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# Workplace Accident Analysis in the Algerian Oil and Gas Industry

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PROCESS SAFETY PROGRESS

ORIGINAL ARTICLE

# Workplace accident analysis in the Algerian oil and gas industry

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## Abstract

A total of 42,032 workplace accidents were reported in 2021 by the Algerian National Social Insurance Fund for Salaried Workers in Algeria, of which 38,225 were accidents within the workplace and 3807 were related to traffic accidents or other reasons. Most of these accidents were recorded in the building and construction field, followed by the oil and gas company exploration and drilling, which comes at the forefront of the Sonatrach company. This study aims to analyze accidents in the workplace using quantitative and qualitative methods to determine the corresponding causes. Our study was carried out in collaboration with Sonatrach in south Algeria where information and reports on work accidents from years 2017 to 2021 were collected. Data acquired were classified and analyzed according to the location and time of the accident. Based on the results obtained, we found that the human factor was the main cause of most accidents due to nonrespect of safety procedures and lack of concentration of workers. The results of the analysis suggest implementation of a break time during the afternoon, avoiding long overtime hours, suspending work outside stations during high temperatures periods in July and August as well as suspending work when sandstorms appear in winter.

**KEYWORDS**

causal tree, Ishikawa diagram, occupational health and safety, oil and gas industry, quantitative and qualitative accident analysis, work accidents

## 1 | INTRODUCTION

Workplace accidents have always greatly impacted various fields, especially in the economic and industrial fields. The Algerian National Social Insurance Fund for Salaried Workers in Algeria reported over 42,000 accidents in 2021.[1] The Algerian law of July 1983 provides in Article 6: "it is considered as an accident at work any accident having caused a bodily injury, attributable to a sudden, external cause and occurring within the framework of the employment relationship".[2] Worldwide, workplace accidents are witnessing frightening statistics, according to the International Labor Organization. Every 15 s, a worker dies from a work-related accident or illness. Also, every 15 s 153 workers suffer a work-related accident and 321,000 people die each year from work-related accidents.[3] Despite all efforts to reduce these incidents, they still occur, especially in some industrial countries. In the past three decades, major industrial accidents have occurred, causing deaths and injuries to workers. Among these incidents:

- The Ocean Ranger tragedy in Newfoundland and Labrador, Canada occurred on 15 February 1982 and caused the death of 84 workers. The rig in Ocean Ranger was designed and built by Onshore Drilling and Exploration Company (ODECO) in 1976.[4]
- Sayano-Shushenskaya power station accident in Yenisei River, near Sayanogorsk in Khakassia, Russia. Occurred on 17 August 2009 at 08:13, 75 people were killed and billions of roubles were lost.[5]

- Deep-water Horizon (the Macondo blowout) in the Gulf of Mexico, US, on 20 April 2010 with 11 workers dying, 17 were injured and millions of gallons of oil spilled in the Gulf.[6]
- The Bhopal disaster in Bhopal, Madhya Pradesh, India. The tragedy happened on December 3, 1984, when a toxic methyl isocyanate (MIC) was released from a storage tank property of the Union Carbide India Limited (UCIL) pesticide plant in Bhopal causing the deaths of at least 3787 people.[7]

In Skikda, Algeria, on 19 January 2004, a very strong explosion occurred at 18:40 at the LNG (Liquefied Natural Gas) Liquefaction Complex GL1/K in Skikda, followed by a fire. Three of the six liquefying units in the Complex were severely damaged and subjected to intense fire. The losses include 23 deaths and 74 injured in addition to economic losses and environmental pollution. The causes of the accident and the lessons learned have been reviewed in detail by the authors in References 8 and 9.

Globally, several laws and norms have been used to control and reduce the number of accidents, for example, the OHSAS 18001 standard whose performance was not perfect, according to a study of Reference 10, and replaced in 2021 by ISO 45001. In Algeria, there is Law 88-07 of January 26, 1988, relating to health, safety, and occupational medicine designates the persons responsible (employer and its structures), the consultation bodies (Joint Health and Safety Committee, health and safety inter-company), as well as the implementation structure (Service of health and safety in the workplace). Also, Law 04-20 of 25 December 2004 relates to the prevention of major risks and the management of disasters within the framework of sustainable development. These norms and laws helped institutions to organize work and workers and reduce the number of accidents within these companies.

Accurate studies were carried out to analyze work accidents to avoid them from happening again in the future and benefit from the experiences gained. A. Palali and J. van Ours[11] present an empirical analysis of the determinants of workplace accidents based on an analysis of fatal and nonfatal workplace accidents and road accidents. Also, job safety analysis,[12] which is an efficient proactive measure for safety risk assessment usually used in industrial manufacturing for planning the safest way to perform a task. Moreover, the authors in Reference 13 used Bayesian networks to analyze workplace accidents that involve a high risk of falls from heights places.

These studies aimed to find the main causes of accidents without accusing any parties. Quantitative analyses were usually used to determine the number of accidents, how they occurred, when, and so on. Furthermore, some studies have used qualitative methods such as the cause–effect diagram and Ishikawa (fishbone) diagram to determine the root cause behind the accident. For example, Fishbone Diagrams and Root Cause Analysis were applied to the in-depth analysis of physical security- and cybersecurity-related events that affected the process industry.[14] A quantitative risk evaluation method that combined a risk matrix, fault tree, and fishbone diagram model is proposed in Reference 15 to define the risk level of a spherical tank.

