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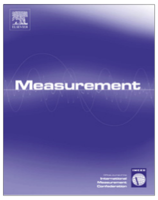

Evaluating accidents in the offshore drilling of petroleum: Regional picture and reducing impact

Zubaidah Ismail [a,*], Keen Kuan Kong [b], Siti Zulaikha Othman [a], Kim Hing Law [a], Shin Yee Khoo [b], Zhi Chao Ong [b], Sharif Muniruzzaman Shirazi [c]

[a] Civil Engineering Dept, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Mechanical Engineering Dept, University of Malaya, 50603 Kuala Lumpur, Malaysia
[c] Institute of Environmental and Water Resources Management, Universiti Technologi Malaysia, Skudai, Johor, Malaysia

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ABSTRACT

This study examined several accidents over the last 56 years in the offshore drilling of petroleum. The aim is to examine the situation in relation to jack-ups, drill ships, semi-submersible and platforms and have a better awareness and understanding which may reduce the number of accidents. The materials examined were available published reports and data on exploration and production activities. From 219 accidents recorded the highest was due to blowouts with 46.1%, followed by storms and hurricanes with 15.1% and structural failures with 11.4%. High fatalities occurred at the Funiwa 5 platform in Nigeria with 230, the Piper Alpha platform in the North Sea with 167 and the Keilland semi-submersible in Norway. Other high fatalities were recorded at the Ocean Ranger fire and sinking, Java Sea sinking, Bohai 2 and Bohai 3 fire and sinking. Worker training and discipline must be maintained at a high level. The facilities must be kept sea-worthy and reliable through regular maintenance.

1. Introduction

The petroleum industry has effective industrial and environmental safety practices. However, whenever an accident happens the impacts are so devastating that the memory lingers for decades and the event is cited time and again.

The key to good industrial and environmental safety lies from a demonstrated management commitment that treats industrial and environmental safety as having equal priority to other organizational goals. Employees are involved in, and know that they have the ownership of the industrial and environmental safety process. Realistic and achievable industrial and environmental safety targets are set for all work groups to achieve. Employees are adequately trained in industrial and environmental safety skills. Incident investigations are carried out not so much as to apportion blame but to minimize and prevent future occurrences. Positive steps are taken to improve employee behaviors, attitudes and values. Ahern [1] pointed out that these include employee involvement and ownership of the industrial and environmental safety process; developing teamwork and supporting leadership within workgroups; recognizing and valuing individual contributions to industrial and environmental safety; and fostering a situation where employees genuinely care about the industrial and environmental safety of their co-workers. Monitoring techniques can be introduced to assist in assessing the general industrial and environmental safety conditions of the organization. In order to reduce risks associated with production facilities, one approach is to provide real time and risk-based accident forecasting mechanisms and tools that

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[*] Corresponding author. Tel.: +60 379675284; fax: +60 379675318.
E-mail address: zubaidah_jka@yahoo.com (Z. Ismail).

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Nomenclature

Colln.	collision	P	platform
GoM	Gulf of Mexico	SS	semi-submersible
Expln.	explosion	Strut.	structure
JU	jack-up		

can enable the early understanding of process deviations and link them with possible accident scenarios. A forecasting algorithm was developed by Gabbar [2] which can identify and estimate industrial and environmental safety measures for each operation step and process model element and validated with actual process conditions.

The industrial and environmental safety management has to be aware and recognize the business hazard, and therefore be proactive to it. The attitudes throughout the organization on the application of the industrial and environmental safety management systems must be honest and sincere as shown by the commitment of senior managers, and that the actions taken are not just because of the threat of legal sanctions. The handling of commercial pressure must demonstrate knowledge that industrial and environmental safety is one of the important overall business priorities. The state of being informed and ready is also important to ensure that incidents do not escalate into worse accidents; and accident investigations and analyses do uncover the underlying factors and any managerial failings that may have led to the accidents [3]. Human factors play an important role in the completion of emergency procedures. Human factor analysis is rooted in the concept that humans make errors, and the frequency and consequences of these errors are related to work environment, work habits, and procedures [4].

An accident could have occurred repeatedly and has become of a routine nature or it can be a unique event. While there are lessons to learn from the experience of routine accidents since the impacts are somewhat similar, a once-off accident or a surprise event is more difficult to manage. Sensible responses to routine accidents can be developed, reviewed every now and again and further improved. These may include disaster warning systems, emergency management schemes, and disaster recovery programs including clean-up activities.. there are available methods to clean-up for on-land cases [5–8] but for offshore cases the recovery has to depend on natural forces. For a surprise event there is not much to draw from experience and the preparedness to face such an occurrence is usually lacking [9]. Each industry and each player in the industry has an approach towards industrial and environmental safety for that industry or that particular organization.

