Safety and Health at Work 10 (2019) 305–313

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Exploring the Contributory Factors of Confined Space Accidents Using Accident Investigation Reports and Semistructured Interviews

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ARTICLE INFO

Article history:
Received 3 November 2018
Received in revised form
21 June 2019
Accepted 24 June 2019
Available online 29 June 2019

Keywords:
Accidents
Confined space
Content analysis
HFACS
Semistructured interview

ABSTRACT

Background: The oil and gas industry is one of the riskiest industries for confined space injuries. This study aimed to understand an overall picture of the causal factors of confined space accidents through analyzing accident reports and the use of a qualitative approach.
Methods: Twenty-one fatal occupational accidents were analyzed according to the Human Factors Analysis and Classification System approach. Furthermore, thirty-three semistructured interviews were conducted with employees in different roles to capture their experiences regarding the contributory factors. The content analyses of the interview transcripts were conducted using MAXQDA software.
Results: Based on accident reports, the largest proportions of causal factors (77%) were attributed to the organizational and supervisory levels, with the predominant influence of the organizational process. We identified 25 contributory factors in confined space accidents that were causal factors outside of the original Human Factors Analysis and Classification System framework. Therefore, modifications were made to deal with factors outside the organization and newly explored causal factors at the organizational level. External Influences as the fifth level considered contributory factors beyond the organization including Laws, Regulations and Standards, Government Policies, Political Influences, and Economic Status categories. Moreover, Contracting/Contract Management and Emergency Management were two extra categories identified at the organizational level.
Conclusions: Preventing confined space accidents requires addressing issues from the organizational to operator level and external influences beyond the organization. The recommended modifications provide a basis for accident investigation and risk analysis, which may be applicable across a broad range of industries and accident types.

1. Introduction

Despite the enormous efforts made toward safety, work-related accidents remain a major concern. Occupational injuries contributed nearly 14% of the 2.78 million work-related deaths in 2017 globally. Furthermore, about 374 million work-related injuries with the consequence of more than 4 days of absence from work occur in a year [1]. Among the types of accidents, those related to confined space activities have the highest ratio of fatalities to lost-time injuries (1:2). Although confined space hazards have been identified during the last decades [2,3] and related safety regulations/standards have been established [e.g., Occupational Safety and Health Administration (OSHA) 29 CFR 1910.146, American National Standards Institute/American Society of Safety Professionals (ANSI/ASSE Z117.1)] [4,5], fatal accidents related to confined spaces still continue. In the oil and gas industry, a wide range of activities are carried out in confined spaces.

There is no universally accepted definition or criterion for classifying a workspace as a confined space [6]. The OSHA regulation defines a confined space as "a space that (1) is large enough for an employee to enter and perform assigned work, (2) has limited means of entry or exit, and (3) is not designed or intended for continuous employee occupancy." In addition, this standard defines a permit-required confined space as "a space that contains or has a potential to contain a hazardous atmosphere, has the potential risk of engulfment by material or an internal configuration that could trap or asphyxiate a worker, or has the risk of other physical hazards" [4].

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2093-7911/$ – see front matter
https://doi.org/10.1016/j.shaw.2019.06.007

Confined space work injuries present across a wide range of sectors. Tanks, vats, pits, manholes, silos, process vessels, boilers, towers, sewers, pipelines, and open top spaces more than 4 feet in depth such as pits or sumps are some instances of confined spaces [7]. Fatalities in confined spaces are due to atmospheric (flammable/explosive, inert gases and simple asphyxiants, oxygen-deficient air, solvents, toxic gases) or physical hazards (engulfment, falls, electrocution, drowning) [8].

Seven main causes of confined space accidents are listed as asphyxiation, poisoning, engulfment, oxygen deficiency, drowning, explosion, and electrocution [9]. Although atmospheric hazards are the mechanism of accidents in up to 62% of the cases and physical hazards contributed for up to 49% of the confined space entry fatalities, the majority of rescuer fatalities (92%) are due to atmospheric hazards [6].

Lack of uniform coding schemes or definitions for confined space accidents among countries creates inconsistencies in confined space–related statistics. Difficulties in the collation of figures from different regulatory authorities likely result in understated statistics [6,10,11].

A review of 4,756 deaths reported in the OSHA database over the period of 1984–1986 showed 146 deaths in confined spaces because of asphyxiation and poisoning and 42 deaths from mechanical asphyxiation due to engulfment. About 12% of the fatalities were rescuers [3]. Other studies, using the National Traumatic Occupational Fatalities and Fatality Assessment and Control Evaluation databases, reported 803 deaths occurred during 1980–1988 in 681 confined space accidents. About 25.5% of fatalities were rescuers [10].