M. Rodgers and R. Oppenheim[16] combine cause-and-effect diagrams with Bayesian belief networks to establish a framework to estimate causal relationships in instances where formal data collection/analysis activities are too costly or impractical which helps to estimate the likelihood of risk scenarios using computer-based simulation. Bayesian networks are widely used for dynamic safety and risk modeling, dynamic risk-based maintenance,[17,18] risk assessment of process industries,[19] and envisaging potential accidents predicting the likelihood of accidents.[20,21]

A comparison of failure mode and effect analysis (FMEA), cause and effect analysis, and a Pareto diagram in conjunction with hazard analysis critical control point (HACCP) are applied to the risk assessment of potato chips manufacturing plant in Reference 22. The same authors[23] made a comparison of ISO22000 analysis with HACCP in salmon processing and packaging where the Ishikawa diagram is used to identify the critical control points.

Root cause analysis based on Ishikawa diagram was applied in Reference 24 to identify, rank, analyze, and categorize the main sources of causes of delays in oil and gas projects. A. Verma and J. Maiti[25] developed a text clustering-based cause and effect analysis methodology based on experts' knowledge of incident data to unfold the root causes behind the incidents in steel plant.

Tortorella et al. in Reference 26 developed a methodology to incorporate lean manufacturing tools in risk management, to reduce work accidents at service companies. They used Ishikawa diagram to analyze the main causes of accidents. Furthermore, A global proposal of prevention approach in cement plants is proposed by Rachid et al.[27] whose purpose is to improve working conditions by technical, organizational, and human solutions to improve the health and safety of employees based on statistical analysis of work accident and cause–effect analysis based on Ishikawa diagram.

In the present paper, a combination of quantitative and qualitative approaches is used to analyze workplace accidents in an oil and gas company. A statistical analysis is firstly applied after gathering and classifying available data, thereafter, Ishikawa diagram and cause–effect diagram are both used to identify the root causes of different accidents. The two methods are very effective educational tools for training and raising awareness of safety because they did not need a specialist to read and understand the diagrams. Both methods are considered posterior analysis methods for preventive purposes that provide a realistic and dynamic map of the accident. The construction of these diagrams depends on group work and encourages dialogue and solidarity. The disadvantage of both methods is that they can only be built after the accident occurs.

## 2 | WORKPLACE METHODOLOGY

The proposed methodology starts with the quantitative assessment obtained from collection of information from the available reports, classifying relevant information, and the identification of the main causes of accident. Then, a qualitative analysis is performed by performing root cause analysis and finished with a set of recommendations to prevent

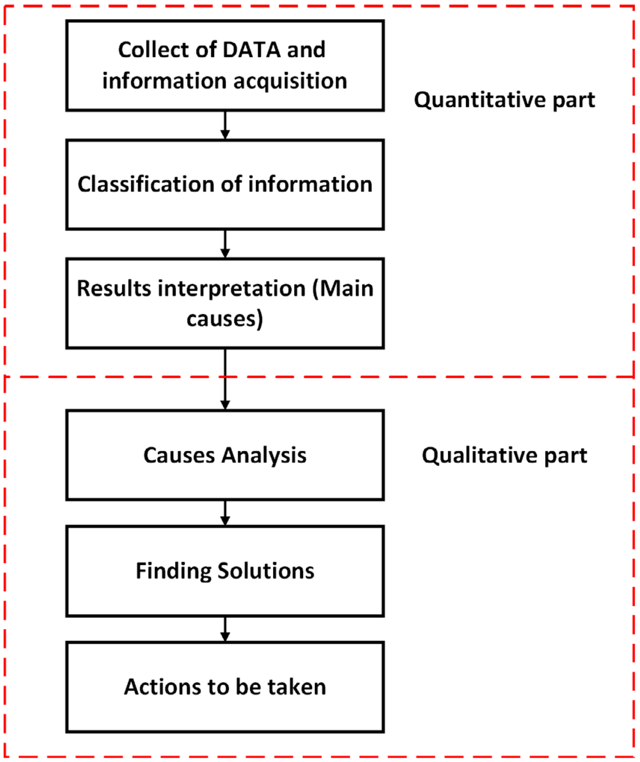



**FIGURE 1** Methodology proposed for work accident analysis

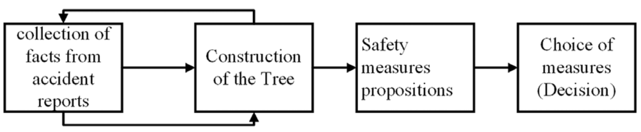



**FIGURE 2** Causal tree construction method

and mitigate consequences of future accidents. Figure 1 shows the steps followed the perform the accidents analysis. This study is a posterior analysis since requires the accident to occur in order to analyze it. Knowing the main causes of past accidents is an essential step for avoiding the repetition of the same or similar situations.

