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Development of Sustainable Occupational Safety and Health Programs in the Petroleum Sector Using Quality Control Techniques

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Abstract

In this research, an analysis of occupational safety and health (OSH) issues in the petroleum sector is presented, specifically in Kuwait, and is sustainable using quality control techniques. To do this, a hybrid approach of Six Sigma DMAIC methodology as a quality improvement technique, safety hazard analysis, and quality control techniques is utilized. An Analysis of several years of accident data shows drilling and production departments, stuck by and caught in, under, or between, being the most frequent types of incidents. Various tools, such as Pareto analysis, Fault Tree Analysis (FTA), and Hazard and Operability Study (HAZOP), are embedded within the DMAIC methodology and utilized to systematically identify, analyze, and suggest solutions to the identified safety concerns. The research suggests improvements, including automated monitoring systems, improved training programs, and standardized safety procedures. These interventions are technically feasible, economically viable, and sustainable in the petroleum sector. The findings highlight the significance of combining quality control techniques, specifically the six-sigma methodology, with conventional safety management methods to develop more efficient and sustainable OSH programs.

Keywords

Occupational Safety and Health (OSH), Quality Control Techniques, Petroleum Industry Hazards, Risk Assessment, Safety Management Systems, Pareto Analysis, HAZOP

1. Introduction

One of the most critical challenges facing industries all over the world is workplace safety and health, particularly in the petroleum sector (Ajmal et al., 2021). Occupational safety and health (OSH) is very critical to any industry and must be taken care of continuously for several reasons, including not only the ethical and human side, which is the most important, but also the financial side, since accidents are very expensive to any workplace. Amongst the most dangerous industries is the petroleum industry, where workers are exposed to a wide range of hazards, from toxic chemical exposure and fire risks to potential falls, especially in drilling operations (Benson et al., 2021). Not only do these workplace hazards put workers' well-being at risk, but they also cost companies huge sums of money through equipment repair, worker compensation, and medical bills.

The significance of this research lies in its hybrid approach of using Six Sigma methodology along with hazard analysis techniques to address safety challenges in Kuwait's petroleum sector. ranks as the largest producer within OPEC, with a daily production capacity of 2.7 million barrels, but as for any workplace in the world, this industry comes with significant occupational risks (Al Rashdan et al., 2018; Al-Hemoud et al., 2019; Alroomi & Mohamed,

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2021). Analysis of accident data from 2012-2020 (ManiKumar et al., 2024) reveals that drilling and production departments account for over 77% of all incidents, with drilling operations alone responsible for 59.10% of accidents. The problem this research addresses is directly related to the analysis of OSH in the petroleum industry and to proposing recommendations for improving and sustaining these improvements. Workers in the petroleum industry face daily exposure to hazardous chemicals, which can cause both acute and chronic health issues. The highly flammable nature of petroleum products, combined with various ignition sources and high-pressure operations, creates constant fire and explosion risks. Additionally, workers frequently face fall hazards while working at heights on drilling rigs and platforms. If a company lacks a comprehensive safety management system, then this will further increase these risks, while many accidents are preventable through the application of proper safety protocols (Kenett, 2014; Kenton, 2023; Knop, 2022).

This project aims to analyze and improve the occupational safety and health (OSH) situation in the petroleum industry through the application of quality control techniques, specifically the six methodology and hazard analysis techniques. The primary objectives include conducting a comprehensive analysis of OSH problems in Kuwait's petroleum sector, enhancing existing safety programs through industrial engineering tools, implementing quality control techniques, including Six Sigma methods, and proposing sustainable solutions tailored to specific hazards. Additional goals involve developing metrics for long-term success, analyzing some historical accident data, and recommending comprehensive training programs.

The research paper is structured into five main sections. Following this introduction, the Literature Review examines existing research and best practices in occupational safety within the petroleum industry, particularly focusing on quality control applications in safety management. The quality control tools and analytical methods used are described in the Methodology section, including Pareto analysis, Fault Tree Analysis, and HAZOP studies. The Analysis of accident data and safety interventions is presented in the Results section. This is followed by the discussion and conclusion sections.

