers to continue being mindful of their workplace safety for favorable results [106]. Figure 4 showed that the compression in between mean ratings of field staff and managerial staff for operations and support functions. The mean scores of two groups for the seven main components are analyzed in a largely parallel manner. Significantly lower scores in both groups are shown by component 3, which is noteworthy since it suggests persistent underperformance, a genuine ineffectiveness, and a serious cause for concern.

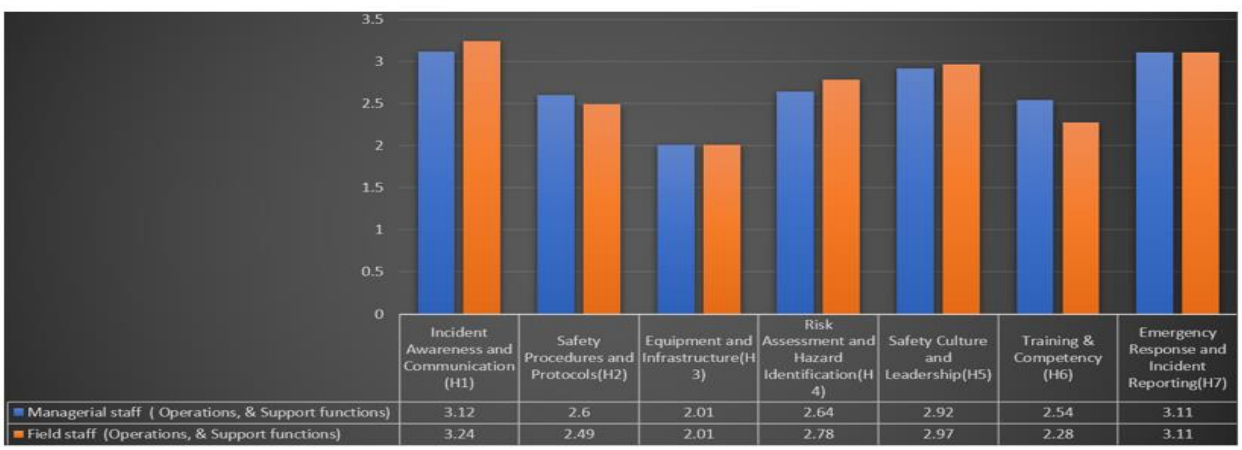

Figure 4.
Compares mean scores between managerial staff (Operations, & Support functions) and Field staff (Operations, & Support functions).

According to this result, each fundamental component's responses from a variety of individuals have distinct consequences. The lack of significant unity across these individual changes indicates that the impacts of the components are different.