Pettit et al [12], studied confined space accidents using National Traumatic Occupational Fatalities data and identified 670 fatalities in 585 confined space accidents during 1980–1989, with a fatality rate of 0.08 per 100,000 workers. Meyer [13] studied confined space fatalities using Census of Fatal Occupational Injuries data and found 458 fatalities over the period of 1997–2001, with a rate of 0.07 fatalities per 100,000 workers, in which 5.5% of fatalities were attributed to rescuers. In addition, Botti et al [9] identified 51 fatalities in 20 confined space accidents in Italian workplaces between 2001 and 2015, with a rate of 2.25 fatalities per accident. Selman et al [14], found 59 accidents relating to confined spaces in Australia over the period of 2000–2012, with an average rate of 0.05 deaths per 100,000 workers. In another study, Selman et al [6] reported that the rate of confined space deaths for similar industrialized countries could vary between 0.05 and 0.08 deaths per 100,000 workers.

A review of International Association of Oil and Gas Producers safety performance indicator reports indicates 21 deaths in confined spaces (3% of fatalities, excluding vehicle accidents) during the period of 2006–2017 while undertaking construction, commissioning, decommissioning, drilling, well services and maintenance, inspection, and testing activities [15].

Although various causal factors have been reported for confined space accidents, the role of human factors has been highlighted [16]. The role of inadequate risk assessment and challenge with the identification of confined workspaces [2,9,11,17–19], causing inadequate risk management [11], and lack of awareness about the presence and risk of confined spaces are highlighted in studies [20]. Furthermore, not adhering to safety protocols, competency issues, inadequacies relating to supervision, subcontractor management, specific training, work procedures [e.g., permit-to-work (PTW) system], improper respirator use, lack of personal protective equipment (PPE), and not using PPE by the casualty have been addressed to be other causal factors as well [3,10,18]. In addition, Selman et al [11] pointed out the risk takers who are aware of potential risks of entry, but enter the confined spaces for the benefits of completing a task, to be an additional causal factor of the accident. Moreover, lack of a proper rescue plan [10], incorrect emergency response by untrained rescuers [6,13,21], and failure in confined space rescue procedures [11] have been reported as contributory factors.

Accident investigation is carried out to identify the root causes to prevent further accidents. It also provides a foundation for safety guidelines, procedures, and regulations [22]. However, some constraints using accident analysis techniques include failure to understand the multiple and complex causes of accidents because of untrained investigators [22], lack of accident data reliability due to methodological problems [23], and the disregarding of organizational factors, job design, and engineering systems during investigation [24]. Less than 1% of accident reports jointly have addressed the immediate and basic causes [25].

To cope with these constraints, certain studies developed accident cause classification frameworks or models [26,27]. The Human Factors Analysis and Classification System (HFACS) is a human error framework that was originally developed to investigate the human factors of aviation mishaps [27]. It has been developed based on Reason's (Swiss cheese) model [28] and includes a four-level hierarchical structure including organizational, supervisory, preconditions of unsafe acts, and unsafe acts levels. The HFACS has been used and customized for various industries such as mining [29], construction [30], and the oil and gas industry [31]. It can also be used to analyze historical events to identify reoccurring trends in human performance and system deficiencies [32].

In addition, underreporting of accidents due to lack of accident reporting procedures and avoidance of unwanted attention from authorities is pointed out as inhibitors to identify accident causations beyond unsafe acts [33]. Therefore, it is required to consider a comprehensive approach to obtain accident causes in detail. Qualitative interviewing is a technique to capture the voices and unfold the meaning of people's experiences and feelings about the subject matter [34].

This study aims to identify proximal causes and the underlying contributory factors of confined space accidents in the oil and gas industry (including upstream, midstream, and downstream) in Iran through analyzing accident investigation reports for 12 years (2006–2017) and using a qualitative approach.

2. Materials and methods

Twenty-one fatal confined space accident reports from the oil and gas industry were selected to identify accident causal factors. It was expected that more details were documented in fatal accident investigation reports. The HFACS framework was applied to systematically classify the identified causal factors. The HFACS focuses on both active and latent failures, especially, the management and organizational aspects of accidents and their interrelationships. It bridges the gap between theory and practice by providing a theoretically based tool for identification and classifying the human causes of accidents and helps improve both the quantity and quality of information gathered in accidents [35,36]. The HFACS has shown remarkable success in a variety of complex, tightly coupled industries and was found to be useful within the different contexts of a variety of industries [32,37–39].

As expected, the accident investigation reports could not demonstrate the details of underlying causes completely, for example, the roots of unsafe supervision that was reported in most of the accidents. It was also required to dig deeper to consider the interaction of personal decisions and their actions propagating in the organization [40]. Therefore, we decided to fill these gaps through the knowledge and experiences of individuals who were involved in the accidents under this study.