The petroleum industry involves activities like exploration and production (E&P), transportation [10–12], processing and refining, product distribution and storage with their own nature of incidents. Each activity is different from another with different general degree of risks involved. The focus of E&P would be drilling activities with the associated blowouts. Contributing factors include human error, equipment and control failure, weak operating systems and procedures and hazardous materials and environmental conditions. Short- comings from one or any combination of the above factors may result in an accident. Human error results from weak leadership, low levels of skills and knowledge, low reliability and poor discipline. Accidents may occur due to failure of equipment through poor state of maintenance and repair, control and emergency shut-down (ESD) system failure, materials of construction, improper design and technology utilization and operability. Technical support needs to be adequate and up-to-date. The ability to trace the drill-string by making a precise 3-dimensional underground survey is helpful. By using inertial technology an anti-disturbance and high accurate positioning can be achieved [13]. Near-bit force measurement and drill-string acoustic transmission of bottom-hole assembly (BHA) can investigate down-hole dynamic behaviors of BHA [14] and to monitor and control the forces acting on the drill assembly which would assist in preventing accidents. Application of industrial and environmental safety systems like hazard and operability (HAZOP), hazard analysis (HAZAN), technical audit and inspection, passive protection and inherent industrial and environmental safety affects the industrial and environmental safety performance. Effective procedures like operating instructions, shift change, start-up and shut-down, isolation and use of blind plates, hot-work permits, check lists, training of contractors' workers, limits of authority and lines of command can all reduce the number and impact of accidents. Escape routes, emergency response and evacuation, use of personal protective equipment (PPE), survival training, fire-fighting and First Aid are also important factors. Natural disasters contribute to the occurrence of accidents. Awareness and state of preparedness to handle the potential hazards of harsh environmental conditions from events like hurricanes, rain-storms and earth-quakes and volcanic activities can also lessen the ultimate impact of such incidents.

Accidents produce external pressures on companies leading to new regulations and renegotiation of enforcement of regulations. Structural characteristics of both the industries and the regulatory regime determine the interactions between the regulated and the regulator. In the industrial sectors where hazards and risks are visible and of public interest, it is easier to implement regulations through outside pressure [15].

Accidents drain resources. They result in loss of human lives and property. They interrupt production and negatively affect market goodwill and the environment. Effective remedial steps must be taken to reduce the frequency and consequence of accidents. The main objective of this study is to examine the situation in relation to jack-ups, drill ships, semi-submersible and platforms and determine the critical areas and have a better awareness and understanding for each activity. which may reduce the number of accidents. These were identified from selected examples based on absolute numbers of these events and the perceived environmental effects they had caused. Remedial steps are proposed.

The main objectives of this study are do the following by region:

- Determine the cumulative number of offshore drilling accidents.
- Determine the cumulative number of fatalities resulting from these accidents.
- Determine the frequency and percentage of various types of accidents.
- Observe for any trends or cycles in the occurrences of these accidents.

2. Material and methods

Data were collected from public records and reports dating back to 1956. In order to lessen the effect of location factor differences, some of which may be hidden, the events are listed by region: North America, Europe, Middle East, South America, Asia and Australia, and Africa. The facilities were classified under jack-ups, drill ships, semi-submersible and platforms. In this study, no attempt is made to relate frequency of incidents or fatality to water depth, so no data on the water depths are presented. For each region the cumulative frequency of accidents and number of fatalities involving drilling was recorded and plotted against weeks after the starting date on a regional basis. The frequency of occurrence for any year can be obtained from this plot. A regular slope indicates that the situation is steady, while an increasing slope indicates a deteriorating condition and a decreasing slope indicates an improving situation. Changes in slopes would indicate the beginning and the end of a possible cycle. Figures for fatality for each region were also recorded and classified under different ranges of 0, 1–10, 11–20, 21–50, 51–100, 101–200 and more than 200. The common basic causes were classified under blowouts, storms, structural failures, towing accidents, gas leaks, soil failures running aground or capsize and miscellaneous causes taken from outstanding examples. The summary of the frequency as percentages of the total global figure for each type of accident were also presented on a regional basis. In the current study no corresponding analysis was done based on facility type Steps were suggested to improve the situation.