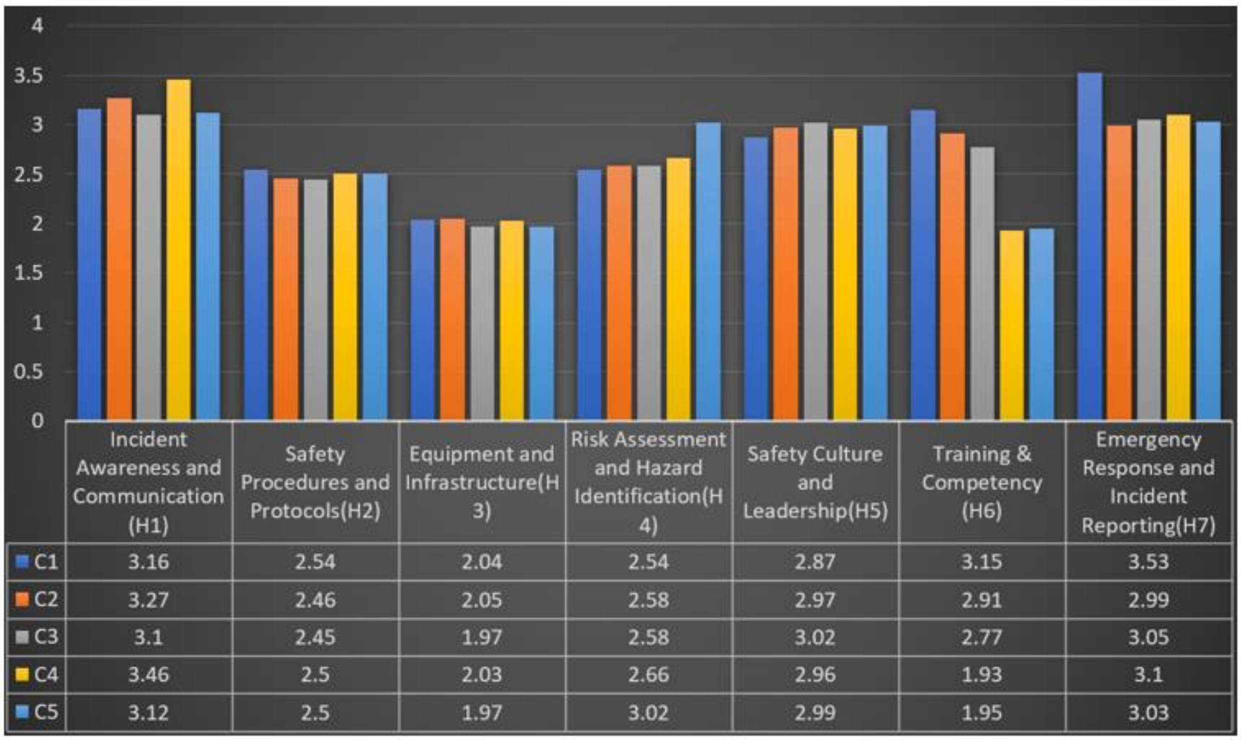

Figure 5.
Difference in mean study variables between different companies using one-way ANOVA.

The bar graph (Figure 5) indicates different rates in diverse security classes. The class "Emergency Response and Incident Reporting" always rates highest suggesting that it is well run with ranges between 2.99 to 3.53 while the class "Equipment and Infrastructure" has the lowest rates indicating that could need more attention with ranges between 1.97 and 2.05 points. Other classes like "Safety Procedures and Protocols", and "Risk Assessment and Hazard Identification" have moderate scores meaning they are neither critically deficient nor outstandingly good. These number variations suggest various focus levels in safety features as such there can be areas needing improvement especially on training as well as infrastructure ones themselves.

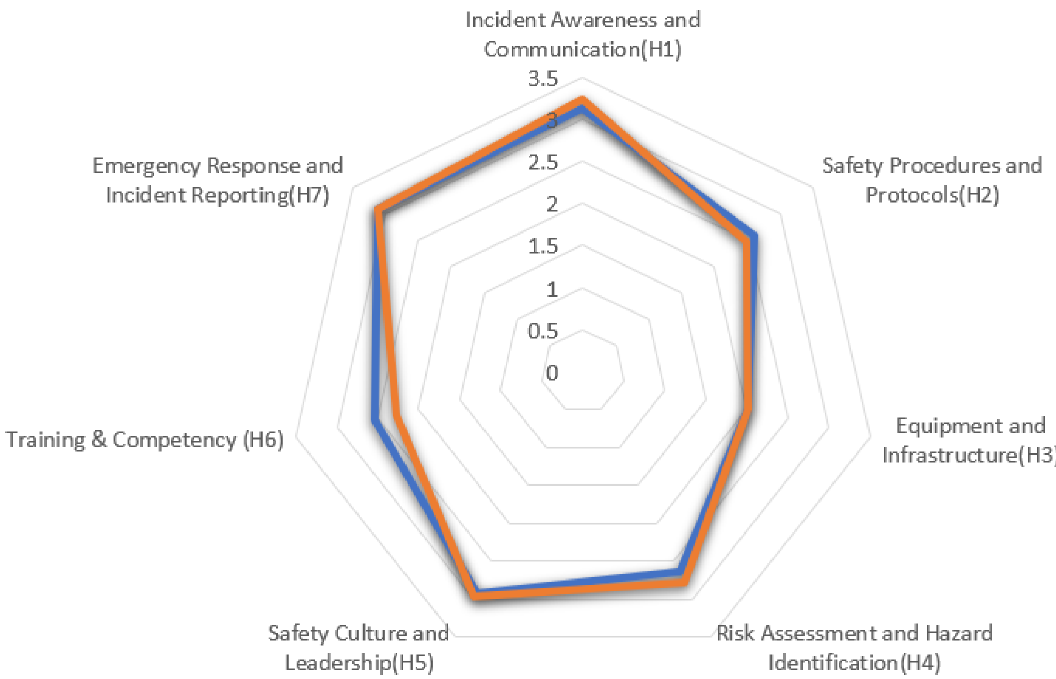

Figure 2.
Radar plot for study variables.