The semistructured interview was applied for data collection. Three pilot interviews were conducted with two safety personnel and one skilled worker of confined space activities. In pilot interviews, we used the questions that were introduced during the analysis of confined space accident reports. Based on the pilot interviews, some of the questions were modified, and some new ones emerged to explore the safety issues in depth [41].

The Snowball method was then used to choose the most appropriate informants based on their work experience and knowledge for the research question [42]. At the beginning of the interview, informed consent was obtained, and the confidentiality of collected data was guaranteed. The interviews were recorded with participant permission, and some notes were taken during the interviews to review and verify them at the end of the interviews to improve the validity of gathered data. Each interview lasted between 45 and 70 min. The interviews continued until data saturation was reached and new information did not emerge from them. A total of 33 face-to-face interviews were conducted with managers/supervisors ($n = 5$), Health, Safety & Environmental (HSE) managers, safety supervisors and safety officers ($n = 18$), and operators ($n = 10$) who are involved in confined space activities directly. The average age of the participants was 40.5 years (standard deviation $= 8.3$), all men with work experience ranging from 2 to 35 (17.5 ± 8.1) years.

The interviews were transcribed to text format. The transcriptions were subjected to content analysis to identify contributing factors. Line-by-line coding was conducted using MAXQDA software (version 10, developed by VERBI Software GmbH), closely adhering to the method of content analysis described by Erlingsson and Brysiewicz [43]. The contributory factor categories and their names were derived directly from the text data (using an inductive reasoning approach) in an iterative process to provide a valid category scheme. Fig. 1 illustrates the steps of the implemented content analysis.

In this study, both the reliability and validity of the coding system and categories were achieved through prolonged engagement of the researcher in analyzing the content. The stability of results over time is a type of reliability test. All the interview codes were recategorized after two months (immersion and distancing) [44]. This process led to some modifications to the codes and their categorization.

A literature review of previous relevant research was carried out to provide a valid category scheme. In addition, the validity and quality of identified categories were ensured by reconducting all data analysis steps through the coding and categorization by an independent person [45].

All identified causal factors from both the reviewing of a sample of accident data and a content analysis of the interview transcripts (from 7 oil and gas companies) were classified using the HFACS framework.

3. Results

3.1. Characteristics of fatal confined space accidents

In the oil and gas data set, we identified 36 fatal confined space accidents, which resulted in 55 deaths and 30 injuries over the period 2006–2017. Table 1 reports the details of confined space–related fatalities at the oil and gas industry. Based on fatality statistics, confined space accidents were the mechanism of incidents, which resulted in 12% of deaths—the fourth leading cause of deaths for the target period (Fig. 2).

Table 1
Confined space accidents in oil and gas companies (2006–2017)

Oil and gas –related company	Number of fatal accidents	Number of fatalities (percentage)	Number of injured persons in fatal accidents (percentage)	Fatalities per accidents
Oil company	11	19 (34.5%)	13 (43.3%)	1.7
Refinery	10	13 (23.6%)	13 (43.3%)	1.3
Gas company	8	13 (23.6%)	3 (10.0%)	1.6
Petrochemical	7	10 (18.2%)	1 (3.3%)	1.4
Total	36	55	30	1.5

The direct causes of fatalities are demonstrated in Table 2. The atmospheric hazards (oxygen-deficient air and toxic gases) both inside and outside of the confined spaces were the main cause for up to 82% of fatalities and also accounted for 89% of injuries. Furthermore, in most cases, confined space accidents resulted in multiple fatalities (1.5 fatalities per accident).

Deaths in confined space accidents occurred during a range of tasks including visual inspection, cleaning, maintenance (welding, grinding, and scaffolding), and radiography test activities. Contractors were involved in more than 90% of the fatalities.

3.2. Customized HFACS for the confined space accident

The review of 21 confined space accidents using the HFACS framework resulted in the determination of 111 causal factors. Table 3 presents an overview of the frequency and overall percentage of each identified causal factor accommodated in the HFACS framework. In addition to the review of accident investigation reports, the content analysis of interviews revealed more contributing factors in the confined space accidents. Both the interviews and accident investigation reports showed there are some causal factors outside of the HFACS framework; thereby, this framework requires expansion. Fig. 3 shows the modified HFACS framework for confined space accidents in the oil and gas industry. The main changes and their reasons based on the hierarchy of influence are presented in the following section.