3. Results and discussion

Out of a global inventory of operating drilling facilities of about 1100, jack-ups represent about 41% of the population, platforms make up about 23%, semi-submersibles represent about 18.3% and drill ships make up about 4.5% with the remainder being represented by drill barges and submersibles. From the 219 accidents reported in this study, 63.5% were from jack-ups, 19.6% were from platforms, 11% were from semi-submersibles and 5.9% were from drill ships [16]. These results showed that it was apparently safer to operate platforms and semi-submersibles than to operate jack-ups. This is not surprising since operating conditions for platforms and semi-submersibles are generally more stable than the conditions on jack-ups where operators usually have to break new exploratory ground. Results are listed according to regions and plots of cumulative number of accidents and fatalities in the various activities are drawn. Bar charts of frequencies of failure types and pie-charts of percentages of each type are also drawn. More detailed accounts of selected examples are presented.

3.1. North America

Table 1 shows details of some of the prominent accidents from N America region including the time lapse in weeks after the zero hour of 1 January 1956 and the number of fatalities associated with each accident. In the current study the accident types (or causes) are grouped into blowouts, towing accidents, running aground, structural failures, gas leaks, storms, soil failures, and others. Fig. 1a shows that over the study period there were a total of 98 recorded accidents. There is an indication of a regular changing slope every about 8–10 years. Fig. 1b shows a cumulative number of fatalities of 188 with a maximum of 84 recorded by the semi-submersible Ocean Ranger flooding. Fig. 1c shows that out of 98 accidents, 38 or 38.8% were due to blowouts followed by 25 or 23.4% caused by storms. Structural failures made up 10.2% and towing accidents made up 6.1%. Fig. 1d is the pie-chart showing the percentage distribution of the basic causes.

There is a slight indication of a presence of cycles in the frequency of accidents over the study period as indicated by periods of fairly constant slopes.

On Valentine's Day, 1982 a terrible storm rages off the coast of Newfoundland some 315 km east of St. John's on the Grand Banks and the Ocean Ranger, the world's mightiest self-propelled drilling rig, was pounded by waves more than 20 m high. At the height of the storm, the "indestructible" rig began to tip over, and then capsized. All 84 men on board perished. It was Canada's worst tragedy at sea since the Second World War. The Ocean Ranger was the largest and most advanced oil rig of its kind, built to withstand the world's stormiest seas. It was learned that design flaws could have started the Ocean Ranger's problems but poor training turned it into a catastrophe. The blame was squarely on the rig's owners and operators. With proper training the crew could have overcome the ballast control problems. With proper survival suits, many of them would be alive today. The mighty Titanic was designed to slice through ice; the mightier Ocean Ranger was designed to tame the hurricane. But the elements might be mightier than one might think.

In October 2007, the Usumacinta was contracted to drill at PEMEX's Kab-101 platform in the Bay of Campeche. The Kab-101 platform was a light production Sea Pony type platform, installed by PEMEX in 1994, which had two wells. The Usumacinta was contracted to complete drilling work on a third well, named Kab-103. The Usumacinta was brought into position alongside the Kab-101 platform to finish drilling the Kab-103 well. A cold weather front

Table 1
Detail of events (N America).