In the quantitative part, we rely on collecting and classifying information over a period of 5 years. In the second stage (qualitative part), two methods are used: Ishikawa diagram (fishbone diagram) and root cause analysis. These two methods are widely used to identify the possible causes of a specific event or, in our case, specific accident.

## 2.1 | Cause-and-effect diagrams

Several methods are often adopted to perform the cause-and-effect diagram such as Bow-tie, Bayesian network, and causal tree. The latter is a practical method of researching the facts that contributed to the occurrence of the accident. As a systemic approach, it considers the accident as the result (the symptom) of a dysfunction within the company. To understand the accident, it is therefore necessary to question all the components of the system (technical, organizational, human) and their interactions.[28] Figure 2 shows the different steps followed to construct the causal tree.

To better understand how to construct the causal tree base on the cause-and-effect diagram, an example of fire and explosion of a liquefied petroleum gas (LPG) spherical storage tank is presented in Figure 3. As we can see, there are two symbols based on the type of events: when the event is ordinary (usual), it is represented by a rectangle, and when an event is unusual, it is represented by an oval or circle. Only the events in the circles need safety measures to avoid or eliminate them.

## 2.2 | Ishikawa/fishbone diagram

The fishbone diagram, also known as Ishikawa diagram, is a cause-and-effect diagram, where starting from specific effect provides the root causes that led to its occurrence.[22] The diagram is used for quality management in manufacturing industries,[29] food industrial processing,[22,23] medical purposes,[30] and also for accident analysis.[27]

In terms of safety and accident analysis, these root causes are usually divided into five main contributors:

- Environment: workstation, physical organization, etc.
- Methods: procedures, information flows, etc.
- Means (machines): equipment, machines, tools, spare parts, etc.
- Working force (labor): human resources, staff qualifications, etc.
- Material: the various consumables used, raw materials, etc.

The Ishikawa diagram starts by defining a problem (an accident in our case) written to the right of the diagram and drawing a horizontal arrow running to it. Thereafter, we choose major categories of causes of the problem (accident) such as methods, machines, materials, etc., and write the categories of causes as branches from the main arrow. In the next step, we gather all the possible causes of the problem by asking "Why does this happen?" and then write each cause as a branch from the appropriate category.

Figure 4 shows an example of a fishbone diagram with the five main causes. It is not necessary that all five causes are present in every incident but each cause can lead to an accident. Depending on the accuracy of the incident report, the number of simultaneous causes presents may change.

# 3 | CASE STUDY

For confidentiality reasons, the name of the regional company is not mentioned and is instead termed "group Sonatrach" throughout this paper. Group Sonatrach is an oil- and gas-producing company that has several oil and gas fields. The station is located approximately 930 km directly south of the capital of Algeria. Our case study focuses on the accidents that occurred in a gas company that contains several operations. These operations include drilling, processing, and transporting