According to Figure 6, the radar chart showed the safety performance of managers compared to field-operation-maintenance staff across various categories. Both groups exhibit strong performance in "Incident Awareness and Communication" and "Emergency Response and Incident Reporting," with scores of 3.12 and 3.24, and 3.11 for both, respectively. "Equipment and Infrastructure" is a consistent low point for both, scoring 2.01, indicating a critical area needing improvement. While the scores for "Safety Procedures and Protocols," "Risk Assessment and Hazard Identification," and "Safety Culture and Leadership" are slightly higher for field-operation-maintenance staff compared to managers, these areas still show room for growth. Notably, "Training & Competency" scores are lower for field-operation-maintenance (2.28) than for managers (2.54), suggesting a more significant need for training enhancements in the field. Overall, the chart highlights strengths in incident communication and emergency response but underscores the need for improvements in infrastructure and training.

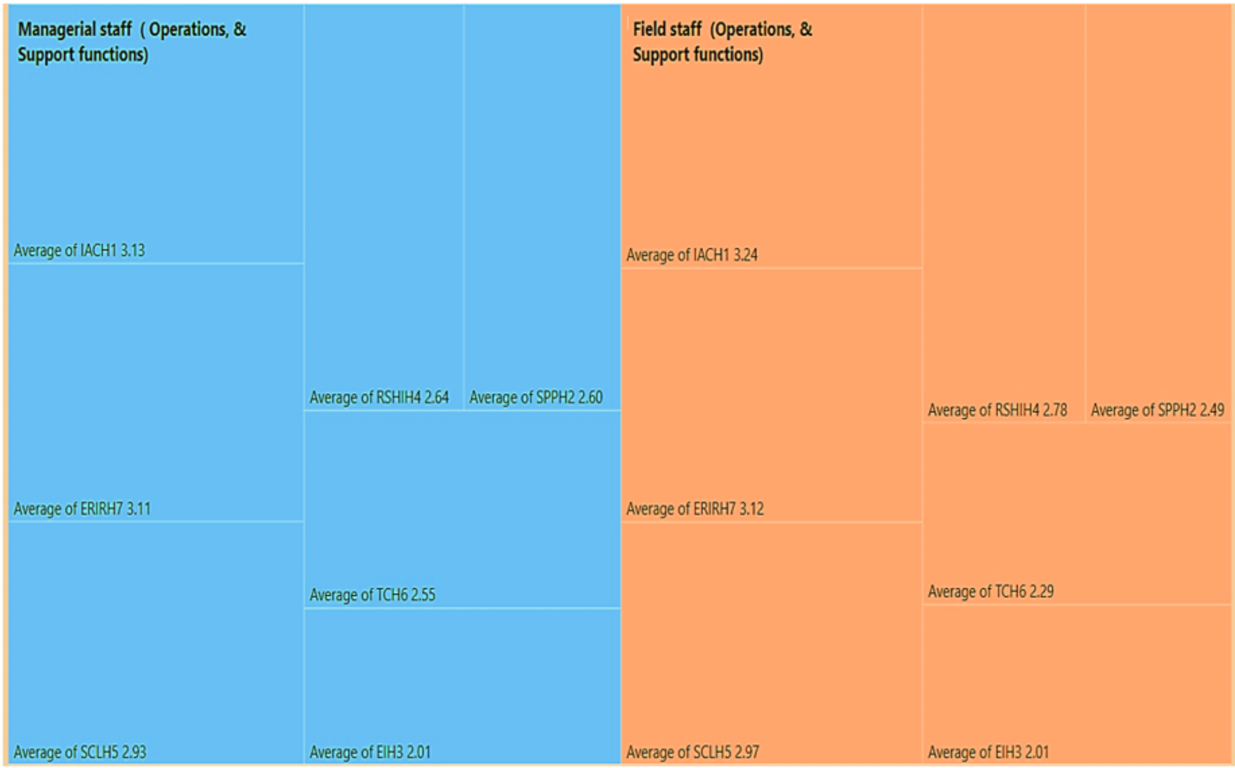

Figure 7.
A mosaic plot is used to examine the variables between field staff and managerial staff (that perform operations and support responsibilities).