Weeks	Facility	Location	Fatality	Cause	Type	Event detail
N America						
31	Sedco No8	GoM	4	Constrn.	JU	Sank
52	Deepwater II	GoM	0	Hurricane	JU	Sank
65	Mr. Gus 1	GoM	1	Capsize	JU	Sank
156	Transgulf Rig 10	GoM	0	Capsize	JU	Sank
443	Baker barge	US	22	Blowout	Drill/S	Fire
469	Zapata Maverick	GoM	0	Blowout	JU	Overturned
469	Trion	GoM	0	Blowout	JU	Destroyed
505	Penrod 52	GoM	0	Blowout	JU	Collapsed
636	Julie Ann	GoM	0	Storm	JU	Sank
643	Dresser 2	GoM	0	Soil failure	JU	Overturned
656	Little Bob	US	7	Blowout	JU	Fire
678	Drake Point L-67	Canada	0	Blowout	LR	Ice volcano
678	Wodeco III	GoM	0	Blowout	Drill/S	Spill
678	Rim. Tidelands	GoM	0	Blowout	SS	Spill
682	Platform Alpha	US	0	Mud failure	P	Maj spill
686	Estrellita	GoM	0	Storm	JU	Sank
730	Stormdrill III	GoM	0	Blowout	JU	Fire
736	Main Pass 41	GoM	0	Fire	P	Burned
778	South Timbalier	GoM	4	Blowout	P	Sank
782	Big John	GoM	0	Blowout	Drill/S	Fire
834	J Storm II	GoM	0	Blowout	JU	Spill
991	J Storm II	GoM	0	Blowout	JU	Spill
991	Mariner II	GoM	0	Blowout	SS	Damage
999	Zapata Topper III	GoM	0	Blowout	JU	Sank
1058	Ocean Express	GoM	13	Fail rescue	JU	Overturned
1095	Placid 66	US	0	Blowout	JU	Sank
1130	Dolphin Titan	GoM	0	On tow	JU	Sank
1217	Ranger 1	GoM	8	Fatigue	JU	Collapsed
1200	Salenergy II	GoM	0	Blowout	JU	Spill
1222	Sedco 135F	GoM	5	Mud fail	JU	Sank, spill
1252	Dixilyn 150	US	0	Storm	JU	Sank
1252	Discoverer 534	GoM	0	Gas leak	Drill/S	Fire
1252	Harvey Ward	GoM	0	Mudslide	JU	Sank
1256	Topper I	GoM	0	Valve failure	JU	Sank
1257	Workhorse IX	GoM	0	On tow	JU	Sank
1262	Ship Shoal 246b	GoM	0	Blowout	P	Spill
1283	Dixilyn Field 81	GoM	0	Hurricane	JU	Sank
1291	Okha	Arctic	0	Storm	JU	Grounded
1294	Dan Prince	Alaska,	0	On tow	JU	Sank
1298	Lake Peigneur	Louisiana	0	Hit salt mine	Drill/S	Sank
1363	Ocean Ranger	Atlantic	84	Storm	SS	Flooding
1391	Marlin 3	GoM	0	Storm	JU	Damage
1408	Cerveza	US	0	Blowout	P	Abandoned
1437	Penrod 52	GoM	0	Blowout	JU	Collapse
1468	Vinland	Sable Is	0	Blowout	SS	Gas release
1480	Getty Platform A	GoM	1	Gas leak	P	Explosion
1497	Z Lexington	GoM	4	Blowout	JU	Fire
1556	Penrod 61	GoM	1	Blowout	JU	Sank
1565	B Buschman	Texas	0	Blowout	JU	Sank
1565	Zacateca	Mexico	0	Blowout	JU	Sank
1617	Pool 55	GoM	0	Soil failure	JU	Sank
1657	Zapoteca	GoM	0	Blowout	JU	Gas release
1659	Bigfoot 2	GoM	0	Leg failure	JU	Capsized
1661	Miss. Cany.311A	GoM	0	Blowout	P	Damage
1668	Steelhead	Alaska	0	Blowout	P	Fire
1669	Labrador I	US	0	Collision	JU	Damage
1677	Key. Marine302	GoM	0	Leg failure	JU	Sank
1719	Rowan Gorilla I	Atlantic	0	On tow	JU	Sank
1723	Teledyne M 16	GoM	0	Blowout	JU	Sank
1734	Five Sisters	GoM	0	On tow	JU	Sank
1795	K Marine 303	GoM	0	Blowout	JU	Gas release
1912	Marlin 3	GoM	0	Hurricane	JU	Damage
1917	Blake IV	GoM	0	Blowout	JU	Fire
2030	Rowan Odessa	GoM	1	Leg damage	JU	Fire
2090	Sundowner 15	GoM	0	Blowout	P	Fire
2100	Jalapa	GoM	0	Flooding	JU	Sank
2139	Ranger 4	GoM	0	Crater slide	JU	Sank

(*continued on next page*)

Table 1 (*continued*)