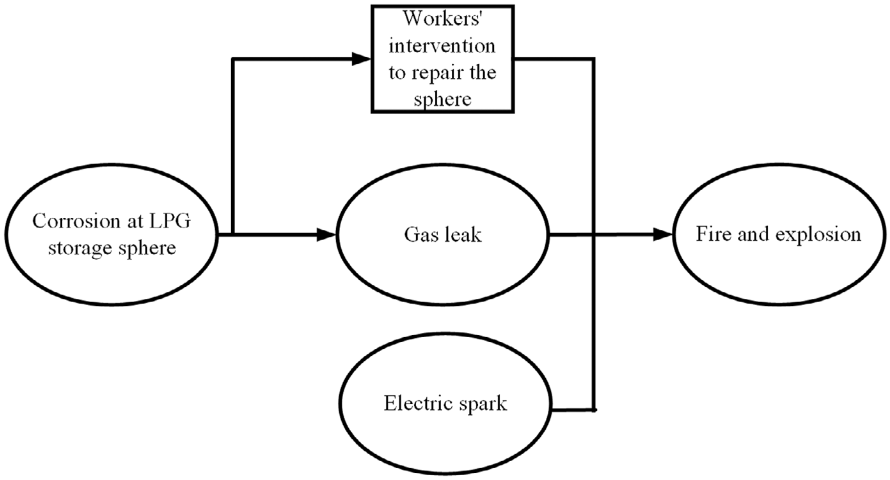



FIGURE 3 Example of LPG spherical storage tank with causal tree

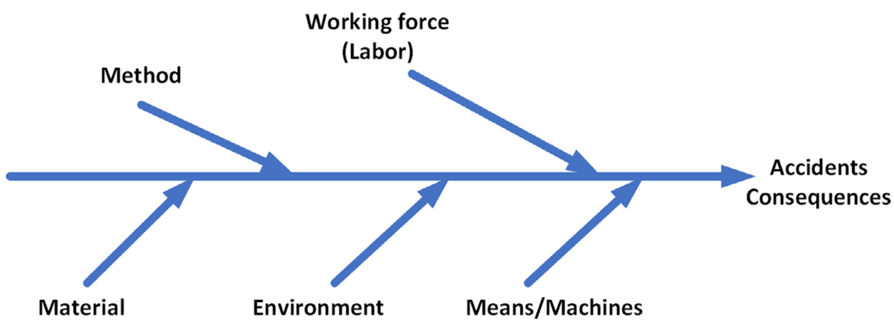



FIGURE 4 Example of an Ishikawa diagram

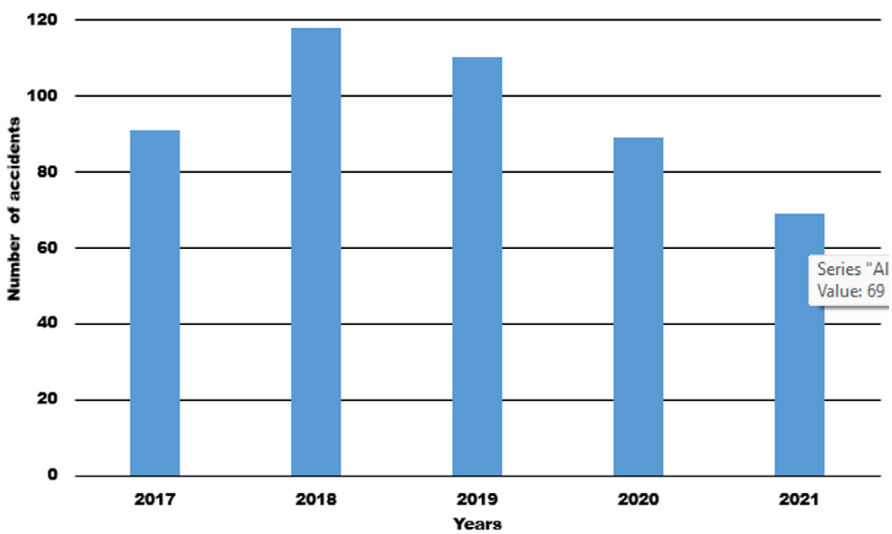



FIGURE 5 Number of workplace accidents during 5 years at group Sonatrach

operations, causing accidents such as falls from heights, vehicle crashes, burns, and electrical shocks.

## 3.1 | Quantitative analysis of workplace accident

Quantitative data based on workplace accident reports from 2017 to early 2021 are used in this paper. During the last 5 years at group Sonatrach a total of 477 work accidents have been recorded and shown in Figure 5. It should be noted that the total number of employees of the enterprise is 1400 workers, where the latter are divided into two groups. The first group is the workers who work in the morning shift only from 7 am until 7 pm. The second group is the workers who work sometimes at night and sometimes during the day for 12 h. It is also worth noting that the number of workers is always divided into two, as the worker, after working for 4 weeks, takes a 4-week vacation to be compensated by another worker.