2. Literature Review

Research in the petroleum sector has been extensive on occupational safety and health, where many factors, such as employee behavior and technological innovations, have been brought to the fore. The literature shows that the integration of quality control techniques with traditional safety measures has been growing in Gulf Cooperation Council (GCC) countries, where the oil and gas industry is a key economic pillar.

There has been a recent emphasis on employee knowledge, attitudes, and practices regarding occupational safety. Quaigrain et al. (2022) examined occupational health and safety in Ghana’s oil and gas industry, finding that workers with sufficient knowledge and good attitudes toward occupational health and safety did not translate into safe workplace practice. The study identified the important gap between theoretical understanding and practical implementation of safety protocols, especially in high-risk operational areas.

Sugiono et al. (2020) extend these findings by examining the links between workforce management, workplace environment, and organizational safety culture in Indonesia’s petroleum sector. Their research among 220 respondents in nine divisions found employee management, workplace conditions, and safety culture to be the core drivers of OHS performance. More specifically, they found that safety culture moderates the relationship between management practices and overall safety outcomes.

Another important area of study turned out to be the role of safety representatives. Hovden et al. (2008) studied this aspect in the Norwegian offshore oil and gas sector and found large differences between safety representatives' and management's views on safety roles and responsibilities. Common challenges uncovered by their research include a lack of resources, little participation in planning, and little power in workplace safety decisions.

In recent literature, risk management and hazard control have been given special attention. Haridoss (2017) stressed the role of a holistic approach toward quality control methods in tackling industry-particular hazards and the need to interact properly with the engineer and the safety expert to identify and reduce hazards through teamwork. Knop (2022) complemented this work with a structured model based on the Six Sigma DMAIC methodology to improve workplace safety by systematic accident reduction through analysis and intervention.

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The literature has delineated the distinction between safety and health hazards. Eyayo (2014) has also stressed the need for this differentiation between safety hazards that induce immediate physical harm and health hazards causing long-term illnesses. This research showed that the ability to deal with certain safety problems requires qualified personnel and that poor safety performance on the part of petroleum companies has financial implications.
Other recent studies have also looked at the effects of technological advancement on safety management. In Leso et al. (2018), they investigate how Industry 4.0 technologies can be integrated into occupational safety and how automation, networking, and computerization can change the management of workplace safety. The research suggested that emerging technologies — such as monitoring and emergency response systems — could dramatically reduce workplace accidents.

The safety programs have become a focus area for sustainability. According to Matias & Coelho (2018), integrated management systems, consisting of quality, environmental, and occupational safety standards, could be used. The research showed how such integration could yield more effective and sustainable safety outcomes and operational efficiency.

Specific challenges in Kuwait's petroleum sector are also revealed in the literature. High accident rates and key areas for intervention were documented by Robertson & Lamm (2008) in drilling operations. This is consistent with more recent studies by Almohammad (2022), where he studied current safety challenges in Kuwait's oil and gas industry, and it is indicated that there is a need for the integration of comprehensive safety management systems into quality control techniques.

Schulte et al. (2019) discussed a methodology with elements of continuous feedback and revision of safety protocols based on performance metrics of safety challenges in a changing industry structure.

AlOthman et. al. (2018) showed that the use of one of the recent technologies in improving quality is through the use of Internet of Things (IoT), including the wireless sensor networks (WSNs). The use of such tools can be directly extended to the field of OSH and thus can play a very important role in improving workplace safety and reducing or eliminating incidents.

This review of the literature shows the progress of safety management in the petroleum sector from traditional to integrated systems with quality control techniques. In addition, this study addresses the gap in research on the specific application of these integrated approaches in Kuwait's petroleum sector.

The content of this comprehensive literature review lays the groundwork for understanding the status quo of occupational safety in the petroleum industry and where we need to focus our research and practical applications, particularly in the context of Kuwait's special industrial environment.

