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# Analysis of accidents caused by human factors in the oil and gas industry using the HFACS-OGI framework

Chizaram D. Nwankwo, Andrew O. Arewa, Stephen C. Theophilus and Victor N. Esenowo

Faculty of Engineering, Environment and Computing, Coventry University, Coventry, UK

**ABSTRACT**

*Objectives.* Human factors have been identified as the most common causes of catastrophic accidents in the oil and gas industry. Therefore, this study aims to analyze human causal factors of accidents in the oil and gas industry using the human factors analysis and classification system for the oil and gas industry (HFACS-OGI) framework. *Methods.* This study involved quantitative data collection for 184 accident cases in the oil and gas industry that occurred from 2013 to 2017 from the International Association of Oil and Gas Producers (IOGP) database. The causal factors of these accidents were coded using the HFACS-OGI framework. Accident data were analyzed using descriptive statistics and the $\chi^2$ test. *Results.* Study findings reveal that 23% of all accidents were recorded in 2013. Thirty-two percent of accidents occurred in Asia, while 69% of accidents were recorded in onshore locations. Contractors were involved in 86% of accidents, while 28% of accidents occurred during drilling, workover and well services. The contractor's work environment was the main human factor in 90% of accident cases. *Conclusion.* The HFACS-OGI framework proves to be a vital tool for robust accident analysis of human factors in the oil and gas industry.

**KEYWORDS**
human factors; accidents; HFACS-OGI; oil and gas industry

## 1. Introduction

In the oil and gas industry, human factors have been identified as the most common causes of catastrophic accidents [1]. For instance, the Piper Alpha disaster in 1988 caused 167 fatalities and complete destruction of the offshore platform [2]. The BP Deepwater Horizon blowout in 2010 – one of the greatest oil spills ever recorded – resulted in 11 fatalities and spilled over 4.5 million barrels of crude oil in the US Gulf of Mexico [3]. The BP Texas refinery fire in 2005 caused 15 fatalities and 180 injuries [4]. After investigations, the predominant causal factors identified in each of these incidents were attributed to human errors and operational flaws. Perhaps, most accident investigation tools used in high-risk industries such as the oil and gas industry were not robust enough to curb accident occurrence [5]. Therefore, there is an urgent need for accident investigation to be extended beyond the scope of direct personnel action or inaction [1]. Consequently, Shappell and Wiegmann [1] developed the human factors analysis and classification system (HFACS) primarily for accident investigation in the aviation industry. This framework modeled the Swiss cheese model initially developed by Reason [6], which explained accident causation at active and latent levels including unsafe acts (active), preconditions for unsafe acts (latent), unsafe supervision (latent) and organizational influences (latent). These active and latent categorizations of accidents helped in shifting the focus from individuals to a more systemic approach of underlying contributing causes. Asides from the aviation industry for which the HFACS framework was designed, this framework has also been applied across various industries such as healthcare, railway [7], maritime [8], construction [9] and mining [10]. The current HFACS framework is useful in analyzing human factors related to a lack of operator competency, equipment failure, organizational failures, safety leadership issues, lack of management commitment and poor safety culture [1]. However, it fails to account for contemporary issues such as sabotage and regulatory deficiencies that are particular to the oil and gas industry. Consequently, Theophilus et al. [5] addressed these flaws by developing the human factors analysis and classification system for the oil and gas industry (HFACS-OGI) framework to analyze human causal factors of accidents specifically for the oil and gas industry. Therefore, this study seeks to analyze human causal factors of oil and gas accidents using the HFACS-OGI framework. The first objective of this article was to appraise the trends of accidents in the oil and gas industry. Secondly, the causal factors of these accidents, particularly those that occurred from 2013 to 2017, were analyzed using the HFACS-OGI framework. Lastly, the study concludes by proffering mitigation measures for accidents in the oil and gas industry based on the accident analysis findings.

### 1.1. Accident statistics in the oil and gas industry

A 2016 key performance indicator (KPI) report by the International Association of Oil and Gas Producers (IOGP) [11] reveals a staggering trend of accidents in the oil and gas industry from 2007 to 2016. Although the numbers of fatal accidents and fatalities have been reduced drastically over the years, 54 fatalities were recorded in 40 accidents in 2015 and 50 fatalities were documented in 29 accident cases in 2016. These results therefore reveal that the fatal accident rate (FAR) is on the increase, at 1.5 in 2015 and 1.7 in 2016. This infers that more

**CONTACT** Chizaram D. Nwankwo nwankwo4@uni.coventry.ac.uk; LinkedIn profile: https://www.linkedin.com/in/dr-chizaram-nwankwo/

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fatalities occurred in fewer accidents in 2016 than in 2015. Thus, this raises the question of how robust safety measures are in oil and gas facilities. A study by Tokarski [12] revealed that over 30% of major accidents experienced in the oil and gas industry are triggered by inadequate maintenance. DeWolf [13] opines that piping failures and chemical releases due to poor maintenance are predominant causal factors of 38% of accidents in the Netherlands petroleum industry. The Norwegian Shelf has also witnessed over 242 storage tank accidents largely attributed to poor maintenance and operations [14]. Nonetheless, Darbra et al. [15] argue that external factors like sabotage, design flaws, equipment malfunction, earthquakes and climate change events like flooding and high temperatures should not be overlooked. A study by Katsakiori et al. [16] suggests that the major reason why offshore accidents keep occurring is due to poor asset integrity, as well as inadequate operational discipline and training of staff. Knegtering and Pasman [17] support this claim by asserting that although accidents could be stochastic and unpredictable in nature, the causal factors of most accidents in the oil and gas industry tend to be similar. Singh et al. [2] suggest that a possible reason for this is the failure to properly learn and benchmark from previous accidents. Consequently, Skalle et al. [14] are of the view that integrating human causal factors with technical factors could help in ascertaining root causes of accidents. A study by Norazahar et al. [18] on the BP Deepwater Horizon accident in 2010 revealed that inadequate emergency preparedness, an unsafe environment, the physical ability of workers and poor communication all contributed as human and organizational failures in the accident. While Lees [19] suggests that incompetence is not solely a causal factor of oil and gas accidents, Lindøe et al. [20] avow that accident statistics differ across various sectors in the oil and gas industry. This claim is buttressed by the IOGP [11] in their 2016 KPI report where the upstream, midstream and downstream sectors have distinct accident causal factors and rates. In their report, various sectors in the oil and gas industry such as exploration, drilling, production and construction were all analyzed. The results revealed that in the last 5 years, the exploration sector experienced the highest FAR of 2.9 per 100 million hours worked. Further analysis showed that in 2016 Europe recorded the highest FAR of 5 per 100 million hours worked. These statistics reiterate the importance of thorough analysis human causal factors in accident causation to develop better mitigation measures for accident prevention in the oil and gas industry.

### 1.2. Human factors and the HFACS-OGI framework

The Swiss cheese model by Reason [6] proposed that there are usually latent and underlying factors associated with active causal factors leading up to accidents. Unsafe acts by workers are classified as the active factor, while preconditions for unsafe acts, unsafe supervision and organizational factors fall under the latent factors [1]. However, Baysari et al. [21] argue that this model does not exactly provide sufficient details about active and latent factors, as well as their implementation. Consequently, Shappell and Wiegmann [1] introduced the HFACS as an update to Reason's Swiss cheese model. The HFACS framework provides sufficient details on each of the active and latent causal factors of accidents, hence providing a holistic approach to address human factors [22]. Reason's Swiss cheese model was used as a template to design the HFACS framework; however, various industries have modified it to suit their scope of operations and activities [7]. Figure 1 illustrates the HFACS-OGI framework designed based on technical reports from oil and gas organizations such as the Society of Petroleum Engineers (SPE) [5]. This technical report was tailored toward addressing the issue of process safety incidents (fires, explosions, toxic releases) and safety culture with regards to human factors.