Weeks	Facility	Location	Fatality	Cause	Type	Event detail
2139	Pride 1001E	GoM	0	Blowout	P	Fire
2191	Rigmar 151	Atlantic	0	Leg failure	JU	Sank
2213	Mr. Bice	GoM	0	On tow	JU	Sank
2219	Nabors	GoM	0	Leg failure	P	Collapsed
2239	Petronius A	GoM	0	Lift failure	P	Sank
2279	NFX Platform A	GoM	0	Blowout	P	Fire
2356	Ensco 51	GoM	0	Blowout	JU	Fire
2366	Glomar Baltic I	GoM	0	Blowout	JU	Gas release
2375	Marine IV	GoM	0	Blowout	JU	Gas release
2431	Ocean King	GoM	0	Blowout	JU	Fire
2439	N Dolphin 105	GoM	0	Leg failure	JU	Collapsed
2439	Rowan Houston	GoM	0	Leg failure	JU	Collapsed
2488	Parker 14-J	GoM	0	Jack failure	JU	Collapsed
2541	Ensco 64	GoM	0	Hurricane	JU	Collapsed
2541	Medusa Spar	GoM	0	Hurricane	P	Collapsed
2556	Transocean 7	US	0	Leg failure	JU	Destroyed
2584	Thunderhorse	GoM	0	Hurricane	SS	Sank
2591	Hercules 25	GoM	0	Hurricane	JU	Collapsed
2591	PSS Chemul	GoM	0	Hurricane	SS	Collapsed
2591	Shell Mars	GoM	0	Hurricane	P	Collapsed
2591	Ocean Warwick	GoM	0	Collapse	JU	Collapsed
2591	New Orleans	GoM	0	Hurricane	JU	Sank
2592	Noble Max Smith	GoM	0	Hurricane	JU	Collapsed
2595	Typhoon	GoM	0	Hurricane	P	Collapsed
2595	Adriatic VII	GoM	0	Hurricane	JU	Collapsed
2595	High Island III	GoM	0	Hurricane	JU	Collapsed
2595	Fort Worth	GoM	0	Hurricane	JU	Sank
2595	Halifax	GoM	0	Hurricane	JU	Sank
2595	Louisiana	GoM	0	Hurricane	JU	Collapsed
2703	Usumacinta	GoM	22	Storm leak	JU	Fire
2833	Deepwater Hor	GoM	11	Cement fail	P	Explosion
2845	Vermilion Bk 380	GoM	0	Blowout	P	Fire

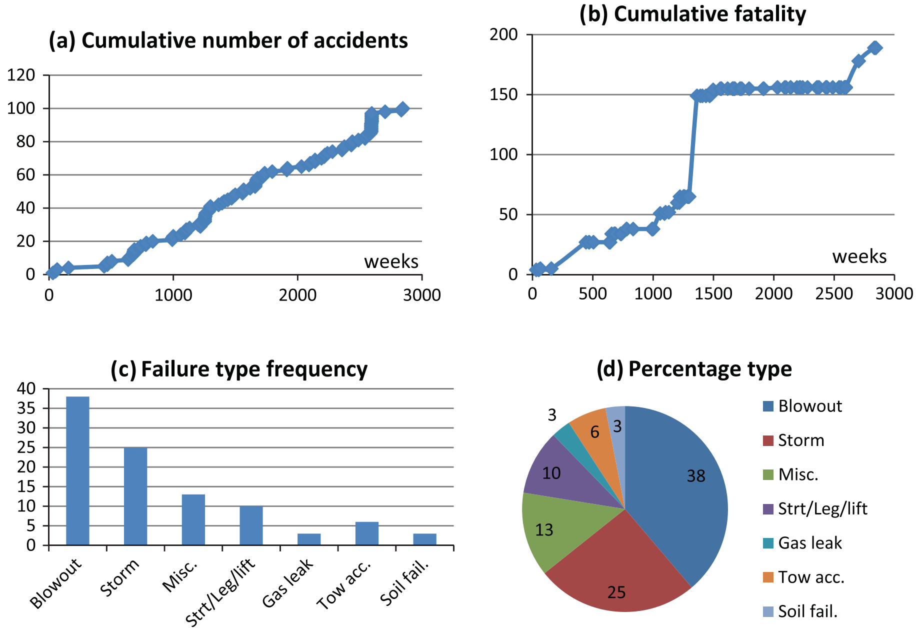

Fig. 1. Accidents type and frequency and fatality (N America).

passed through the Gulf of Mexico bringing storm winds of 130 km/h with waves of 6–8 m. The adverse weather conditions caused oscillating movements of Usumacinta. These movements caused the cantilever deck of the Usumacinta to strike the top of the production valve tree on the Kab-101 platform, resulting in a leak of oil and gas.

The subsurface safety valves of wells 101 and 121 were closed by PEMEX personnel, but the valves were unable to seal completely. The 81 personnel on the Usumacinta were evacuated by lifeboat. Rough seas hampered the rescue operation and caused the break-up of at least one life raft. Fires and bad weather delayed operations. There were 21 reported deaths during the evacuation of the Usumacinta, with one worker missing, presumed dead. There were some criticisms over the use of dispersants causing the oil to sink to the seabed easily. There was also been speculation that the rig suffered some structural or jacking failure.