3.2.1. Unsafe acts (Level 1)

Based on accident data, a significant portion of unsafe acts involved the Routine Violations (7.2% of overall causal factors) due to unauthorized entry to confined spaces, not using PPE, and carrying out work in nonroutine work time. In the Errors category, examples of the identified direct causes were an inappropriate rescue operation, wrong response to process events such as leakage or accidental release from the vault valve, and inattention to confined space hazard signs.

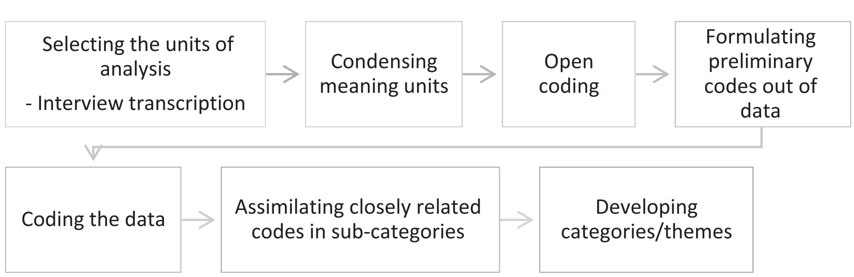

Fig. 1. Qualitative content analysis process.

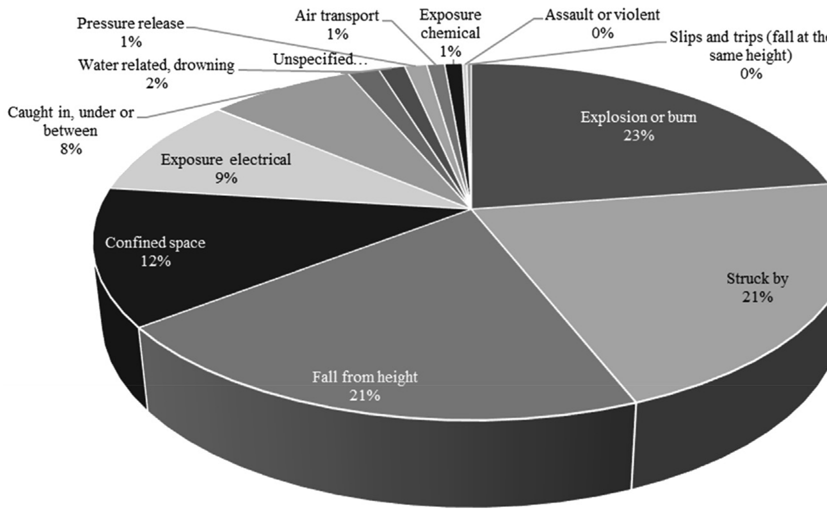

Fig. 2. Percentage of fatalities by accident categories under study in the oil and gas industry (2006–2017). Vehicle accidents were excluded.

3.2.2. Preconditions of Unsafe Acts (Level 2)

The second level in the HFACS framework deals with factors such as personnel, the work environment, the team resource, and design flaws. In the present study, the design flaws emerged as an influencing factor in both interviews and accident histories; thereby, the Technological Environment category in the original HFACS was changed to the Design and Technology category. Deficiency in Team Resource Management (known as Crew Resource Management in the original HFACS), design flaws, and personal readiness accounted for 4.5%, 2.7%, and 1.8% of the total causal factors, respectively.

The inappropriate Team Resource Management provoked poor coordination and communication between operators. According to the accident reports, some obvious cases of inadequacy in the informational resource of the team were miscommunication during shift handover and lack of toolbox talks or operational briefing about the specific hazards of the task in confined spaces. In addition, inadequate coordination between different teams that were simultaneously working at connected confined spaces was also identified as a case in one of the accident reports.

3.2.3. Unsafe Supervision (Level 3)

In confined space activities, supervisors are responsible for providing a safe environment based on PTW requirements and ensuring that the procedures are followed. Three types of Unsafe Supervision including Inadequate Supervision, Planned Inappropriate Operations, and Supervisory Violations accounted for about 36% of causal factors of the accidents. The failure to follow procedures and regulations such as the PTW system and authorizing the work without a site visit were the most common types of supervisory violation.

Failure to plan work in a safe manner and issuing incomplete work permits were contributory factors in the Planned Inappropriate Operations category. Examples were choosing the inappropriate work method such as catalyst regeneration or an unsuitable cleaning method, inadequate risk assessment, inadequate ventilation of confined spaces (dead points), and issuing two permits for one confined space simultaneously.