The accident investigation report following the Bhopal disaster in 1984 identified sabotage as the predominant causal factor that led to the incident [23]. Therefore, the HFACS-OGI framework included acts of sabotage in its analytical framework. There are suggestions that contractors experience more accidents in the oil and gas industry since they are unfamiliar with the working environment, compared to company employees [24]. Hence, the HFACS-OGI framework also considered the contractor environment as a key human factor in oil and gas accident analysis. The HFACS framework addressed operators' conditions from the standpoint of the entire team, without taking into account the individual capacity of operators [5]. To ensure the safety of oil and gas operations, individuals and teams are required to possess both interpersonal and technical skills [25]. Consequently, the HFACS-OGI framework included individual and team capacity as a precondition for unsafe acts. It has also been identified that most offshore accidents are caused when process changes are not efficiently planned, communicated and coordinated [26]. Hence, the HFACS-OGI framework included management of change to cater for any changes in the organizational process, operating procedures, temporary processes and process hardware/software. Process safety culture was also included in the HFACS-OGI framework but not considered in the general HFACS framework. This is because of the distinct difference between process safety and occupational safety. While conventional risk management considers occupational hazards such as slips, trips and falls, there is often oversight when it comes to process hazards such as fires, explosions and toxic releases due to loss of containment events [27]. While the HFACS framework has four levels of accident causation, the HFACS-OGI framework extended this to include regulatory and statutory influences that comprise national regulatory frameworks and international industry standards as subcategories.

## 2. Materials and methods

### 2.1. Research design

This study utilized a quantitative research method to systematically examine the human causal factors of accidents in the oil and gas industry. The quantitative method is more effective for larger sample sizes and is better than qualitative methods in yielding unbiased and empirical results [28]. The study predominantly adopted the use of secondary data from the IOGP accident database and journal papers. The information gathered from secondary sources and findings obtained from their data were used as the basis for analyzing oil and gas accidents using the HFACS-OGI framework. The HFACS-OGI framework comprised 25 human factors that were used to code accidents obtained from the IOGP database. Similar to the study by Shirali et al. [29], a binary system was used to codify the causal factors that were present or absent in each of the accident cases, such that 0 = *absent* and 1 = *present*. This helped in identifying the most frequently occurring human causal factors of accidents in the oil and gas industry.

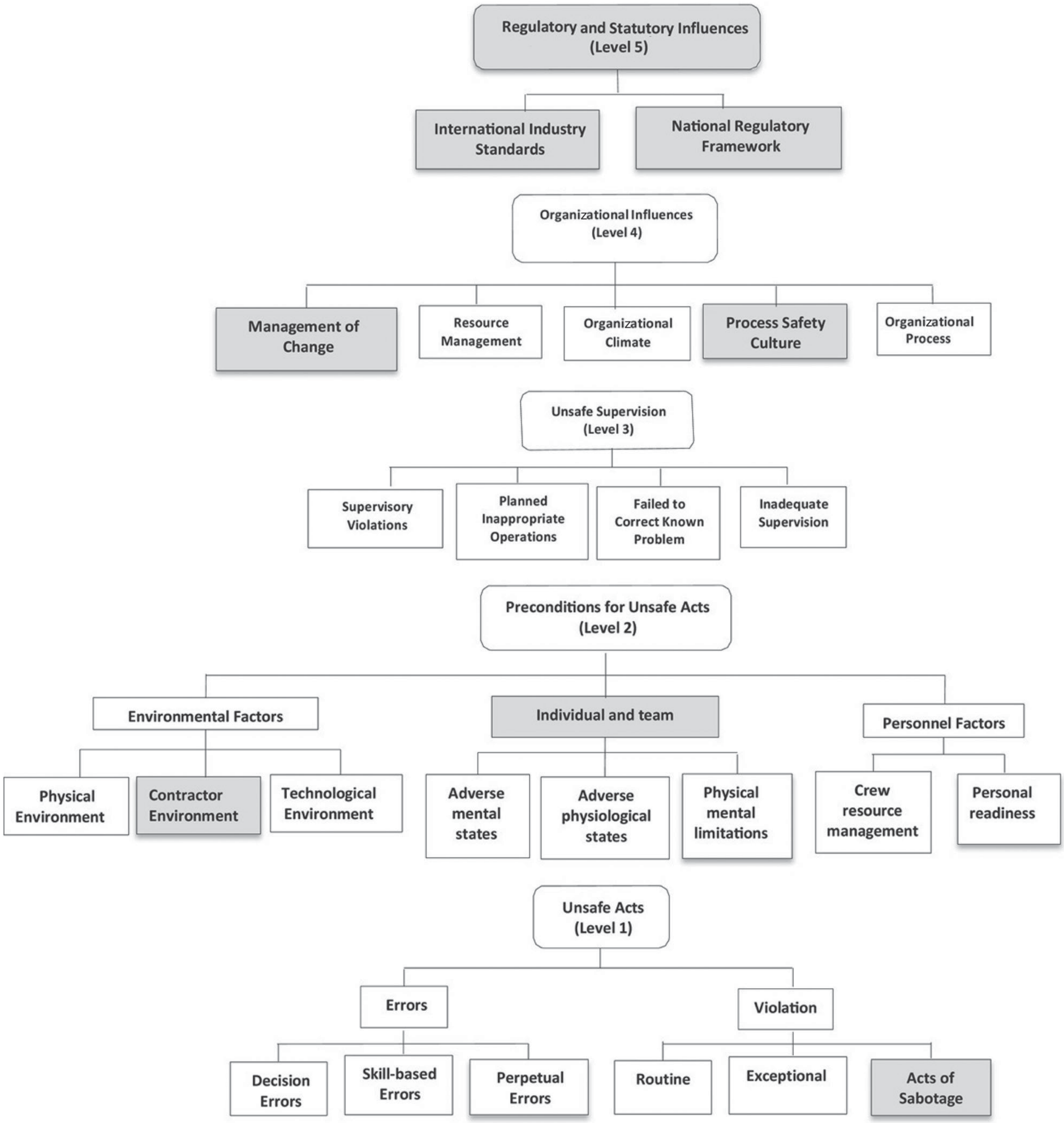


**Figure 1.** HFACS-OGI framework for accident causation [5].

Note: HFACS-OGI = human factors analysis and classification system for the oil and gas industry.

## 2.2. Data collection

The study used the IOGP database as a source of data collection for accidents in the oil and gas industry. The IOGP is the voice of the global upstream industry comprising member countries who produce 40% of the world's oil and gas supply in regions such as Australia, Asia, the Caspian, the Middle East, Europe, Africa and the Americas. They partner with industry regulators to improve safety, environmental and social performance through the sharing of knowledge and statistics by member countries to improve health, safety, environment, security and social responsibility. The IOGP retains an accurate worldwide accident and incident database in the oil and gas industry for over 90 organizations and agencies; hence, their data offer a true reflection of health and safety statistics in the oil and gas industry [30].

The study collected data concerning fatal accidents in the oil and gas industry from 2013 to 2017. These fatal accidents involved any incidents with one or more fatality. The search criteria in the IOGP database were streamlined to accident cases in all oil and gas regions, countries, functions, activities, accident causes, locations and employers. After searching using these criteria, a total of 184 accident cases were identified from 2013 to 2017. Each of these accidents had their incident descriptions, number of fatalities and the events leading up to the accidents. For reference purposes, the search criteria applied to obtain the results are shown in Appendix 1 (see Supplemental data). These data were then collected, exported and collated using Microsoft Excel version 2017. The collected data were grouped into different categories according to year, region, country, fatalities, employer type, location, accident category, operation, incident description and causes. A detailed presentation of the collected and collated data can be found in Appendices 1 and 2 (see Supplemental data).