3. Methodology

A systematic approach to developing sustainable occupational safety and health programs in Kuwait's petroleum sector using the six sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology along with OSH hazard analysis tools was used in this research. Thus, this paper presents a hybrid Six Sigma hazard analysis methodology for the improvement and sustainability of OSH situation in the petroleum industry. The application of this hybrid approach is very appropriate in the OSH field, as the main goal of safety engineering is to reduce or eliminate errors and incidents in the workplace, which is basically the same goal of the six-sigma approach, which also aims to reduce or eliminate errors to improve quality.

Project charter, including statement, objectives, scope, and business case along with the SIPOC diagram, including suppliers, input, process, output and customers are all presented in the Define phase. This provides a clear understanding of the problem at hand, i.e., the occurrence of incidents in the petroleum industry leading to severe health and financial consequences.

Next, data about incidents in the petroleum industry, specifically historical data of incidents between the years 2012 and 2020, is presented along with quality control tools. Quality control tools are used during the Measure phase, including the Pareto analysis, which is a well-known statistical tool to bring attention to the vital few categories that lead to the majority of safety incidents. Pareto charts show priorities by focusing on the highest contributors to

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workplace accidents in order to address them first. 2 Pareto charts are presented, one for incidents by department and the other for incidents by type of incident.

During the Analyze phase, several hazard analysis tools are used to analyze safety incident root causes and patterns. Fault Tree Analysis (FTA) is a systematic approach to identifying potential causes for failure of safety (Manikumar et al., 2024). This analysis is supplemented with the fishbone (Ishikawa) diagram to categorize the causes into major groups such as equipment, environment, procedures, and human factors. HAZOP (Hazard and Operability) studies are employed to analyze process deviation systematically, as well as their possible consequences (Kelechi, 2023).

The Improve phase takes what we found and develops and implements solutions. The first of these phases is the generation and evaluation of potential interventions based on the results of the hazard analysis.

The control phase shows recommendations for the sustainability of improvements, as controlling the improvement is very critical to any improvement project. If not controlled, all of the achievements of any improvement project can go away very quickly, bringing things back to what they were previously.

This methodology provides a comprehensive hybrid approach that ensures a systematic and data-driven method for the identification, analysis, and resolution of safety concerns in the petroleum sector. By integrating quality control tools, specifically the six-sigma methodology, with traditional safety management approaches, a robust framework is developed to develop sustainable occupational safety and health programs.

This methodology offers a basis for immediate safety improvements and long-term development of safety programs in Kuwait's petroleum sector with the potential for application to similar industrial settings.

4. Results

The results of this study are presented following the DMAIC methodology framework, demonstrating the systematic approach to improving occupational safety in Kuwait's petroleum sector.

4.1. Define Phase Results

The initial analysis established the problem statement, objectives, business case, and scope of this study about safety analysis in Kuwait's petroleum sector through the project charter as follows.

Problem statement: One of the most dangerous industries, the petroleum sector, damages businesses financially and jeopardizes the rights of employees to a safe workplace. To determine the primary cause of accidents and encourage safe business practices, effective data-driven strategies are required.

Objectives:

- To apply industrial engineering tools, specifically the six-sigma quality improvement methodology, along with OSH analysis tools, to study and analyze the safety situation in the Petroleum industry.
- To propose recommendations that can help improve OSH programs in the Petroleum industry, which hopefully will lead to much lower incident rates.
- To propose recommendations that can ensure the sustainability of suggested improvements to the OSH safety programs.

Business case:

OSH improvement and sustainability studies are very important not only from a human and ethical point of view, where the value of human life is always a top priority, but also very important from a financial point of view. For example, if an employee gets hurt, the company has to take care of hospital bills, compensation, wages while the employee is recovering, the direct damaged assets, in addition to the fines and penalties. The reputation of any company that does not take OSH very seriously can also be damaged, which can have serious consequences for any workplace. Thus, taking care of safety decreases losses and increases profits, making the OSH program justified economically as well as ethically.

Scope:

- **In scope**:
  - Studying and analyzing the OSH situation in the Petroleum industry.