Figure 7 showed an overview of safety performance metrics comparing managers and field-operation-maintenance staff. Analyzed-similarities in safety performance metrics for managers and field-operation-maintenance staff. Strengths shown by both groups include "Incident Awareness and Communication" and "Emergency Response and Incident Reporting" which ranked highest indicating effective practices in these areas. Both have a consistent low point as "Equipment and Infrastructure" which ranked 2.01 thus indicating the need for improvement in this area. The field-operation-maintenance staff score slightly higher in "Risk Assessment and Hazard Identification" (2.78) compared to managers (2.64); however, they are slightly lower in "Training & Competency" (2.29) compared to managers (2.55). The plot overall indicates that while both groups are good at incident communication and emergency response, there are notable gaps in equipment and infrastructure, as well as in training that should be attended to if overall safety performance were to be improved.

5. Conclusion

In high-risk industries like chemical, oil and gas etc., efficient safety management procedures are crucial to preserving a low incidence of workplace accidents. The main requirement for management is to provide strong infrastructure in order to stop leakage from expanding and becoming worse. establishing a safe workplace by implementing more accurate IPF (Instrumented Protective Function) systems, appropriate/upgraded SIL ratings, and strict leak detection systems. Additionally, process equipment should be properly tripped or stopped before a leak grows into a hazardous situation. The requirement for regular, error-free maintenance to guarantee equipment integrity and process safety. To improve overall safety and operational reliability, strong infrastructure and equipment are combined with essential elements including safety culture, leadership, training, competency, emergency response, incident awareness, and communication. Here, in this paper we discussed the statistical techniques of workplace safety and its factors like strategic insights into communication, procedure, infrastructure, leadership & emergency procedure. Also highlight on the bases of core components of workplace safety like incident awareness and communication, safety procedures and protocols, equipment and infrastructure, risk assessment and hazard identification, safety culture and leadership, training and competency, emergency response and incident reporting. It draws attention that the safety management techniques, incident communication and emergency response can lower workplace accidents in safety-sensitive organisations. According to comparison in between 5 companies, there is significant difference in the mean performance of companies in the areas of incident awareness and communication, risk assessment and hazard identification, training and competency, and emergency response and incident reporting, which demonstrated by the p-values. Resultant, company 4 has high mean in incident awareness and communication (3.46 ± 0.21). Company 5 has high mean in risk assessment and hazard identification. Company 1 has high mean in Training & Competency including emergency response and incident reporting. Furthermore, in light of the study's findings, it has been recommended that in order to comprehend their function in safety performance, research should incorporate safety management and safety compliance metrics. There are safety hazards for employees in sectors like oil and gas, thus future research should take safety compliance and safety management procedures into consideration. The results of the current study, however, showed that management should concentrate on enhancing workplace safety-management procedures in order to reduce the expense of occupational accidents and safety with safety compliance. To set the requirements for safety compliance, practical steps are also required. To generalise the findings, future research must compare safety-management approaches with real-world applications in organisations and measure safety climate, culture, and compliance.

Additionally, the results of the investigation showed that industrial chemical laboratories' hazards evaluations pose a high danger of fire or explosion due to their designation of hazardous chemical storage. The findings of the study can therefore be used to produce measurements for accident prevention and reduction. According to a risk assessment of chemical exposure, different employees in the chemical laboratory must be familiar with the specifics of the proper operating procedures, including the operating handbook [107]. Assessing the probability of gas leaks from power plants necessitates setting up surveillance systems and being ready for any emergency in order to avert potential mishaps or accidents [108]. According to Chaiprakarn [24] engineering principles such as engineering, teaching, and enforcement can be used to prevent accidents [24]. In conclusion the workplace safety risk assessment is essential to raising quality of work and motivating owners of companies to ensure worker safety, which is in line with the findings of the study. Also, strongly recommend that organisations must provide top priority to practices and infrastructure which comply with global safety standards. Organisations to think about the regular evaluation and re-validation of PHA (process hazard analysis), HAZOP, HSEIA, in order to assess the performance of the current asset facilities and improve infrastructure to meet international standards in order to prevent the possibility of catastrophic incidents and hazardous gas leaks, chemical handling and processing companies of all sizes must also think about integrating their proactive measures.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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Copyright:

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