Table 2
Direct cause of fatalities for thirty-six of the surveyed confined space accidents (2006–2017)

Cause of fatality due to confined space accidents	Number of fatalities (percentage of fatalities)	Number of injuries (percentage of injuries)
H_2S and N_2 poisoning and O_2 deficiency inside confined spaces	39 (70.91%)	16 (53.3%)
Explosion	7 (12.73%)	3 (10%)
H_2S poisoning outside confined spaces	6 (10.91%)	11 (36.7%)
Electrocution	3 (5.45%)	0 (0.0%)

Table 3
Breakdown of the confined space accident (n = 21) casual factors based on HFACS categories

HFACS levels and categories	*Number of cases identified per contributing category	†Percentage %
Level 4: Organizational Influences		
Organizational Process	25	22.5
Organizational Climate	12	10.8
Resource Management	9	8.1
Level 3: Unsafe Supervision		
Inadequate Supervision	10	9
Planned Inappropriate Operations	14	12.6
Failed to Correct a Known Problem	0	0
Supervisory Violations	16	14.4
Level 2: Preconditions for Unsafe Acts		
Physical Environment	0	0
Technological Environment	3	2.7
Adverse Mental States	0	0
Adverse Physiological States	0	0
Physical/Mental Limitations	0	0
Team Resource Management	5	4.5
Personal Readiness	2	1.8
Level 1: Unsafe Acts		
Decision Errors	3	2.7
Skill-based Errors	0	0
Perceptual Errors	3	2.7
Routine Violations	8	7.2
Exceptional Violations	1	0.9
Total	111	100

HFACS, Human Factors Analysis and Classification System.
* Each accident has a number of causal factors; hence, the sum of number is more than 21 (accident cases).
† The column-labeled percentage reflects the overall percentage among all 111 identified casual factors.

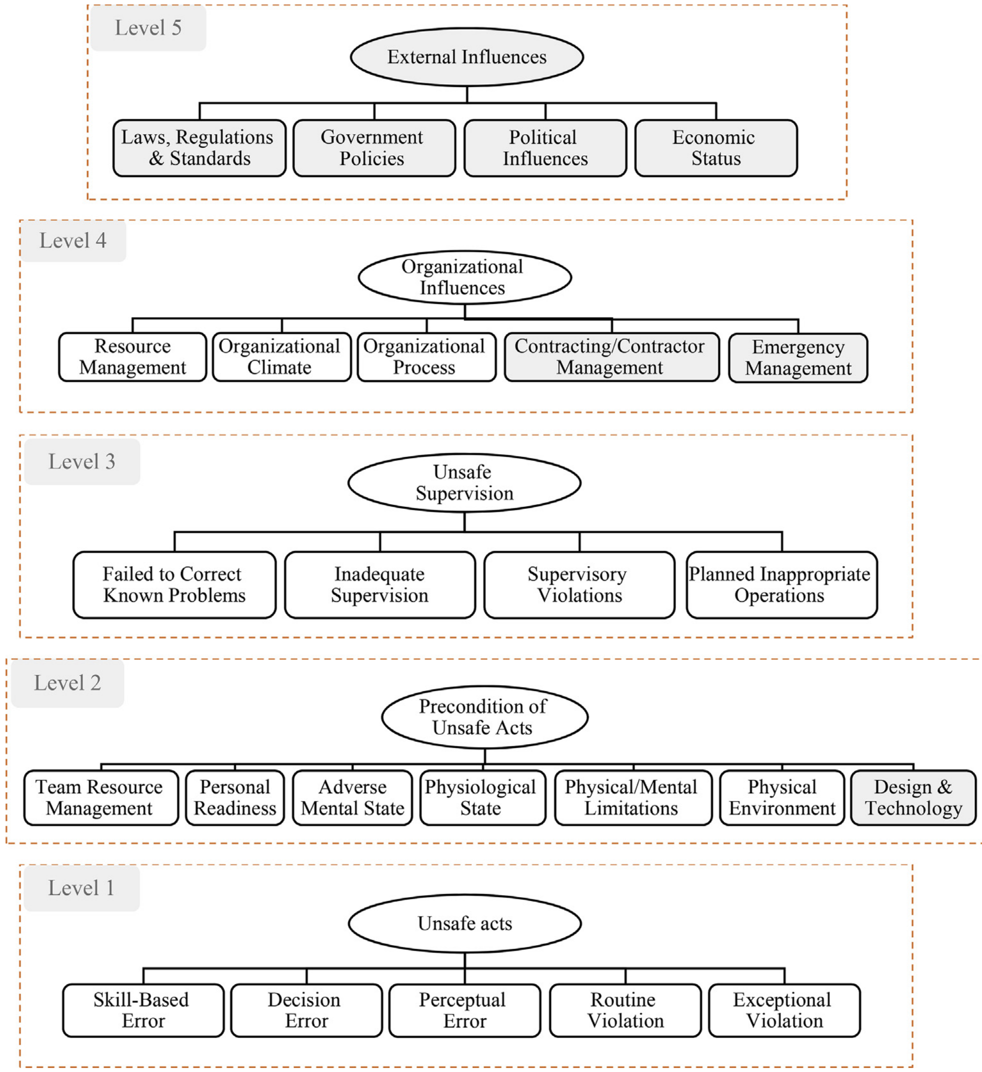

Fig. 3. Proposed framework for the HFACS in confined space accidents. HFACS, Human Factors Analysis and Classification System.