Also, as shown in Appendices 1–3 (see Supplemental data), an HFACS incident description sheet from the HFACS website? was downloaded and used as a guide to understand what each human factor in the HFACS-OGI framework entailed. For example, skill-based errors in the HFACS-OGI framework was described as:

> Highly practiced behavior that occurs with little or no conscious thought. These 'doing' errors frequently appear as breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgotten intentions, and omitted items in checklists often appear. Even the manner or technique with which one performs a task is included HFACS [31].

Therefore, any accident that had any of these factors highlighted in their incident descriptions on the IOGP database was identified to have been caused by skill-based errors. The same process was repeated for all human factors in each accident, which helped in coding the root causes of the accidents. The entire process of data collection for the study lasted for a period of 1 month.

### 2.3. Data analysis

Trend analysis was used to analyze the coded accident data in order to understand the accident trend in recent years, location, geographical region, worker type, accident category and nature of operation. Descriptive statistics were employed to obtain the percentage frequency of human factor occurrence in all 184 accident cases. The $\chi^2$ test of association was conducted in this study using SPSS version 25.0 to ascertain the degree of association between various levels of accident causation.

## 3. Results

### 3.1. Trend analysis

Figure 2 illustrates the 5-year accident trend in the oil and gas industry from 2013 to 2017. The highest number of 43 accidents occurred in 2013, while the least number of 29 accidents occurred in 2016. Forty-two accidents were recorded in 2014, 40 in 2015 and 30 in 2017. Similarly, the most fatalities of 80 deaths occurred in 2013 while the least fatalities of 33 deaths were recorded in 2017. Also, the FAR showed that the average number of fatalities per accident were highest in 2013 at 1.86, followed by 2016 with 1.72, then 2015 with 1.35, 2017 with 1.10 and 2014 with 1.07. The highest number of accidents and fatalities were recorded in 2013, and this year also had the highest average number of fatalities recorded in each accident. Hence, the FAR provides a better yardstick for ascertaining the trends of fatal accidents [11]. A linear trend line was also used to project future trends of oil and gas accidents, and showed a steady decrease in the number of oil and gas accidents. However, judging by the line regression $R^2$ value of 0.1463 (which becomes more accurate as it tends toward 1), this trend line may not be exactly accurate in its predictions [32]. A major reason for this could be the unpredictable and stochastic nature of accident occurrence, thereby implying that there may not necessarily be a decrease in oil and gas accidents in the future as predicted by the trendline, especially if adequate mitigation measures are not put in place [33].

### 3.2. Descriptive statistics

Table 1 presents the IOGP accident data categorized according to accident trends, location, worker type, accident category, nature of operations and human factor analysis. The accidents in this study were also analyzed accordingly basing on operating regions across the globe. Asia recorded 59 accidents, North America 48 accidents, Africa 31 accidents, Europe 25 accidents, South and Central America 15 accidents and Australasia 6 accidents. While the onshore regions recorded 69% of accidents from 2013 to 2017, offshore locations witnessed 31% of accidents. The numbers of workers involved in oil and gas accidents during this period were also analyzed according to their roles; either company or contract staff. A total 86% of accident cases were recorded among contractor workers, while 14% of accidents involved company workers. Under the accident categories, the most predominant accident was 'struck by', in which operators were hit by equipment in 31%

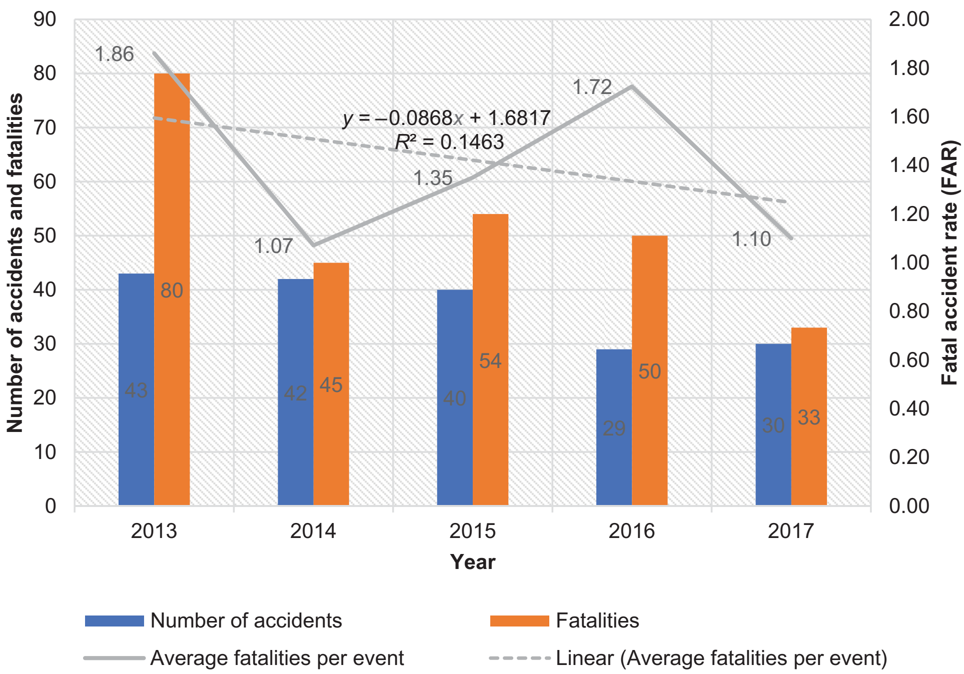


**Figure 2.** Trend analysis showing the number of accidents, fatalities and fatal accident rates of oil and gas accidents from 2013 to 2017.

**Table 1.** Descriptive statistics of International Association of Oil and Gas Producers (IOGP) accident data collected from 2013 to 2017.

| | Oil and gas region | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Africa | | | | | Asia | | | | | Australasia | | | | | Europe | | | | | North, South and Central America | | | | |
| Variable | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 |
| Accident trends | | | | | | | | | | | | | | | | | | | | | | | | | |
| Number of accidents | 9 | 5 | 7 | 4 | 6 | 11 | 9 | 10 | 17 | 12 | 0 | 2 | 1 | 2 | 1 | 8 | 7 | 7 | 2 | 1 | 15 | 19 | 15 | 4 | 10 |
| Fatalities | 27 | 5 | 10 | 10 | 6 | 12 | 10 | 13 | 18 | 12 | 0 | 2 | 1 | 3 | 1 | 12 | 7 | 8 | 14 | 2 | 29 | 21 | 22 | 5 | 12 |
| Average fatalities per accident | 3 | 1 | 1.4 | 2.5 | 1 | 1.1 | 1.1 | 1.3 | 1.1 | 1 | 0 | 1 | 1 | 1.5 | 1 | 1.5 | 1 | 1.1 | 7 | 2 | 1.9 | 1.1 | 1.5 | 1.3 | 1.2 |
| Location | | | | | | | | | | | | | | | | | | | | | | | | | |
| Onshore | 5 | 3 | 6 | 3 | 2 | 8 | 4 | 8 | 14 | 11 | 0 | 2 | 0 | 2 | 1 | 6 | 6 | 6 | 1 | 1 | 7 | 14 | 6 | 3 | 8 |
| Offshore | 4 | 2 | 1 | 1 | 4 | 3 | 5 | 2 | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 1 | 0 | 8 | 5 | 9 | 1 | 2 |
| Worker type | | | | | | | | | | | | | | | | | | | | | | | | | |
| Company | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 1 | 0 | 3 | 1 | 2 | 1 | 1 |
| Contractor | 8 | 5 | 6 | 4 | 5 | 11 | 9 | 9 | 16 | 7 | 0 | 2 | 1 | 2 | 1 | 6 | 5 | 5 | 1 | 1 | 12 | 18 | 13 | 3 | 9 |
| Accident category | | | | | | | | | | | | | | | | | | | | | | | | | |
| Assault or violent act | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aviation accident | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Caught in, under or between | 1 | 2 | 1 | 0 | 2 | 3 | 0 | 2 | 4 | 5 | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 2 | 0 | 0 | 1 | 5 | 5 | 0 | 2 |
| Confined space | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Cut, puncture or scrape | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Electric shock | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Explosion or burns | 0 | 0 | 0 | 2 | 1 | 2 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 1 | 4 | 4 | 2 | 2 |
| Exposure to noise, chemical, biological or vibration | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Fall from height | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 3 | 2 | 0 | 1 | 0 |
| Other | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| Overexertion, strain | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

(*continued*).