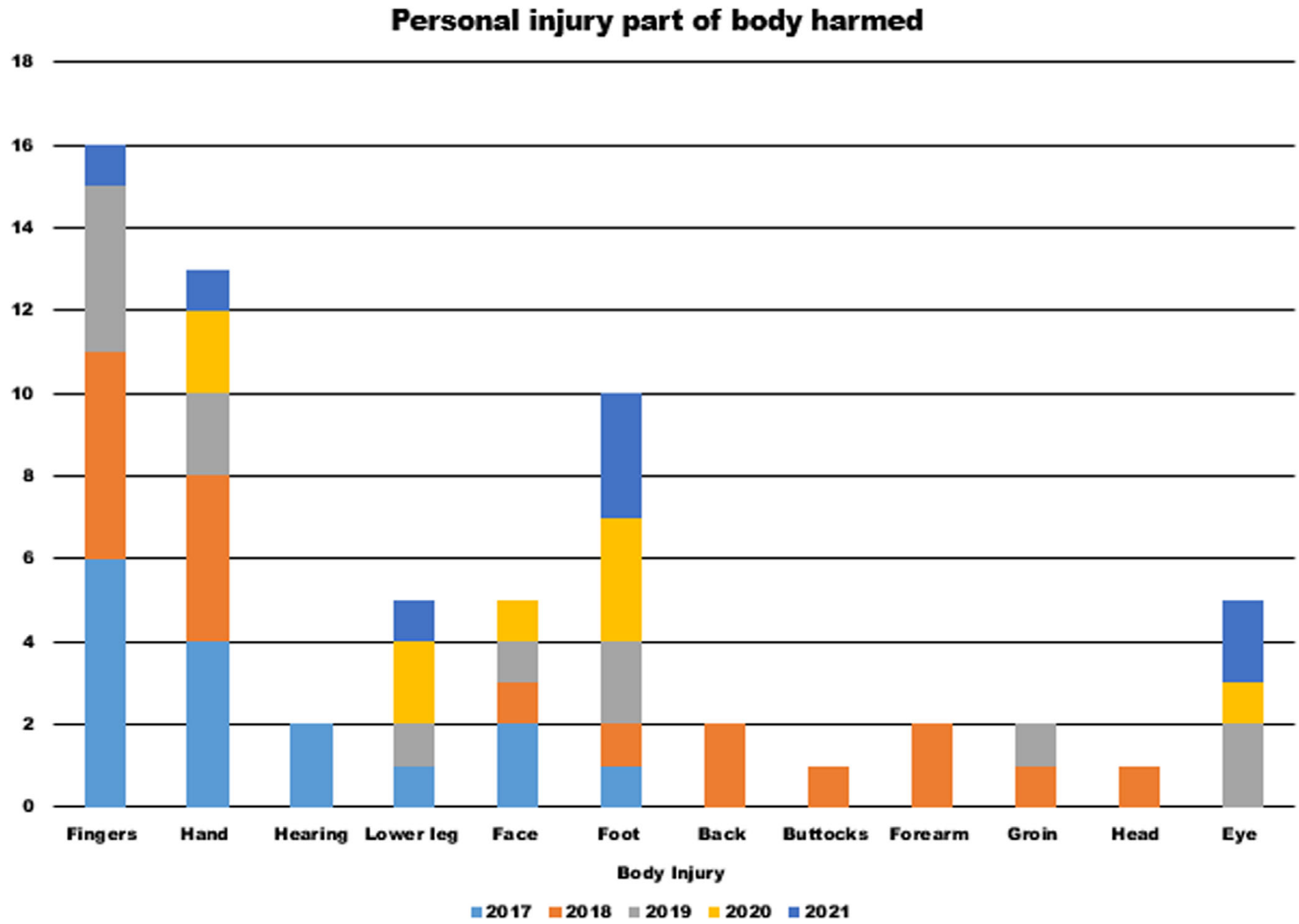



**FIGURE 6** Accident distribution by part of body injured

The number of accidents peaked in 2018 followed by a gradual decrease in the number of accidents and registering 69 accidents in 2021. This is a decrease of 37% compared with 2018. It is true that the company has made efforts to improve the means of safety and protection of workers. This significant drop in the number of accidents is attributed to the following reasons:

- Strength of health, safety, and environment (HSE) team with new recruitments.
- Majority of procedures updated since 2018, with the target of implementing all HSE procedures by 2020.
- Requirement for the contractors to retain experienced personnel (problems occur when contractors bring new staff who need trainings and take time to familiarize themselves with the procedures of the company).
- Training program for all staff initiated in 2017 that identifies the safety needs of every service such as maintenance, HSE, production, etc.
- Likewise, the actions from external Audits ISO 14001 and ISO 45001 oblige the company to train and certify all team leaders and HSEs.
- The restrictions applied to the company and the workers due to the COVID-19 pandemic and subsequent reduction in the number of workers.

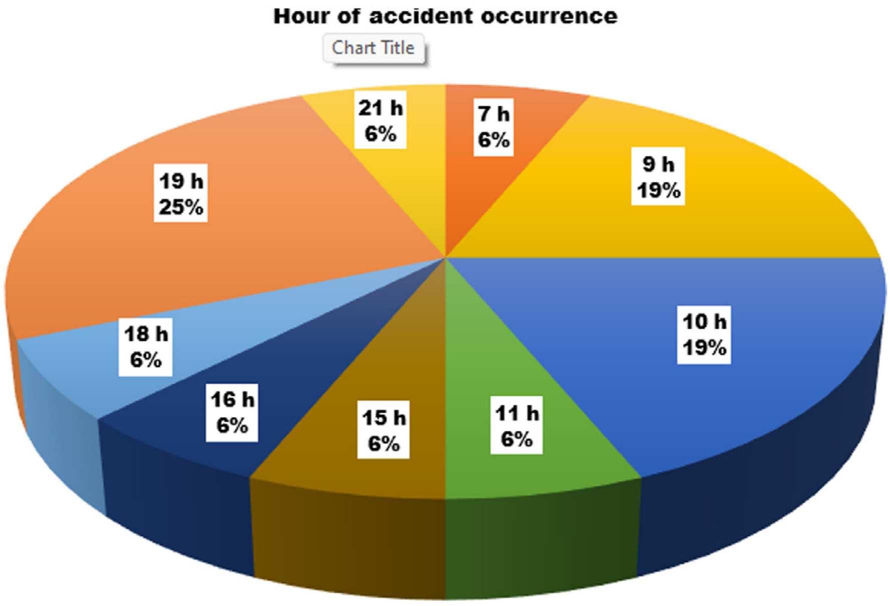
The accidents are then classified depending on the information available in the following categories:

- Time of the accidents.
- The months in which the accidents occurred to identify the season with the huge number of accidents.
- Consequence of the accidents to identify which type of injuries are more likely to occur.

After analyzing the work accident reports, we classified them into three categories such as part of body harmed, time, and month of accident. We tried to classify these accidents according to the age and domain of the workers, but the registered reports do not contain these details.

Figure 6 indicates that the most frequently affected part of the body is fingers, with 17 accidents in the last 5 years representing 37% of the total accidents. This number is followed by hand injuries, with

**FIGURE 7** Distribution according to the time of accident




13 accidents and 25% of total accidents. It is worth noting that the number of accidents reported in Figure 6 is less than the number recorded in Figure 5. This is because some reports are not detailed and not all the exact details are mentioned. Therefore, these statistics only address what was mentioned in these reports without examining their accuracy due to a large number of recorded accidents.

In Figure 6, we also can note that 67% of injuries are centered on the hand, this is a very high rate compared with injuries in other body parts. This is usually due to not using personal protection equipment (specially gloves) because most of the workers cannot do some specialized work such as opening small screws with gloves.