3.2.4. *Organizational Influences (Level 4)*

The largest proportion (41%) of the identified causal factors was attributed to the Organizational Influences level. The Organizational Process category accounted for 22.5% of causal factors. Inadequate training, lack of standard operating procedures, inappropriate risk management, and poor planning for inspection and maintenance operations were the most common causal factors. The Organizational Climate category accounted for about 11% of the identified causal factors, in which communication issues comprised the largest proportion (9%) of causal factors. In the Resource Management category, lack of rescue equipment, gas detectors, and rescue teams and other staff shortages were considered the main issues. Both accident investigation reports and content analysis of interviews demonstrated it is necessary to expand the HFACS framework by adding new emerged categories in the Organizational Influences level. Contracting/Contractor Management and Emergency Management emerged as two new categories in the organizational and managerial level. Examples of causal factors in the new Contractor/Contracting Management category included lack of competency management, contractor performance monitoring and oversights, lack of job description, and irrelevant task assignment to contract employees. Regarding the new Emergency Management category, lack of emergency management caused multiple fatalities in some cases.

3.2.5. *External Influences (Level 5)*

The External Influences is a new level that emerged during the content analysis of semistructured interviews. Four categories are included in this level and named Laws, Regulations and Standards, Government Policies, Political Influences, and Economic Status.

Most interviewees referred to the shortcoming of Laws, Regulations, and Standards regarding safety. Most concerns were about inadequacy of existing laws, regulations, and standards for safe work.

In addition, inappropriate Government Policies due to lack of permanent employment and inadequate budget allocation that resulted in staff shortage, the outsourcing of work and responsibilities, and financial constraints in companies were other issues considered by interviewees. The role of Political Influences includes the interference of external authorities in corporate schedules and plans, for example, deferring overhaul schedules, delaying or early start-up of the projects, and hiring/firing of personnel were described by the interviewees. In addition, high unemployment rates and economic constraints have led to education–job mismatches among contractor employees and job insecurity as well as incompetency issues.

4. Discussion

This research aimed to establish a comprehensive insight into the potential causal factors of confined space fatal accidents in the oil and gas industry. The HFACS framework was applied for the analysis and classification of identified causal factors. We found some causal factors outside of the HFACS framework, which emerged during the coding process of both accident databases and the content of interviews. Therefore, a modified version of the HFACS framework has been suggested by adding a new level as External Influences that considered contributing factors beyond the organization and adding two new categories in the organizational contributory factors. The study results showed that a five-level model including 25 categories was useful for identifying the causal factors of confined space accidents.

4.1. Identified safety issues

The results showed that causal factors outside of the organizational level need to be considered in the HFACS framework for accident investigations. This finding is consistent with that of previous studies conducted by the HFACS method that considered modifications for contributing factors beyond the organization level including regulations and the political and economic environment as the fifth level [31,46–50]. Level 5, which we termed External Influences, included four categories: Laws, Regulations, and Standards, Government Policies, Political Influences, and Economic Status. There are some similarities between these newly identified categories in the external level with the earlier studies in the oil and gas industry [26,31].

The shortcoming of Laws, Regulations, and Standards regarding safety was factors, which had an impact on employee safety. The interviewees pointed out the inappropriateness of tender law, which compromises safety by considering the lowest tender price, or insurance law, which authorizes anonymous insurance and potentially affects compliance with safety regulations by contract employers. Another case highlighted by the interviewees was the lack of national standards/guidelines that force the contractor to use international standards, which are not compatible with the methods and materials of the oil and gas industry regulations. The category of Government Policies was another category in the External Influences level that has been addressed during interviews. The corresponding causal factors in this category include inadequate support for safety due to poor labor inspection services, lack of permanent employment that causes staff shortage in oil and gas companies, and allocating an inadequate budget that leads to cost cutting in safety. Esenowo et al [31] discussed that the lack of industry-governance-management in the oil and gas industry causes cost cutting in the use of accident preventative barriers. Furthermore, there is inadequate legal requirement for contract workers to be certified in terms of safety, resulting in workers being vulnerable to confined space hazards.