Deepwater Horizon was an ultra-deepwater, dynamically positioned, semi-submersible offshore oil drilling rig with a crew of 146. In September 2009, the rig drilled the deepest oil well in history at a depth of 10,685 m in the Tiber Oil Field at Keathley Canyon block 102, approximately 400 km southeast of Houston, in 1259 m of water. On 20 April 2010, while drilling at the Macondo Prospect, an explosion on the rig caused by a blowout killed 11 crewmen and ignited a fireball visible from 56 km away. The resulting fire could not be extinguished and on 22 April 2010 Deepwater Horizon sank, leaving the well gushing at the seabed and causing the largest offshore oil spill in US history. An important factor in the rapid escalation of the Macondo blowout was failure by drill floor personnel to use the diverter, which is designed for just such a situation.

3.2. Europe and North Sea

Table 2 shows details of some of the prominent accidents from the European and North Sea region including the time lapse in weeks after the zero hour of 1 January 1956 and the number of fatalities associated with each accident. In the current study the accident types (or causes) are grouped into blowouts, towing accidents, running aground, structural failures, gas leaks, storms, soil failures, and others. Fig. 2a shows that over the study period there were a total of 32 recorded accidents. There is an indication of a regular changing slope every about 9–11 years. Fig. 2b shows a cumulative number of fatalities of 330 with a maximum of 167 recorded by the platform Piper Alpha fire and explosion in the North Sea. The figure shows that there is a clear change in the trend in both the numbers of accidents and fatalities recorded after the Piper Alpha disaster. This could be due to positive developments in Regulations following the Cullen Report. Fig. 2c shows that out of 32 accidents, 9 or 28% were due to blowouts followed by 6 each or 18.8% caused by gas leaks and structural failures. Storms and towing accidents made up 3 each or 9.4%. Fig. 2d is the pie-chart showing the percentage distribution of the basic causes.

There is an indication of a presence of cycles in the frequency of accidents over the study period as indicated by periods of fairly constant slopes.

Table 2
Detail of events (Europe).

Wks	Facility	Location	Fatality	Cause	Type	Event detail
Europe						
382	Mr. Louie	Germany	0	Blowout	JU	Damage
477	Sea Gem	UK	13	Leg failure	JU	Sank
505	Saipem Paguro	Italy	0	Blowout	JU	Fire
635	Ocean Prince	UK	0	Storm, strut.	SS	Sank
724	Zapata Scorpion	Canary Is	0	On tow	JU	Sank
725	Constellation	UK	0	On tow	JU	Sank
939	Transocean 3	UK	0	Leg break	SS	Collapsed
1034	Ekofisk A	Norway	6	Riser rupture	P	Fire
1043	Gatto Selvatico	Italy	0	Blowout	JU	Sank
1052	Deep Sea Driller	Norway	6	Storm	SS	Sank
1111	Ekofisk B	Norway	0	Cont valve	P	Oil spill
1152	Orion	Guernsey	0	Broke loose	JU	Sank
1264	Kielland/Edda	Norway	123	Brace break	SS	Flooding
1428	Placid L10a	N Sea	0	Corrosion	P	Blowout
1452	Byford Dolphin	Norway	5	Explosion	SS	Diving acc.
1461	Ali Baba	Norway	0	Break loose	SS	Grounded
1461	Treasure Seeker	Norway	0	Blowout	SS	Gas release
1513	Glomar Arctic II	UK	2	Pump fail	SS	Explosion
1513	West Vanguard	Norway	1	Blowout	Drill/S	Gas release
1553	West Vanguard	Norway	1	Blowout	SS	Explosion
1669	Oseberg B	Norway	0	Collision	P	Damage
1692	Piper Alpha	N Sea	167	Gas leak	P	Explosion
1707	Ocean Odyssey	UK	1	Blowout	SS	Fire
1722	Ekofisk P	Norway	0	Gas leak	P	Fire
1737	Cormorant A	UK	3	Gas leak	P	Explosion
1766	Interocean II	UK	0	Flooding	JU	Sank
1807	West Gamma	N Sea	0	On tow	JU	Sank
1856	Fulmar A	UK	0	Gas leak	P	Explosion
1859	Sleipner A	Norway	0	Implosion	P	Sank
2217	Glomar Arctic IV	N Sea	2	Gas leak	SS	Explosion
2534	Ghislanghien	Belgium	24	Rupture	Pipe	Fire
2552	Snorre A	Norway	0	Blowout	P	Gas release
2625	Maersk Giant	Norway	0	Blowout	JU	Gas release