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- Figuring out the root cause of some common OSH problems to eliminate or at least reduce them.
- Suggest improvements to OSH programs in the Petroleum industry in addition to sustainability recommendations.

- **Out of scope:**
  - Following up with the implementations (this might be a point for future research)
  - Hiring and training new employees

The SIPOC analysis, presented in Table 1, mapped the key components of the safety management process, including the suppliers, the input, the process, the output, and customers, where the methodology followed in this work is again the six-sigma methodology along with the hazard analysis techniques.

Table 1. SIPOC Analysis of Safety Management Process Components in Petroleum Operations

SUPPLIER	INPUT	PROCESS	OUTPUT	CUSTOMER
Petroleum companies	Data about injuries and operations	Drilling operations	Improved OSH program	Petroleum companies (external)
				OSH Team (internal)

4.2. Measure Phase Results

Quantitative analysis of accident data revealed certain patterns in incident distribution. The distribution of incidents by type across departments is shown in Table 2, highlighting the concentration of accidents in specific operational areas (Manikumar, D. et al., 2024).

Table 2. Incident Type

Incident Type	Construction	Not Specified	Drilling	Exploration	Production
Caught in, under or between	1	0	3	1	3
Explosions or burns	0	0	1	0	1
Fall from height	1	0	0	0	0
Fatigue and health issues	0	0	0	1	0
Overexertion and strain	0	0	1	0	0
Struck by	0	1	8	0	0

The Pareto analysis results, depicted in Figure 1, revealed that drilling operations accounted for 59.10% of all incidents, while production departments contributed 18.20%. Together, these two departments represented 77.30% of total incidents, establishing clear priority areas for intervention.

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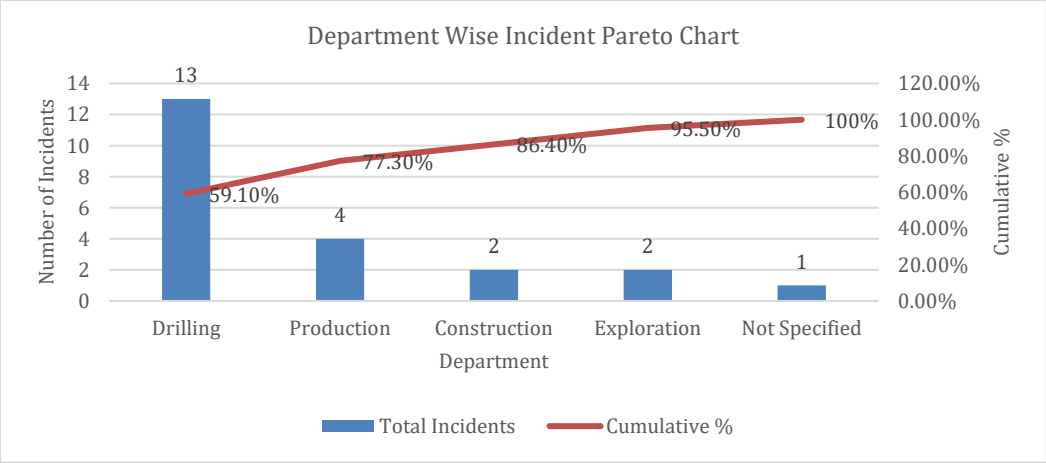

Figure 1. Department-Wise Incident Pareto Chart

Figure 4 presents a Pareto analysis of workplace accident types, illustrating both the frequency of incidents and their cumulative percentage. The chart demonstrates that "struck by" incidents account for 16 cases (44.44% of total incidents), followed by "caught in, under, or between" accidents with 15 cases (reaching 86.11% cumulatively).