However, even when protective gloves are used, accidents continue to occur as gloves may not have proper protection against chemical and mechanical risks.[31,32] The problem is that the gloves do not protect against shocks such as a hammer blow, nor against injuries such as cuts on the skin or amputation of fingers by an angle grinder.

The work regime in Sonatrach company is 4 weeks work and 4 weeks off. In the weeks of work, they work 13 nights with 12 h shift each. Then, they take a rest day then they work 14 days with 12 h shift each. In Figure 7, a distribution of accidents per time of the day is presented. From Figure 7, we noted that there are two periods in which the number of accidents is significantly higher. The first time period is from 8 until 10 (morning time) with 38% of the accidents, and the second period is from 18 until 19 with 25% of the accident. The former time period is associated with the presence of a large number of workers (around 1000) compared with other periods (between 255 and 820 workers). Furthermore, many of the most challenging works begin in the morning, such as maintenance, cleaning, and operating machinery. This requires a frequent movement of workers from one location to another. In summary, this period represents the busy period of work and the period of maximum production.

The latter period from 18:00–19:00 has an average where the number of workers on site is around 300. The reduced number of workers is due to the fact that the majority of the maintenance workers, electricians, and mechanics leave before 18:00. This time period corresponds to the departure of the morning-shift workers and the entry of the night-shift workers, that is, it is the end of daytime working hours. This period is characterized by a lack of worker concentration, errors, and mistakes that may increase toward the end of a 12 h shift.[33] In addition, older workers fare less well on 12 h shifts (particularly at night).[34] The number of workers over 50 years of age represents 30% of the total number of workers. When the release period approaches, the worker begins to make mistakes such as making hasty decisions, as they start feeling sleepy and tired. Also, the delay of the second group of workers who come to perform night work can cause anxiety and dissatisfaction to the day workers.[35]

It can be seen in Figure 8 that the number of accidents is higher in winter, especially in January. This is due to the bad weather experienced during this period of rain and sandstorms. The desert of Algeria is characterized by a dry climate, hot in summer and cold in winter. In the latter, sandstorms are formed causing many problems such as lack of vision, especially on the roads. During rainy season, although it has little accumulation, it can cause slip and fall accidents. When sandstorms occur, these can cause poor visibility and confusion. All these harsh weather conditions can also increase road accidents and cause bad manipulation of different vehicles and machines.

There is also an increase in the number of accidents in the month of July as can be seen in Figure 8. In fact, Southern Algeria is characterized by high temperature in summer, which can even exceed 50 C° under the shade. This extreme temperature causes sunstroke or heat stroke that can cause damage to the brain and other internal organs. In addition, the higher temperature increases the probability of ignition to gas or gasoline storage tanks, causing fires that lead to burns and fatalities among workers.

Furthermore, the analysis shows a significant decrease in the number of accidents in 2021. This is mainly due to the reduction in the number of workers due to the Corona pandemic and the suspension of most of the construction work outside the stations.