**Table 1.** Continued.

| | Oil and gas region | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Africa | | | | | Asia | | | | | Australasia | | | | | Europe | | | | | North, South and Central America | | | | |
| Variable | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 |
| Pressure release | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 0 |
| Struck by | 3 | 3 | 3 | 1 | 0 | 3 | 3 | 4 | 7 | 7 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 1 | 0 | 1 | 7 | 3 | 1 | 5 |
| Water-related, drowning | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 |
| Nature of operations | | | | | | | | | | | | | | | | | | | | | | | | | |
| Construction, commissioning, decommissioning | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 3 | 1 | 0 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 2 | 2 | 2 | 0 | 0 |
| Diving, subsea, ROV | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Drilling, workover, well services | 3 | 1 | 0 | 0 | 7 | 4 | 1 | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 3 | 9 | 2 | 2 | 4 |
| Lifting, crane, rigging, deck operations | 1 | 1 | 1 | 1 | 4 | 0 | 2 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 3 | 2 | 1 | 2 |
| Maintenance, inspection, testing | 2 | 0 | 0 | 1 | 4 | 1 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 1 | 4 | 1 | 1 | 0 | 1 |
| Office, warehouse, accommodation, catering | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Production operations | 1 | 0 | 2 | 1 | 5 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 2 | 2 | 1 | 1 |
| Seismic survey operations | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| Transport – air | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Transport – land | 0 | 2 | 1 | 0 | 3 | 4 | 3 | 4 | 4 | 4 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 2 |
| Transport – water | 1 | 0 | 1 | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Unspecified | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 2 | 0 | 0 |
| Unsafe acts (%) | | | | | | | | | | | | | | | | | | | | | | | | | |
| Skill-based error | 5 | 4 | 2 | 2 | 4 | 4 | 6 | 3 | 10 | 12 | 0 | 1 | 1 | 2 | 1 | 4 | 2 | 1 | 1 | 0 | 9 | 7 | 6 | 3 | 8 |
| Decision error | 4 | 1 | 0 | 0 | 0 | 7 | 2 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 6 | 1 | 1 | 0 | 0 | 6 | 2 | 2 | 0 | 1 |
| Perceptual error | 3 | 2 | 1 | 0 | 1 | 2 | 4 | 2 | 2 | 2 | 0 | 2 | 1 | 0 | 0 | 6 | 1 | 0 | 0 | 0 | 7 | 4 | 5 | 0 | 1 |
| Routine violation | 5 | 1 | 2 | 2 | 4 | 7 | 1 | 4 | 10 | 12 | 0 | 1 | 0 | 1 | 1 | 4 | 2 | 4 | 1 | 0 | 5 | 8 | 5 | 4 | 8 |
| Exceptional violation | 4 | 3 | 0 | 0 | 0 | 7 | 4 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 5 | 1 | 3 | 0 | 0 | 7 | 8 | 2 | 0 | 0 |
| Acts of sabotage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 |
| Preconditions for unsafe acts (%) | | | | | | | | | | | | | | | | | | | | | | | | | |
| Physical environment | 3 | 1 | 1 | 2 | 4 | 5 | 4 | 0 | 11 | 11 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 0 | 6 | 8 | 3 | 4 | 8 |

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Contractor environment | 6 | 4 | 7 | 4 | 6 | 8 | 7 | 10 | 17 | 12 | 0 | 1 | 1 | 2 | 1 | 7 | 7 | 6 | 1 | 1 | 14 | 16 | 14 | 4 | 10 |
| Technological environment | 7 | 3 | 5 | 4 | 6 | 8 | 4 | 6 | 16 | 12 | 0 | 1 | 1 | 2 | 1 | 4 | 6 | 7 | 1 | 1 | 10 | 13 | 10 | 4 | 10 |
| Adverse mental state | 0 | 2 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 1 | 3 | 0 | 0 |
| Adverse physiological state | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 2 | 0 | 0 |
| Physical/mental limitations | 2 | 2 | 1 | 2 | 4 | 2 | 6 | 1 | 9 | 12 | 0 | 1 | 1 | 1 | 1 | 4 | 2 | 0 | 1 | 0 | 5 | 6 | 9 | 3 | 8 |
| Crew resource management | 5 | 1 | 3 | 2 | 4 | 5 | 6 | 6 | 11 | 12 | 0 | 1 | 0 | 2 | 1 | 6 | 0 | 5 | 1 | 0 | 10 | 6 | 6 | 4 | 8 |
| Personal readiness | 4 | 1 | 2 | 2 | 4 | 3 | 5 | 6 | 11 | 12 | 0 | 2 | 0 | 2 | 1 | 3 | 1 | 4 | 1 | 0 | 8 | 5 | 9 | 3 | 8 |
| Unsafe supervision (%) | | | | | | | | | | | | | | | | | | | | | | | | | |
| Supervisory violations | 6 | 2 | 0 | 2 | 4 | 4 | 1 | 0 | 9 | 12 | 0 | 0 | 0 | 1 | 1 | 6 | 1 | 1 | 1 | 0 | 6 | 5 | 0 | 4 | 8 |
| Planned inappropriate operations | 6 | 4 | 3 | 0 | 0 | 8 | 5 | 5 | 4 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 2 | 6 | 0 | 0 | 6 | 10 | 6 | 1 | 0 |
| Failed to correct known problem | 4 | 1 | 1 | 2 | 4 | 5 | 2 | 2 | 9 | 12 | 0 | 0 | 0 | 1 | 1 | 3 | 4 | 0 | 1 | 0 | 6 | 7 | 4 | 4 | 8 |
| Inadequate supervision | 5 | 1 | 3 | 0 | 0 | 8 | 6 | 7 | 6 | 1 | 0 | 0 | 0 | 1 | 0 | 7 | 2 | 6 | 0 | 0 | 11 | 11 | 9 | 2 | 1 |
| Management of change | 2 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| Organizational influences (%) | | | | | | | | | | | | | | | | | | | | | | | | | |
| Resource management | 1 | 2 | 0 | 0 | 0 | 1 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 0 | 1 | 5 | 7 | 0 | 0 |
| Organizational climate | 6 | 2 | 3 | 2 | 4 | 7 | 6 | 6 | 10 | 12 | 0 | 2 | 0 | 2 | 1 | 6 | 3 | 6 | 1 | 0 | 9 | 14 | 11 | 4 | 8 |
| Process safety culture | 3 | 1 | 4 | 0 | 0 | 3 | 3 | 3 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 5 | 3 | 4 | 0 | 0 | 10 | 7 | 5 | 0 | 0 |
| Organizational process | 8 | 4 | 7 | 4 | 6 | 11 | 7 | 9 | 16 | 12 | 0 | 1 | 1 | 2 | 1 | 7 | 4 | 5 | 1 | 1 | 14 | 14 | 10 | 4 | 10 |
| Regulatory and statutory influences (%) | | | | | | | | | | | | | | | | | | | | | | | | | |
| International industry standards | 6 | 1 | 1 | 0 | 0 | 5 | 2 | 1 | 3 | 0 | 0 | 1 | 1 | 0 | 0 | 6 | 1 | 1 | 1 | 0 | 6 | 6 | 3 | 1 | 1 |
| National regulatory framework | 6 | 1 | 1 | 0 | 0 | 4 | 2 | 1 | 3 | 0 | 0 | 1 | 1 | 0 | 0 | 4 | 1 | 1 | 1 | 0 | 6 | 6 | 3 | 1 | 1 |

of accidents. Twenty-one percent of accidents involved workers getting caught in, under or between equipment and 14% of accidents were associated with explosions or burns. The operation with the highest number of accidents was drilling, workover and well services, which was recorded in 28% of all accidents. A total of 16% of accidents occurred during land transportation, 12% of accidents were recorded during maintenance, inspection and testing operations, while construction, commissioning and decommissioning activities led to 11% of accidents.