Interviewees explained that an education–job mismatch among contractor employees due to the high rates of unemployment has resulted in job insecurity, job dissatisfaction, and stress. The workers felt they could not refuse to perform unsafe works. This situation could affect the motivation of individuals for safety compliance [51] and injury rates [52]. In addition, it decreases employees' bargaining power to seek their rights and leads to dissatisfaction. In an interview, one safety supervisor said, "*Contract employees' situation is getting worse day by day, due to economic downturns and high unemployment rates. Contractor take benefit this situation and provide low wage to their workers. They tell the workers if you don't like to work with this wage you are free to leave the job*."

Organizational Influences (Level 4) showed a major contribution to the confined space accidents. According to the identified causal factors, we suggested the need to add new categories in this level. Therefore, Contracting/Contract Management and Emergency Management were new categories added to the organizational factors. Esenowo et al [31] studied process accidents in refineries and suggested the inclusion of two additional categories to the organizational level of the HFACS framework: "Process Safety Culture and Management of Change." In addition, they proposed adding the "Contract Environment" category in the Preconditions of Unsafe Acts level (Level 2); however, our finding considered this issue to be an influencing factor at the managerial level.

The issues related to the PTW system (in the supervisory level) were frequently highlighted in interviews and accident investigation reports and were found to be due to organizational influences. The lack of PTW procedures, lack of a permit office with recognizable authorities as permit issuers, and lack of monitoring of PTW procedures were explained by the interviewees. The unfamiliarity of operational engineering authorities and contractors with the PTW system was pointed out in the accident reports. In addition, the Organizational Process category included failures in training needs assessment, periodical retraining, and the performance management system, especially for key personnel. In addition to all aforementioned issues, poor planning and programming and the lack of scheduled maintenance and regular technical inspection to detect defects in installation, for example, the underground valve or pit for valve (regulator vault), accounted for a critical factor in accident investigation reports. The proportions of contributing factors are different in studies conducted in different industries. For example, Celik and Cebi [38] reported the major contribution of skill-based errors, personal factors, and organizational process for shipping accidents. Esenowo et al [31] reported 50% of the contributing factors were due to failures in Level 2 (Prediction of Unsafe Acts) and Level 4 (Organizational Influences) in process accidents in the oil and gas industry.

Weaknesses in Organizational Climate were obvious in accident data and interviewees' statements. The priority of production, miscommunication, poor regulation enforcement, lack of commitment, and lack of accountability in the managerial and staff level suggested poor safety culture issues [53]. In an interview, one operative stated, "*Safety isn't followed at all. When there is an urgent, managers force us to enter the reactor. They force us to finish the work as soon as possible*." Guzley [54] found employees' organizational commitment is positively affected by their perceptions of the organizational climate and the communication climate, which emphasizes the importance of the safety commitment by management.

Communication issues were the most important item in the Organizational Climate category. The role of communication on safety performance is acknowledged [55]. Communication climate is considered a subset of organizational climate that refers to the relationship in the workplace [56]. Communication issues were identified during shift handover between different units such as operational and maintenance engineering and also construction contractors and pre–start-up contractors.

Contracting/Contractor Management was a newly identified category at the Organizational Influences level that needs to be considered as a distinctive category in the HFACS framework. Items such as lack of monitoring and oversight on contractor performance during projects/overhauls have led to low commitment toward safety among contractors and cost cutting in manning. Using unskilled workers and inappropriate equipment was recognized as major problems threatening safety. Hiring unqualified individuals as safety officers by contractors resulted in unsafe supervision issues. The contractor-related causal factors including violation of key contractor personnel, having multiple job positions held by safety supervisors/officers, and inadequate supervision were the case in some of the accident investigation reports. When workers feel completing the work is the first priority of the system, it could affect their compliance with safety rules. One contract employee said, "*I work for the contractor, if we do things in a short time; contractor would benefit for cost saving by short time staying in hostel facilities/camps etc. Contractors only think about their profits, our safety is not an important issue, there is not enough monitoring for contract employer by host plan*t."

In this regard, the lack of a job description for contract employees, especially at the operator level, resulted in assigning their responsibilities out of their skills. In addition, an inappropriate contracting strategy due to considering price instead of HSE criteria in outsourcing and a lack of specific knowledge about oil and gas installation hazards along with inadequate training were found to affect the safety of contract employees [57,58]. The importance of contractor management has been emphasized previously by the modified version of the HFACS for catastrophic events in the oil and gas industry [31] and industries involved in confined space activities [18].