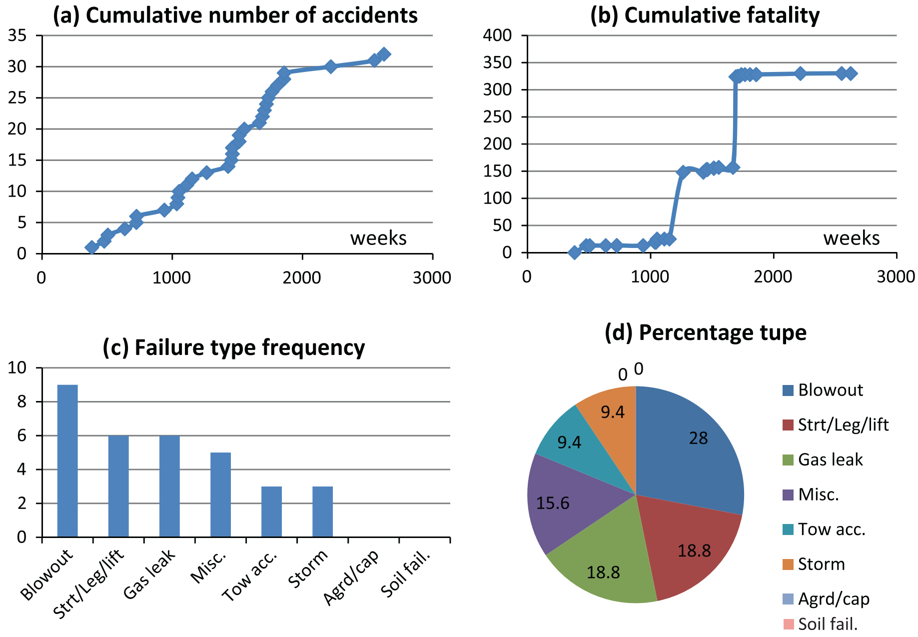

Fig. 2. Accidents type and frequency and fatality (Europe).

On 27 February 1965 the Sea Gem, a ten legged jack-up, became the first rig to break up and sink in the North Sea while attempting to move to a new location. The disaster claimed 13 lives and 5 serious injuries.

The Ocean Prince was built from a Gulf of Mexico semi-submersible template and it was reasoned that if this design had operated successfully in the Gulf it would also operate successfully in the North Sea. This was a gravely wrong assumption. The rig design was probably adequate to withstand the rigors of the North Sea weather, however, only in a floating mode and not sitting on bottom. The rig was not equipped with a motion compensator, as this piece of machinery had not yet been invented. To compensate for the rig vertical heave, bumper subs were utilized in the drill string. This proved to be extremely inefficient. The rig was fitted with Gulf of Mexico type anchors designed for the soft mud bottom in the Gulf. They were not designed for the hard sand bottom of the North Sea. These anchors would not seat and constantly slipped causing the rig to go off location on many occasions. The work boat captains were inexperienced in drilling support operations. They would constantly run their vessels into the rig causing serious damage to both the boat and the rig. The rig was drilling in a bottom setting position which had caused very severe scouring. In high wave conditions the rig could be lifted off the bottom and smashed back down causing visible structural cracks. The weather was miserable on the morning of 6 March 1968. The rig collapsed due to unattended structural cracks and eventually sank.

The Alexander L. Kielland was a semi-submersible located in the Ekofisk Field for Phillips Petroleum. It was supporting the Edda rig for workers who travelled between the two rigs via a bridge. On 27 March 1980, one of the main horizontal braces supporting one of the five legs failed due to a fracture. The remaining five braces attached to the leg failed in quick succession and the rig almost immediately listed partially submerging the main deck and accommodation block.

Attempts were made to launch lifeboats, with only two of the seven lifeboats launched successfully. Three of the lifeboats were smashed against the rig's legs as result of the storm winds and waves whilst being lowered, leading to a number of casualties. There were 212 men aboard and only 89 survived the accident. On top of the high winds and waves, the men also faced near freezing waters with little protection.