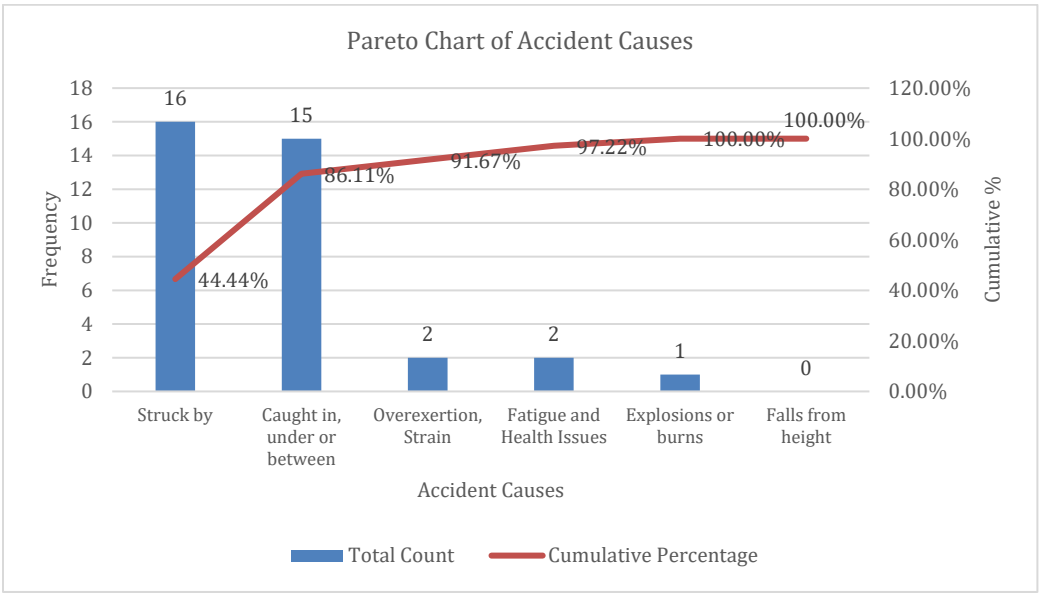

Figure 2. Pareto Analysis of Workplace Accident Types

4.3. Analyze and Improve Phases Results

The root cause analysis employed multiple analytical tools to understand incident causation. The fishbone diagram analysis (Figure 3) revealed six major categories of causal factors for struck-by incidents in drilling operations, encompassing machine, environment, material, measurement, method, and manpower-related issues. Each category identified specific contributing factors requiring attention.

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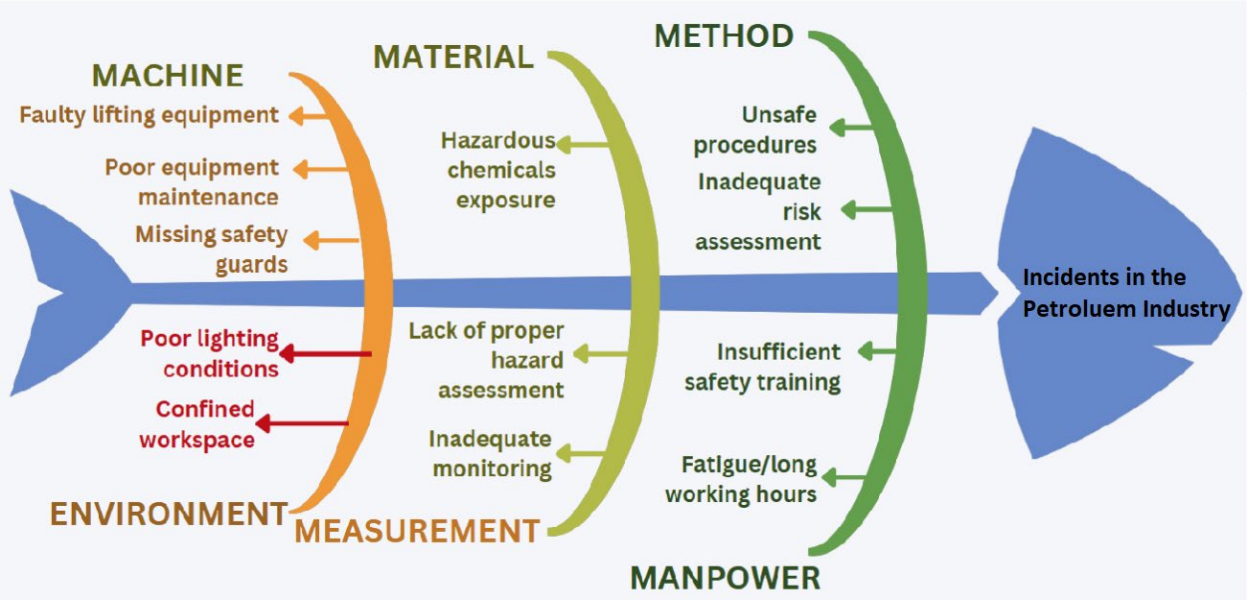