Another new proposed category in the Organizational Influences level of the HFACS was Emergency Management. A review of accident investigation reports indicated inappropriate emergency responses led to multiple fatalities as cited by previous studies [10,12,13,21], especially in the case of existing toxic gas or oxygen deficiency [6]. Studies also highlighted the contribution of inappropriate emergency management planning in confined space fatalities [2,20]. Regulations, standards, and guidelines have differing requirements for rescue provisions relating to confined space activities [11]. A review of accident investigation reports showed a lack of emergency preparedness, and a poor response by an emergency team or inappropriate use of emergency equipment aggravated the situation in a number of cases of confined space accidents and contributed to the death of coworkers, HSE officers, or firefighters. Owing to the major contribution of emergency arrangements in control of multiple fatalities in a confined space accident, proper allocation of resources at the managerial level is required. Therefore, Emergency Management was considered a separate category at the organizational level.

Supervisory Violations were the most commonly referred category at the Unsafe Supervision level, followed by Planned Inappropriate Operations and Inadequate Supervision. Disregarding PTW systems was the most common violation at the Unsafe Supervision level. Some mechanisms lying behind the issues linked to PTW systems were discussed at the Organizational Influences level. Supervisory interventions revealed significant changes to safety climate, safety behavior, and safety performance [59]. Inadequate knowledge by supervisors [18] and delegating safety supervision to contractor companies [60] decreased effectiveness of safety supervision. Yanar et al [61] reported a supportive direct supervisor can alleviate the effects of deficiencies in policies, procedures, worker awareness, and empowerment.

Flaws in the design of confined spaces were reported in Precondition of Unsafe Acts at Level 2, as previously described by Burlet-Vienney et al [18]. Therefore, the Design and Technology category was included in the HFACS framework. Inaccessible points for isolating confined spaces, lack of safe access means such as elevators, fixed ladders, improper design of the drainage system (at the lowest point of storage tanks), and the use of similar outlet couplings for the supplied air respirator and the inert gas system were recognized items in this category.

Environmental conditions were not included in accident investigation reports. However, interviewees stated exposure to high temperature and humidity owing to the utilization of steam before entry, noise, and inadequate lighting could predispose conditions for committing unsafe acts in confined space activities [62–65]. Poor environmental factors increase the workload [66].

Interviewees declared that poor relationships between supervisors and workers resulted in inadequate safety communication, particularly in the case of contractor workers who could affect safety performance [59]. The lack of lifelines or the use of inappropriate and low-quality PPE such as loose-fitting respirators in a supplied air hood and high workload due to shortage of the workforce and inadequate time allocation were stated as safety-threatening situations by interviewees.

The direct causes (Unsafe Acts level) of confined spaces accidents were Routine Violations and Perceptual and Decision Errors. Unauthorized entry to confined spaces due to perceptual and decision errors or committing violations was found to be the main reason for fatal accidents. Perceived seriousness of a threat was considered the major determinant that could influence decision and action [67]. The significance of violations in comparison with errors was similar to that reported for coal mine accidents [68]. A set of factors are accounted for by interviewees to cause worker involvement in unsafe acts such as work pressure, poor risk perception and safety awareness, work environment, perception of management's commitment to safety, previous accidents, and long work service without accidents [13,69–71].

4.2. Conclusions and further research

Considering the strong background theory of the HFACS framework and its successful application in different industries, the HFACS has been introduced as a useful tool for accident causation analysis and classification. This study proposed an expanded version of the HFACS to cover confined space accidents.

In this study, we sought to understand an overall picture of the causal factors of confined space accidents. The results of the accident review emphasize the importance of the organizational- and supervisory-level interventions to control and prevent further accidents. However, the qualitative approach revealed more causal factors are responsible for accidents even beyond the organizational level. Then, modification of the HFACS framework is required to consider External Influences as the 5th level, and some extra categories were included in the Organizational Influences level.

The new adopted HFACS framework can provide a basis for confined space accident analysis and a reference to address risks of confined spaces in the safety management system. In addition, the suggested HFACS framework may be applicable across a broad range of industries and accident types because of considering external influences and contractor issues that can affect other accidents types and industries in the same way.

Further research is needed to explore the causal factors of other types of accidents in the oil and gas industry, especially for the most common types of work-related deaths, to discover common background factors and to provide more relevant solutions for improving occupational safety and similarly process safety. In addition, future research should consider external influencing factors such as performance influencing factors of governmental organizations, which are responsible for contractor safety and health and safety legislation.

Conflicts of interest

The authors have no conflicts of interest to declare.

Acknowledgments

The research reported in this article is part of the PhD thesis. The authors gratefully acknowledge all the personnel in the oil and gas industry who have participated in the research and personnel who facilitated access to subsidiary companies.

Institution and ethics approval and informed consent: The study was approved by the university's institutional review board and performed in Iran oil and gas subsidiary companies. Verbal informed consent was obtained from all participants for audio recording of interviews, and confidentiality of collected data was guaranteed.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.shaw.2019.06.007.

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