## 3.3. HFACS-OGI analysis

### 3.3.1. Unsafe acts

As illustrated in Figure 3, unsafe acts of oil and gas accidents were analyzed according to their geographical regions. Asia recorded the highest number of 35 accidents caused by skill-based error, followed by 33 in America, 17 in Africa, 8 in Europe and 5 in Australasia. Similarly, decision errors were highest in Asia with 13 accidents, next to 11 in America, 8 in Europe, 5 in Africa and 1 in Australasia. However, America had the highest number of 17 accidents with perceptual error, followed by 12 in Asia, 7 each in Africa and Europe, and 3 in Australasia. Routine violation led to 34 accidents in Asia, 30 in America, 14 in Africa, 11 in Europe and 3 in Australasia. However, exceptional violation led to 17 accidents in America, 13 in Asia, 9 in Europe, 7 in Africa and 2 in Australasia. No accidents were caused by acts of sabotage in Africa, Asia or Australasia; however, Europe recorded one accident and America recorded two accidents.

### 3.3.2. Preconditions for unsafe acts

Figure 4 illustrates oil and gas accidents in various geographical regions caused by preconditions for unsafe acts. The physical environment was responsible for 31 accidents in Asia, 29 in America, 11 in Africa, 6 in Europe and 4 in Australasia. Fifty-eight accidents in America were caused by the contractor environment, 54 in Asia, 27 in Africa, 22 in Europe and 5 in Australasia. Similarly, the technological environment led to 47 accidents in America, 46 in Asia, 25 in Africa, 19 in Europe and 5 in Australasia. In America, adverse mental state led to 8 accidents, 3 in Asia, 2 in Africa and 1 in Europe, and Australasia recorded no incidents. Six accidents in America were caused by adverse physiological state, 3 in Africa, 2 in Europe, 1 in Asia and none in Australasia. Physical/mental limitations were highlighted in 31 accidents in America, 30 in Asia, 11 in Africa, 7 in Europe and 4 in Australasia. However, in Asia, there were 40 accidents caused by crew resource management, 34 in America, 15 in Africa, 12 in Europe and 4 in Australasia. Personal readiness caused 37 accidents in Asia, 33 in America, 13 in Africa, 9 in Europe and 5 in Australasia.

### 3.3.3. Unsafe supervision

Figure 5 illustrates oil and gas accidents in various geographical regions caused by unsafe supervision. Supervisory violations led to 26 accidents in Asia, 23 in America, 14 in Africa, 9 in Europe and 2 in Australasia. However, planned inappropriate operations triggered 23 accidents in America, 22 in Asia, 13 in Africa, 11 in Europe and 2 in Australasia. Failure to correct a known problem was recorded as a causal factor in 30 accidents in Asia, 29 in America, 12 in Africa, 8 in Europe and 2 in Australasia. Inadequate supervision was responsible for 34 accidents in America, 28 in Asia, 15 in Europe, 9 in Africa and 1 in Australasia. Lastly, management of change caused four accidents in Asia and three in each of America, Europe and Africa, and Australasia recorded no accidents.

### 3.3.4. Organizational influences

Figure 6 illustrates oil and gas accidents in various geographical regions caused by organizational influences. Resource management was the cause of 13 accidents in America, 8 in Asia, 5 in Europe, 3 in Africa and none in Australasia. Similarly,

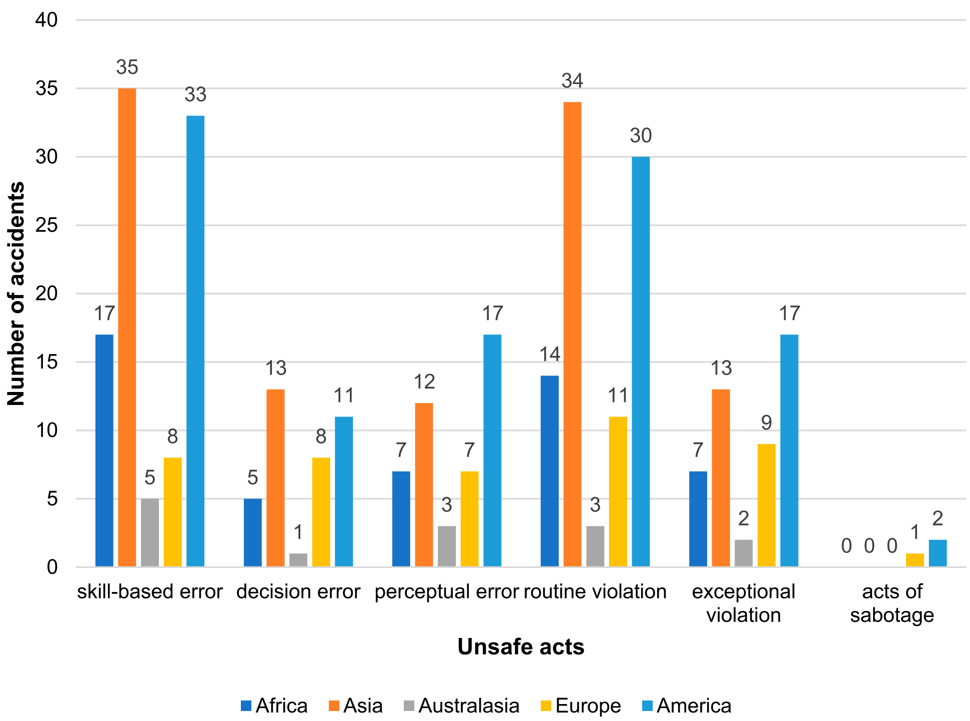


**Figure 3.** Oil and gas accidents caused by unsafe acts using the HFACS-OGI framework.

Note: HFACS-OGI = human factors analysis and classification system for the oil and gas industry.

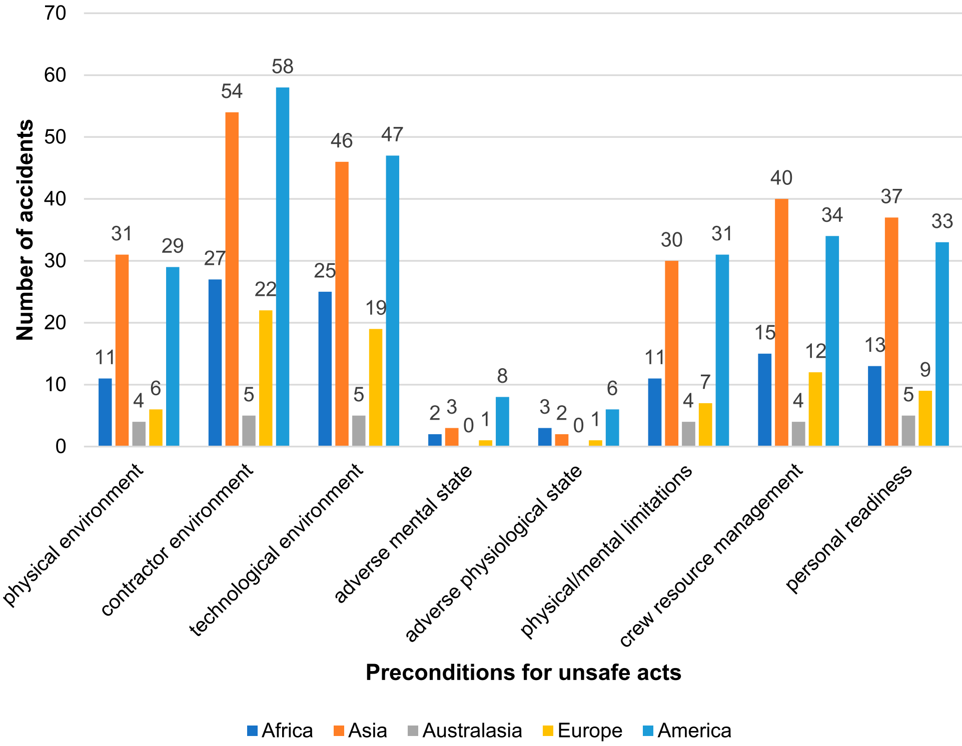


**Figure 4.** Oil and gas accidents caused by preconditions for unsafe acts using the HFACS-OGI framework.
Note: HFACS-OGI = human factors analysis and classification system for the oil and gas industry.