Figure 3. Fishbone Diagram Analysis of Struck-by Incidents in Drilling Operations

The Fault Tree Analysis for struck-by incidents in drilling operations (Figure 4) demonstrated the interrelation between equipment factors, work environment conditions, and human factors. This analysis highlighted how various combinations of basic events could lead to accident occurrence.

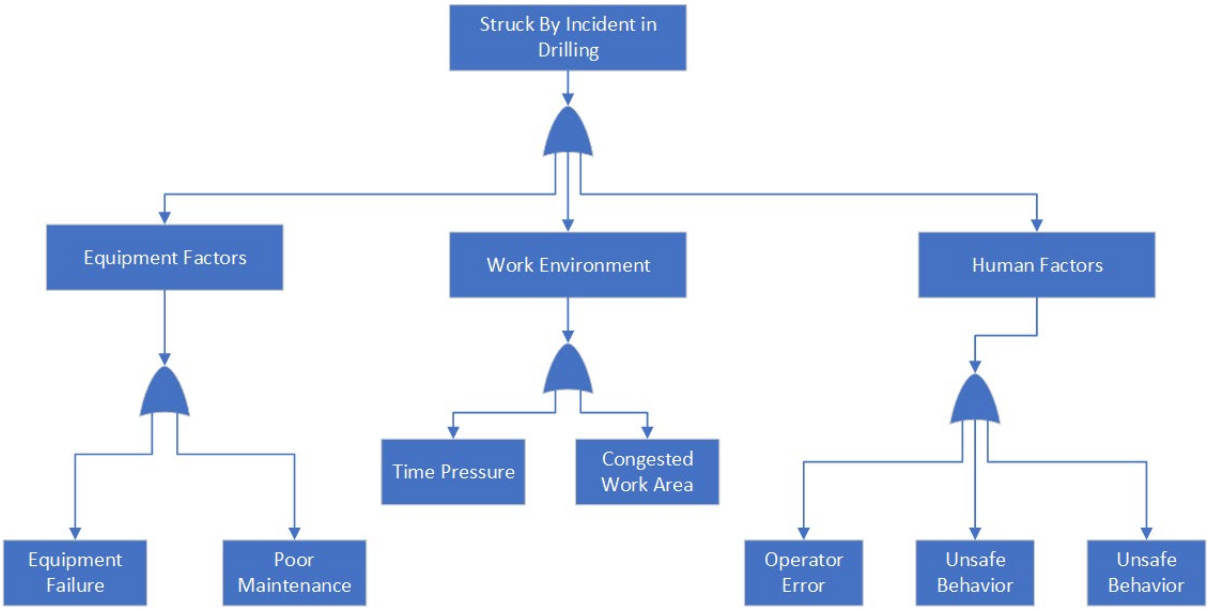

Figure 4. Fault Tree Analysis for Struck-By Incidents in Drilling Operations

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The HAZOP analysis results, presented in Table 3 and Table 4, provided detailed insights into potential process deviations and their consequences in both drilling and production systems. The analysis identified critical control points and necessary safety measures for various operational components.

Table 3. HAZOP Analysis of Critical Drilling Systems and Components

System/Process Component	Factor Analyzed	Guide-word	Resulting Difference	Potential Problem	Recommended Remedy
Mud Pump	Flow Rate	NO	No circulation of drilling fluid	Loss of cooling, cuttings transport, and well pressure control	Install redundant pump system, pressure/flow monitors, automated alarms
Drilling Fluid Lines	Pressure	MORE	Pressure exceeds system design	Equipment damage, formation fracturing, loss of well integrity	Install pressure relief valves, additional monitoring points, automated shutdown systems
Return Line System	Flow	LESS	Reduced return flow volume	Lost circulation, potential well kick, formation damage	Implement automated pit volume monitoring, enhance well control procedures, install flow meters

Table 4 presents a detailed analysis of these production systems.