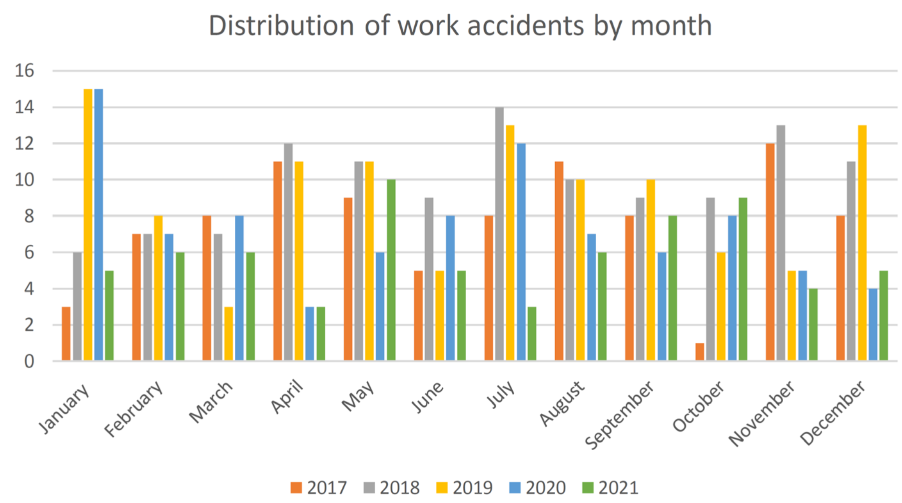



**FIGURE 8** Distribution of work accidents by month

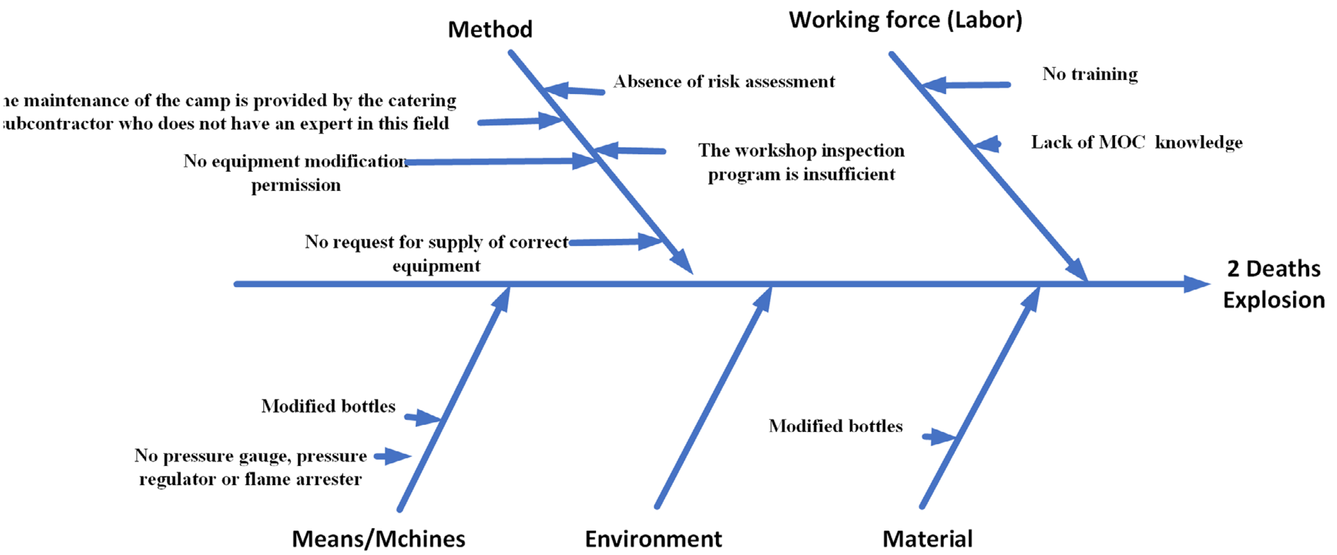



**FIGURE 9** Ishikawa diagram for explosion of oxyacetylene bottle

## 3.2 | Qualitative approaches for workplace accident analysis

After the statistical analysis of the accidents, two incidents were selected for further investigation by qualitative methods. The Ishikawa diagram and causal tree were adopted to find the causes of the accident of the proposed cases and gain information and formulate possible countermeasures.

In this section, we examine one of the most catastrophic accidents in this establishment.

### 3.2.1 | Explosion of an oxyacetylene bottle

The incident occurred on the 27 February 2019 at Sonatrach company, located in the south of Algeria, during an oxyacetylene welding repair. The repair was carried out by an air conditioning technician in the workshop of the accommodation camp. During the repair, a bottle containing acetylene exploded, causing fatal injuries to two workers.

To facilitate the transportation of oxyacetylene welding equipment around the camp, the welding gas was transferred to lightweight refrigerant cylinders to perform the welding. There is no evidence of who modified this equipment. Acetylene, highly explosive when pressurized, was supplied as a solution of acetylene in acetone in low-pressure cylinders. If a cylinder is pressurized, acetylene decomposition reaction does not require the presence of oxygen. No gauges, pressure regulators, or flame arresters were fitted to the modified refrigerant cylinders and their valving was modified to allow filling. The explosion of the container into multiple fragments was caused either by the influx of oxygen, and a flashback on ignition, or by decomposition under the effect of pressure.

Based on the accident report, we built the fishbone diagram as shown in Figure 9 for the accident divided into the principle of five items (environment, methods, means, labor, and material).

*Recommendations based on the Ishikawa diagram*

Table 1 presents the identified actions that can improve the work conditions based on the Ishikawa diagram shown in Figure 9. Note that there are no actions regarding the environment line. This is due to lack of information since we do not have a detailed report about the accident. Moreover, the available report did not provide details about time and environment of the accident.

### 3.2.2 | Contamination with diesel fuel

Sonatrach has a diesel refueling station for refueling vehicles on site. This mainly comprises a retention tank and a pumping station. On 27 November 2020 at 14:15, during the filling of the crude diesel fuel tank, the operator noticed that the tank was overflowing. Excess fuel flowed over the side of the tank and was contained in the dike. Approximately 2.8 $m^3$ of crude diesel fuel was spilled.

During the COVID-19 period, the storage tank was refueled approximately twice a month. This is because of the large number of cases of COVID-19 infections and the necessity of transporting

**TABLE 1** List of improvement measures based on Ishikawa diagram

| 5 items | Mitigation Actions |
|---|---|
| Materials | Use special pressure cylinders for acetylene and oxygen.<br>Protect bottles from direct sunlight and heat sources. |
| Working force/labor | Awareness of the danger presented by oxygen and acetylene is essential when using gas welding.<br>Require HSE training of all workers involved in the hot work. |
| Method | Make a precise risk analysis to identify all the dangers encountered.<br>A risk assessment is needed to rank the risks.<br>The MOC process is essential to ensure the transfer of training and evaluation files.<br>Knowledge/skill of workers should be re-evaluated. |
| Means/Machines | The use of manometer, pressure regulator, and flame arrester is necessary. |
| Environmental | Information not available to assess |