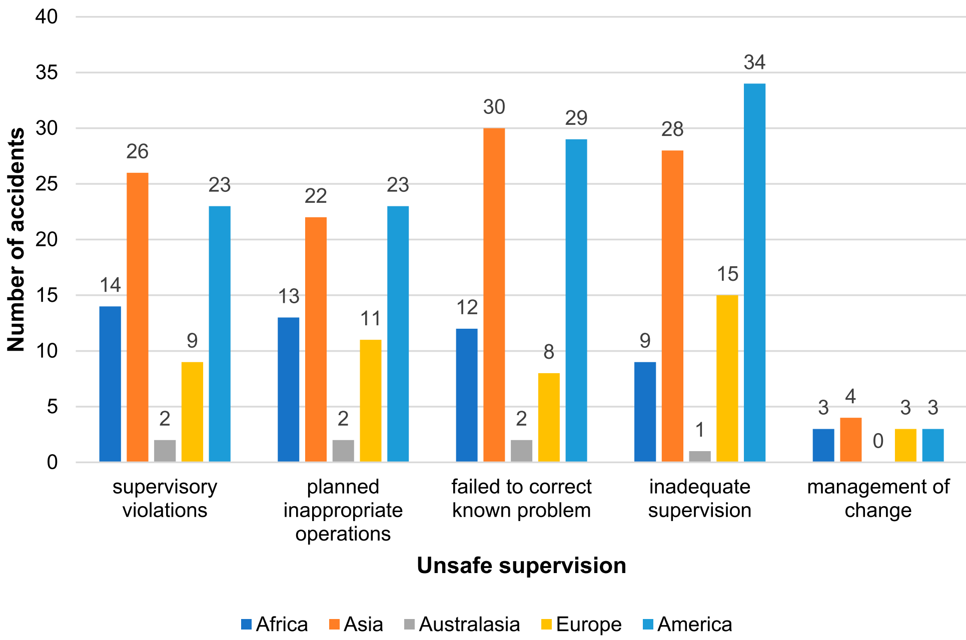


**Figure 5.** Oil and gas accidents caused by unsafe supervision using the HFACS-OGI framework.
Note: HFACS-OGI = human factors analysis and classification system for the oil and gas industry.

the organizational climate triggered 46 accidents in America, 41 in Asia, 17 in Africa, 16 in Europe and 5 in Australasia. However, process safety culture led to 22 accidents in America, 12 in Europe, 11 in Asia, 8 in Africa and 2 in Australasia. Organizational process caused 55 accidents in Asia, 52 in America, 29 in Africa, 18 in Europe and 5 in Australasia.

#### *3.3.5. Regulatory and statutory influences*

Figure 7 illustrates oil and gas accidents in various geographical regions caused by regulatory and statutory influences. International industry standards led to 17 accidents in America, 11 in Asia, 9 in Europe, 8 in Africa and 2 in Australasia. Similarly, the national regulatory framework caused 17 accidents in America, 10 in Asia, 8 in Africa, 7 in Europe and 2 in Australasia.

### *3.4. $X^2$ test of association*

Pearson's $\chi^2$ statistical test was conducted using SPSS version 25.0. An asymptotic significance value less than 0.05 in the $\chi^2$ test indicates that there is a statistically significant relationship between two variables. Table 2 presents strong degrees of association across various latent and active human causal factors in the HFACS-OGI framework, with 0.000–0.033 being

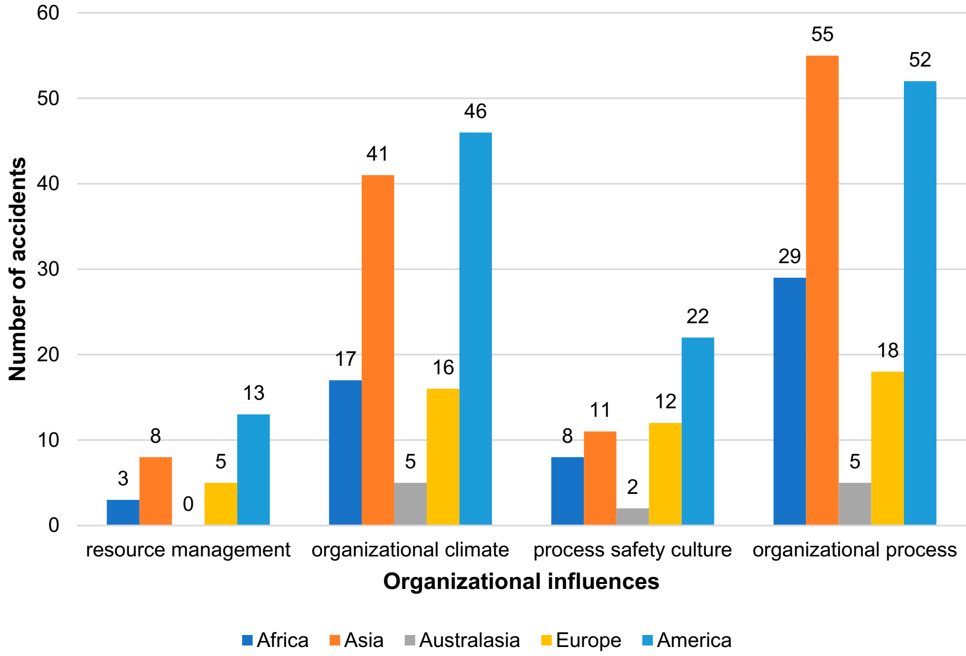


**Figure 6.** Oil and gas accidents caused by organizational influences using the HFACS-OGI framework.
Note: HFACS-OGI = human factors analysis and classification system for the oil and gas industry.

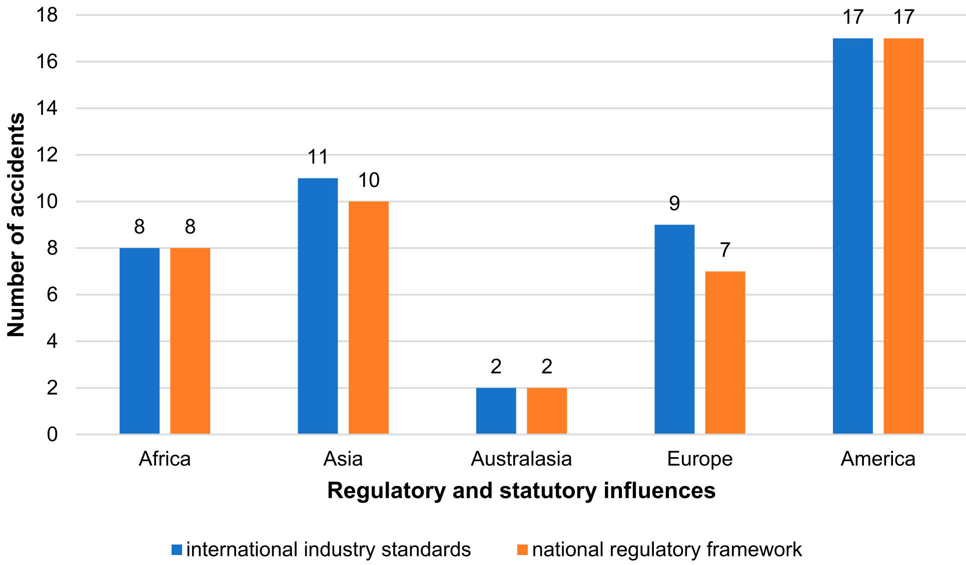


**Figure 7.** Oil and gas accidents caused by regulatory and statutory influences using the HFACS-OGI framework.
Note: HFACS-OGI = human factors analysis and classification system for the oil and gas industry.

the range of values between active and latent human factors. These values indicate strong association between the active and latent human factors in the HFACS-OGI framework. For example, one of the causes of skill-based error from Table 2 is crew resource management, which also had inadequate supervision as one of its causes. Inadequate supervision was further linked to the organizational climate and then flaws in the national regulatory framework. This applies to every other active causal factor that must have been triggered by a long chain of latent factors.