Table 4. HAZOP Analysis of Production Systems and Components

System/Process Component	Factor Analyzed	Guide-word	Resulting Difference	Potential Problem	Recommended Remedy
Wellhead Control System	Pressure	MORE	Pressure exceeds design limits	Wellhead seal failure, blowout potential, equipment damage	Install high-pressure shutdown system, pressure relief valves, regular pressure testing and monitoring
Separation Vessel	Level	HIGH	Liquid level above normal	Carryover of liquids to gas outlet, vessel overflow, inefficient separation	Install level control valves, high-level alarms, automated shutdown system, regular maintenance of level sensors
Gas Compressor	Flow	NO	Loss of gas compression	Process shutdown, flaring, loss of production	Install backup compressor, condition monitoring system, preventive maintenance program
Production Pipeline	Temperature	LESS	Temperature below design minimum	Hydrate formation, wax deposition, flow restriction	Install heating system, chemical injection points, temperature monitoring and control system

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Control Valve	Operation	REVERSE	Reverse flow through valve	Backflow contamination, process upset, equipment damage	Install check valves, flow meters, valve position indicators, automated emergency shutdown
Storage Tank	Level	MORE	Overfilling of tank	Tank overflow, environmental spill, fire hazard	Install high-level alarms, overflow protection, secondary containment, level monitoring system

The Job Safety Analysis results (Table 5) broke down drilling operations into specific tasks, identifying associated hazards and recommending appropriate control measures for each step of the process.

Table 5. Job Safety Analysis (JSA) for Drilling Operations

Job Title: Drilling Operator		
Location: Onshore Rig Site		
Sequence of Job Steps	Potential Hazards	Recommended Action or Procedure
1. Rigging Up Equipment	- Dropped objects - Slips, trips, and falls	- Use proper lifting techniques. - Inspect the area for obstacles. - Wear proper PPE.
2. Drilling Operations	- Equipment malfunction - High-pressure systems failure - Line-of-fire incidents	- Conduct pre-operation inspections. - Follow SOPs for high-pressure handling.
3. Adding Drill Pipe to String	- Struck-by hazards - Pinch points - Falling objects	- Use safety pins and clamps. - Avoid standing under hoisted loads.
4. Monitoring Drilling Process	- Exposure to harmful gases (e.g., H2S) - Equipment overheating	- Use gas detection systems. - Follow emergency response protocols.
5. Tripping Out (Removing Drill Pipe)	- Collisions - Heavy lifting injuries	- Use cranes and forklifts correctly. - Train workers on proper lifting techniques.
6. Maintenance of Equipment	- Electrical hazards - Improper lockout/tagout	- Follow lockout/tagout procedures. - Conduct regular equipment checks.
7. Rigging Down Equipment	- Falls from height - Dropped tools or equipment	- Use fall protection equipment. - Conduct a dropped objects survey before starting.

Based on the analytical findings, improvement strategies were developed focusing on the most critical areas identified through the Pareto analysis. The distribution of accidents caused by error type and accident reason guided the development of targeted interventions for specific risk factors. The analysis of workplace accident types demonstrated that addressing struck-by incidents (44.44% of total incidents) and caught-in/between accidents (reaching 86.11% cumulatively) would address the majority of safety concerns.

4.4. Control Phase

The control phase is crucial for any project's success to ensure that the improvements are continuous and not only short-term. This can be achieved in multiple ways:

- Continuous audits of the workplace to ensure that everyone is following proper safety protocols.