**TABLE 2** List of improvement measures based on root cause analysis

| Event | Recommended measures |
|---|---|
| Operating procedures are not clear.<br>The operator does not follow the correct work procedure. | The operator and the supervisor, with the help of the site HSE engineer, create a workable procedure that considers not only how to perform the task, but also the risks associated with it. |
| No training was provided to the current operator. | Design, develop, and deliver training for this filling operation to all personnel who will operate it. |
| Lack of concentration or inattention (human error). | Provide amenities for the worker, especially with regard to reducing working hours. |
| Electronic level indicator not working. | Add a redundant electronic level indicator. |
| Glass level indicator is uncertain due to weather conditions (dust). | Change the indication on the digital level gauge to a percentage indication so the operator can easily read levels in poor weather conditions. |
| Red warning light on local panel not showing well due to sunlight. | All warning lights must be protected from harsh weather conditions (placed in special covers). |
| High-level audible alarm in off state. | Verify alarm's status periodically. |
| Tank overflow. | Install a pump shut-off system with very high-level detector. |

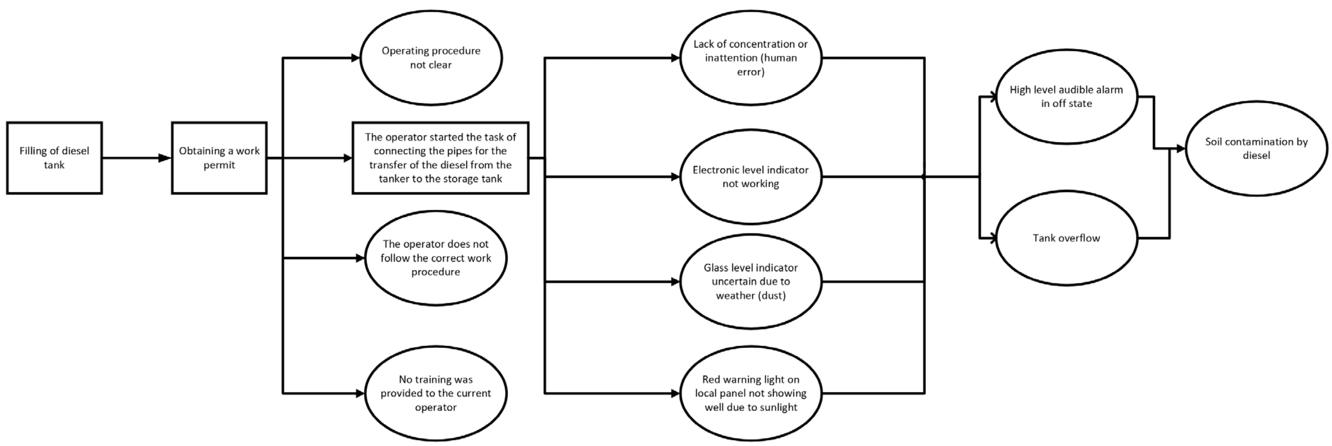



**FIGURE 10** Root cause analysis of soil pollution by diesel fuel spill

workers to the hospital, as the nearest hospital is located about 230 km away. The working capacity of the tanks is approximately 42 $m^3$.

While this system has a low-level sensor to shut down the diesel transfer pump from empty running, it did not have an automated control system for high-level shut down. The level measurement method included a glass site gauge, an electronic level indicator, and a red-light high-level alarm. However, shutdown depended upon an operator to intervene when a high-level audible alarm was initiated. In this case, the high-level alarm was not working at the time of the accident (in the off position). Further sunlight and dusty conditions interfered with seeing the progress of the filling process.

Using the accident report, we constructed a root cause analysis shown in Figure 10 to clarify the sequence that led to the soil contamination by diesel fuel.

*Recommendations based on causal tree analysis*

The events in the circles in the section of root cause analysis are taken into consideration for improvement measures since these events represent unusual actions that led to the accident. These events are shown in Table 2.

## 4 | CONCLUSIONS

This paper highlights the risk of occupational accidents in an oil and gas company where the risks and root causes behind accidents have been identified. Statistical analysis was carried out by gathering and classifying accident reports for 5 years from 2017 until 2021. Thereafter, Ishikawa diagrams and causal trees were used to determine the root causes of specific accidents.

Through this study using both quantitative and qualitative methods, it has been found that most workplace accidents were caused by human error through omissions, lack of concentration, and lack of compliance with safety work procedures. Quantitative methods are characterized by their ease of application, but they suffer from the need for precise reporting, which generally lacks precision in the data. As for qualitative methods, they require a lot of time. We only analyzed two incidents, but the accuracy was high because we were able to find the main causes of the accident.

This research also highlighted the importance of the working conditions and the importance of carefully considering the impact on the safety of tiredness and fatigue in oil and gas industry due to the long hours shift per day, extended hours per week, night shifts work as well harsh environmental conditions due to extreme heat in summer and sandstorms and rain during winter.

### AUTHOR CONTRIBUTIONS

**Hamza Zerrouki:** Conceptualization (lead); formal analysis (lead); funding acquisition (lead); methodology (lead); software (lead); supervision (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Mohamed Djamel Eddine Ghozlane:** Data curation (equal); formal analysis (equal); investigation (lead); resources (lead); software (equal). **Hector Diego Estrada Lugo:** Supervision (supporting); writing – review and editing (supporting). **Edoardo Patelli:** Supervision (supporting); writing – review and editing (supporting).

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