## 4. Discussion

The human factor analysis results reveal that the contractor's environment was the most predominant human causal factor of 90% of oil and gas accidents from 2013 to 2017. The organizational process was also identified in 86% of these accidents, while 77% were attributed to technological environment factors. The organizational climate led to 68% of accidents during this period, while crew resource management was responsible for 57% of accidents. Skilled-based error and personal readiness played a role in 53% of the accidents, while routine violation caused 50%. Therefore, the evidence suggests that the working conditions of contractors put them at risk of exposure to accidents as they are the main operating staff in the oil and gas industry [24]. Also, contractors are usually unfamiliar with the work environment and often have disparities in safety standards and processes from their contracting organizations [34]. This explains why there are huge flaws in the organizational process and technology used in carrying out these operations. Ideally, human factor analysis examines the relationship between man (contractor), machine (technology) and procedure (process) [1]. Hence, these three main facets of human factors were identified as the main causes of accidents in the study.

**Table 2.** $\chi^2$ results showing significant associations between active and latent human factors.

| Significant association across HFACS-OGI categories | Asymptotic significance (two-sided) | Significant association across HFACS-OGI categories | Asymptotic significance (two-sided) |
|---|---|---|---|
| Skill-based error × adverse mental state | 0.011 | Technological environment × supervisory violations | 0.001 |
| Skill-based error × physical/mental limitations | 0.000 | Technological environment × failure to correct problem | 0.003 |
| Skill-based error × crew resource management | 0.000 | Physical/mental limitations × supervisory violations | 0.000 |
| Skill-based error × personal readiness | 0.000 | Physical/mental limitations × planned inappropriate operations | 0.006 |
| Decision error × crew resource management | 0.000 | Physical/mental limitations × Failed to correct problem | 0.000 |
| Perceptual error × adverse mental state | 0.000 | Crew resource management × supervisory violations | 0.000 |
| Perceptual error × adverse physiological state | 0.006 | Crew resource management × failed to correct problem | 0.000 |
| Perceptual error × physical/mental limitations | 0.000 | Crew resource management × inadequate supervision | 0.000 |
| Supervisory violations × organizational climate | 0.000 | Personal readiness × supervisory violations | 0.000 |
| Routine violation × physical environment | 0.000 | Personal readiness × failed to correct problem | 0.001 |
| Routine violation × adverse mental state | 0.005 | Supervisory violations × organizational process | 0.000 |
| Planned inappropriate operations × process safety culture | 0.000 | Planned inappropriate operations × organizational climate | 0.004 |
| Routine violation × physical/mental limitations | 0.000 | Failure to correct problem × organizational climate | 0.000 |
| Routine violation × crew resource management | 0.000 | Inadequate supervision × organizational climate | 0.005 |
| Routine violation × personal readiness | 0.000 | Inadequate supervision × process safety culture | 0.000 |
| Act of sabotage × technological environment | 0.001 | Resource management × international industry standards | 0.033 |
| Inadequate supervision × organizational process | 0.000 | Organizational climate × international industry standards | 0.010 |
| Physical environment × supervisory violations | 0.000 | Process safety culture × international industry standards | 0.000 |
| Physical environment × failed to correct problem | 0.000 | Process safety culture × national regulatory framework | 0.000 |
| – | – | Organizational climate × national regulatory framework | 0.008 |

Note: HFACS-OGI = human factors analysis and classification system for the oil and gas industry.

From the $\chi^2$ analysis, national regulatory frameworks and international regulatory standards were found to be significant root causal factors that triggered flaws in the process safety culture, organizational climate and resource management. Singh et al. [2] assert that the BP Deepwater Horizon blowout in 2010 was caused largely by regulatory deficiencies of the Minerals Management Service (MMS), which was the institution in the USA responsible for licensing and regulation of oil and gas operations.

The poor process safety culture and organizational climate in turn led to inadequate supervision and failing to correct known problems due to a lack of management commitment. Fuller and Vassie [35] identify poor safety culture and climate as key drivers of accident causation in the oil and gas industry. Crew resource management flaws were significantly influenced by inadequate supervision, failure to correct problems and supervisory violations. Besides, Crichton [25] opines that attitude to teamwork and leadership are predominant causal factors among drilling teams in the upstream oil and gas sector. Further evidence from results shows that failure to correct problems, planned inappropriate operations and supervisory violations led to physical and mental limitations in workers. Skalle et al. [14] stress that the complex nature of oil and gas operations affects the ability of workers to effectively conduct safe operations. There were also issues with the physical and technological environments, which were both caused by failure to correct problems and supervisory violations. Ismail et al. [3] posit that the nature of the oil and gas work environment has an extremely high risk profile, thus increasing the likelihood and severity of accidents.

The $\chi^2$ test results also revealed that weaknesses in the technological environment also increased alongside acts of sabotage. Routine violation of procedures was usually caused by a fair number of underlying factors such as lack of personal readiness, poor crew resource management, physical/mental limitations of workers, adverse mental state of employees and unsafe physical environment. Saleh et al. [4] argue that lack of operational discipline could lead to routine violations, especially when there is poor safety climate throughout the organization. Perceptual errors were also jointly caused by an adverse physiological state, an adverse mental state and physical/mental limitations. The risk perception of workers is suggested to be improved by ensuring that competent workers with adequate knowledge, ability, training and experience are selected for specialized tasks [22]. There is evidence that decision errors were triggered by poor crew resource management while skill-based errors were caused by personal readiness, crew resource management, physical/mental limitations and adverse mental state of workers. Routine drills, exercises and refresher trainings are pivotal in ensuring that workers make the right decisions when confronted with emergency situations [18].

## 5. Conclusion

The oil and gas industry has witnessed numerous catastrophic accidents that are undoubtedly attributed to human factors. The IOGP accident database for the oil and gas industry was instrumental to the 184 accident cases used for the study analysis. This study utilized the HFACS-OGI framework as an accident investigation and analysis tool for determining the root causes of accidents. The study findings reveal that 2013 recorded the highest number of 43 accidents. Asia recorded the highest number of 59 accidents, with 127 accidents occurring in onshore locations. Contractors were involved in 159 accidents, while 51 accidents occurred during drilling, workover and well services. The contractor's work environment was the main cause of human factors, accounting for 90% of total accidents analyzed in the study. The human errors identified in this study responsible for accidents caused by contractors may be reduced through the formulation and implementation of policies where contractors are provided with site induction and tours by the contract owner before mobilization to site and job commencement. This will provide site familiarization and relevant information for the contractor to consider when preparing risk assessments and safety plans. The risk assessments and safety plans should be reviewed by the contract owner, which will provide the opportunity for standards and processes of both parties to be aligned and discussed by both parties during a kick-off meeting. The $\chi^2$ results confirm that the root causal factors of these accidents arise from failures in national and international regulations influenced by operating personnel. Another deduction from the study is that the HFACS-OGI framework proved to be a vital tool for robust accident analysis of human factors in the oil and gas industry.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

*Chizaram D. Nwankwo* http://orcid.org/0000-0001-7404-0759
*Andrew O. Arewa* http://orcid.org/0000-0002-8872-5799
*Stephen C. Theophilus* http://orcid.org/0000-0001-6677-2589
*Victor N. Esenowo* http://orcid.org/0000-0002-7947-0165

## References

[1] Shappell SA, Wiegmann DA. A human error approach to aviation accident analysis: the human factors analysis and classification system. Aldershot: Ashgate; 2012.