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- Regular training sessions for all employees to keep them up to date with occupational safety issues relevant to the petroleum industry. This can be achieved by utilizing internal experts in the field or hiring outside specialists.
- The standardization of processes in the processes performed in petroleum industry to make sure same steps are being performed safely again and again.
- Continuous real-time monitoring of every single accident, including minor accidents and also near misses, even if no damage at all has occurred, to ensure that it will not happen again. Sophisticated technologies like Internet of Things (IoT), including wireless sensor networks (WSN) mentioned above, can play a very important role in achieving that. This monitoring system will help discover and resolve any issues as they arise and as quickly as possible. For example, a simple MATLAB code can be used to visualize this goal, which can be extended and applied with more sophisticated programs and sensor networks in real life. A screenshot of a potential code output is shown below. Control charts like individual-moving range (I-MR) charts and exponentially weighted moving average (EWMA) can be very useful in achieving continuous real-time monitoring. The EWMA charts are especially important in tracking small and sustainable shifts in the incidents, including the negligible ones.

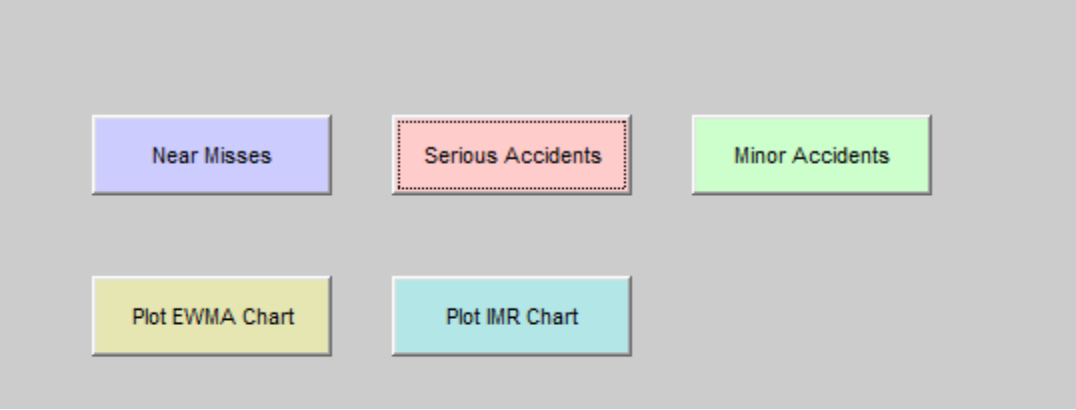

Figure 5. Potential Code

5. Discussion

The results of this research show the importance of quality control in occupational safety and health programs in Kuwait's petroleum sector. Our analysis showed that drilling and production departments are responsible for 77.3 percent of the total incidents, with struck-by incidents (44.44 percent) and caught in between (30.56 percent) being the most common types. This concentration of incidents in particular operational areas suggests that targeted interventions in these departments would yield great safety improvement. Quality control tools, namely Pareto analysis, Fault Tree Analysis, and HAZOP studies, were integrated to develop a systematic way of identifying and addressing safety issues. Thus, using such a hybrid Six Sigma hazard analysis approach can significantly help achieve a sustainable way for safety improvement in the petroleum sector.

6. Conclusion

Based on the extensive analysis of accident data and systematic application of quality control tools, targeted and sustainable safety interventions have been developed. The results of the analyses, for example, the Pareto analysis, suggest that accident rates could be reduced by as much as 50 percent if attention is focused only on drilling and production operations, and more specifically on striking and being caught in or between. Given the practical framework of the proposed solutions, which incorporate technological improvements with better training and standardized procedures, it is shown how occupational safety and health in the petroleum industry can be improved, and how the results can be applied to similar industrial settings. Several recommendations that are mentioned in this paper are feasible and can be applied in real life. For future work, further data can be collected about the major categories of incidents in the Petroleum industry. Having such extensive data can directly lead to even more specific results and recommendations. In addition, the suggested monitoring system can be extended to include sensor networks and other sophisticated technology that can help identify problems as they occur or even give warnings before they appear. Achieving such a system and following up with that can significantly reduce or, in some cases, even eliminate the occurrence of incidents in the Petroleum industry.

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