[2] Singh B, Jukes P, Poblete B, et al. 20 Years on lessons learned from Piper Alpha. The evolution of concurrent and inherently safe design. J Loss Prev Process Ind. 2010;23(6):936–953. doi:10.1016/j.jlp.2010.07.011

[3] Ismail Z, Kong KK, Othman SZ, et al. Evaluating accidents in the offshore drilling of petroleum: regional picture and reducing impact. Measurement. 2014;51:18–33. doi:10.1016/j.measurement.2014.01.027

[4] Saleh JH, Haga RA, Favarò FM, et al. Texas City refinery accident: case study in breakdown of defense-in-depth and violation of the safety–diagnosability principle in design. Eng Failure Anal. 2014;36:121–133. doi:10.1016/j.engfailanal.2013.09.014

[5] Theophilus SC, Esenowo VN, Arewa AO, et al. Human factors analysis and classification system for the oil and gas industry (HFACS-OGI). Reliabil Eng System Saf. 2017;167:168–176. doi:10.1016/j.ress.2017.05.036

[6] Reason J. Human error: models and management. BMJ. 2000;320(7237):768–770. doi:10.1136/bmj.320.7237.768

[7] Reinach S, Viale A. Application of a human error framework to conduct train accident/incident investigations. Accident Anal Prev. 2006;38(2):396–406. doi:10.1016/j.aap.2005.10.013

[8] Chen S-T, Wall A, Davies P, et al. A human and organisational factors (HOFs) analysis method for marine casualties using HFACS – maritime accidents (HFACS-MA). Saf Sci. 2013;60:105–114. doi:10.1016/j.ssci.2013.06.009

[9] Hale A, Walker D, Walters N, et al. Developing the understanding of underlying causes of construction fatal accidents. Saf Sci. 2012;50(10):2020–2027. doi:10.1016/j.ssci.2012.01.018

[10] Patterson JM, Shappell SA. Operator error and system deficiencies: analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS. Accid Anal Prev. 2010;42(4):1379–1385. doi:10.1016/j.aap.2010.02.018

[11] IOGP. Safety performance indicators – 2016 data [Internet]. London: International Association of Oil and Gas Producers; 2017 [cited 2017 Jul 6]. Available from: https://www.iogp.org/bookstore/product/safety-performance-indicators-2016-data/

[12] Tokarski E. The safety professional's role: in support of industrial facilities operations and maintenance (O&M). Bloomington (IN): Xlibris Corporation; 2013.

[13] DeWolf GB. Process safety management in the pipeline industry: parallels and differences between the pipeline integrity management (IMP) rule of the Office of Pipeline Safety and the PSM/RMP approach for process facilities. J Hazardous Mat. 2003;104(1–3):169–192. doi:10.1016/j.jhazmat.2003.08.008

[14] Skalle P, Aamodt A, Laumann K. Integrating human related errors with technical errors to determine causes behind offshore accidents. Saf Sci. 2014;63:179–190. doi:10.1016/j.ssci.2013.11.009

[15] Darbra RM, Palacios A, Casal J. Domino effect in chemical accidents: main features and accident sequences. J Hazardous Mat. 2010;183(1–3):565–573. doi:10.1016/j.jhazmat.2010.07.061

[16] Katsakiori P, Sakellaropoulos G, Manatakis E. Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models. Saf Sci. 2009;47(7):1007–1015. doi:10.1016/j.ssci.2008.11.002

[17] Knegtering B, Pasman H. The safety barometer. J Loss Prev Process Ind. 2013;26(4):821–829. doi:10.1016/j.jlp.2013.02.012

[18] Norazahar N, Khan F, Veitch B, et al. Human and organizational factors assessment of the evacuation operation of BP Deepwater Horizon accident. Saf Sci. 2014;70:41–49. doi:10.1016/j.ssci.2014.05.002

[19] Lees F. Lees' loss prevention in the process industries: hazard identification, assessment and control. Oxford: Butterworth-Heinemann; 2012.

[20] Lindøe PH, Engen OA, Olsen OE. Responses to accidents in different industrial sectors. Saf Sci. 2011;49(1):90–97. doi:10.1016/j.ssci.2009.12.007

[21] Baysari MT, McIntosh AS, Wilson JR. Understanding the human factors contribution to railway accidents and incidents in Australia. Accid Anal Prev. 2008;40(5):1750–1757. doi:10.1016/j.aap.2008.06.013

[22] Aas AL. The human factors assessment and classification system (HFACS) for the oil & gas industry. In International Petroleum Technology Conference, Kuala Lumpur, Malaysia, December 3–5; 2008. Available from: https://doi.org/10.2523/IPTC-12694-MS

[23] Goh YM, Tan S, Lai KC. Learning from the Bhopal disaster to improve process safety management in Singapore. Process Saf Environ Prot. 2015;97:102–108. doi:10.1016/j.psep.2015.02.004

[24] Berends K. Engineering and construction projects for oil and gas processing facilities: contracting, uncertainty and the economics of

information. Energy Policy. 2007;35(8):4260–4270. doi:10.1016/j.enpol.2007.02.027

[25] Crichton M. Attitudes to teamwork, leadership, and stress in oil industry drilling teams. Saf Sci. 2005;43(9):679–696. doi:10.1016/j.ssci.2005.08.020

[26] Zwetsloot GIJM, Gort J, Steijger N, et al. Management of change: lessons learned from staff reductions in the chemical process industry. Saf Sci. 2007;45(7):769–789. doi:10.1016/j.ssci.2006.08.028

[27] Attwood D, Khan F, Veitch B. Offshore oil and gas occupational accidents – what is important? J Loss Prev Process Ind. 2006;19(5):386–3398. doi:10.1016/j.jlp.2005.10.006

[28] Al-Ghamdi AS. Using logistic regression to estimate the influence of accident factors on accident severity. Accid Anal Prev. 2002;34(6):729–741. doi:10.1016/S0001-4575(01)00073-2

[29] Shirali G, Shekari M, Angali KA. Quantitative assessment of resilience safety culture using principal components analysis and numerical taxonomy: a case study in a petrochemical plant. J Loss Prev Process Ind. 2016;40:277–284. doi:10.1016/j.jlp.2016.01.007

[30] IOGP. IOGP fatal incidents [Internet]; London: International Association of Oil and Gas Producers 2019 [cited 2019 Sep 26]. Available from: https://safetyzone.iogp.org/FatalIncidents/fatalincidents.asp

[31] HFACS. HFACS, Inc | Definitions [Internet]. 2014 [cited 2019 Sep 26]. Available from: https://www.hfacs.com/definitions.html

[32] Kirchsteiger C. Trends in accidents, disasters and risk sources in Europe. J Loss Prev Process Ind. 1999;12(1):7–17. doi:10.1016/S0950-4230(98)00033-3

[33] Reiman T, Rollenhagen C, Pietikäinen E, et al. Principles of adaptive management in complex safety-critical organizations. Saf Sci. 2015;71:80–92. doi:10.1016/j.ssci.2014.07.021

[34] Griffiths S. A review and assessment of energy policy in the Middle East and North Africa region. Energy Policy. 2017;102:249–269. doi:10.1016/j.enpol.2016.12.023

[35] Fuller CW, Vassie LH. Benchmarking the safety climates of employees and contractors working within a partnership arrangement: a case study in the offshore oil industry. Bench Int J. 2001;8(5):413–430. doi:10.1108/EUM0000000006386