On 6 July 1988 at about 2200 h an explosion occurred on the Piper Alpha platform facility in the North Sea. The subsequent fire escalation was swift and dramatic with the first of three gas risers failing catastrophically after 20 min. In the disaster 167 persons out of 229 lost their lives. Available evidence has been examined to explain the rapid fire escalation and fire dynamics are now being considered in the design and operation of UK offshore installations [17]. At the height of the blaze on the platform, flames could be seen 100 km away. Survivors slid down pipes and jumped into the icy sea to escape the flames. The UK Offshore Operators' Association said accidents have fallen by 50% since the Piper Alpha disaster and workers and unions are consulted on matters of industrial and environmental safety. Cullen stated that the company operating the rig was not prepared for a major emergency and adopted a superficial attitude to the assessment of the risks of a major hazard [17].

The Piper platform represented a major step in both the development of the UK offshore resources and technology. The basic design of the topsides was based on those used in the Gulf of Mexico. The oil production from the Piper Alpha platform represented some 10% of the UK production from the UK sector of the North Sea [17].

The disaster remained as the worst ever oil rig disaster costing billions of dollars in property damage. It was caused by a massive fire which was the result of an accumulation of errors and questionable decisions [18]. A key lesson from Piper Alpha in 1988 was that the OIM had no realistic training in emergency response. Since then major emergency response (MEM) training, competence development and assessment for OIMs and deputies has become standard practice in the UK sector.

Aspects of design can be important. Design of fire and explosion barriers fits well with the current engineering skills and work-processes in investment projects [19]. The perception on industrial and environmental safety by operators on the platforms had been gauged by some researchers [20].industrial and environmental safety climate surveys on 13 platforms had also been conducted to assess the confidence of off-shore workers after an incident [21]. The type of approaches towards industrial and environmental safety can also differ from one installation to another which can affect overall morale and confidence and state of mind of the workers [22]. In conjunction with forecasting techniques indicators can also be introduced to monitor the general trend of the conditions on the platform in relation to industrial and environmental safety habits and practices. There are individual indicators for active fire protection and mustering of personnel [23].

3.3. Middle East

Table 3 shows details of some of the prominent accidents from the Middle Eastern region including the time lapse in weeks after the zero hour of 1 January 1956 and the number of fatalities associated with each accident. In the current study the accident types (or causes) are grouped into blowouts, towing accidents, running aground, structural failures, gas leaks, storms, soil failures, and others. Fig. 3a shows that over the study period there were a total of 14 recorded accidents. There is an indication of a regular changing slope every about 7–8 years. Fig. 3b shows a cumulative number of fatalities of 69 with a maximum of 20 recorded by the Nowruz platform fire in the Persian Gulf. Despite the fatalities from the Hasbah Platform blowout the trend in the frequency of accidents does not seem to change. Fig. 3c shows that out of 14 accidents, 5 or 35.7% were due to blowouts followed by 3 each or 21.4% each caused by towing accidents and storms. There were 2 gas leaks or 14.3% and 1 structural failure or 7.1%. Fig. 3d is the pie-chart showing the percentage distribution of the basic causes.

There is an indication of a presence of cycles in the frequency of accidents over the study period as indicated by periods of fairly constant slopes.

In December 1956 the Qatar 1 had a towing accident and sank in the Arabian Gulf.

On 2 October 1980 the Hasbah Platform drilled by the Ron Tappmeyer jack-up, exploratory well No. 6 blew out in the Persian Gulf for 8 days and cost the lives of 19 men. In 1983, the Nowruz Oil Field in the Persian Gulf, Iran, was involved in a number of oil pollution incidents from war hostilities resulting with 20 deaths.

3.4. South America

Table 4 shows details of some of the prominent accidents from the South American region including the time lapse in weeks after the zero hour of 1 January 1956 and the number of fatalities associated with each accident. In the current study the accident types (or causes) are grouped into blowouts, towing accidents, running aground, structural failures, gas leaks, storms, soil failures, and others. Fig. 4a shows that over the study period there were a total of 35 recorded accidents. There is no indication of any regular changing slopes. Fig. 4b shows a cumulative number of fatalities of 61 with a maximum of 42 recorded by the Enchova platform explosion. The figure shows that the trends for both the frequency of accidents and the number of fatalities decrease dramatically around the end of the eighties. These correspond to the positive change of E&P operating regimes in Brazil which dominated the oil and gas upstream activities of South America following the Enchova disasters [24]. Fig. 4c shows that out of 35 accidents, 29 or 82.8% were due to blowouts followed by 4 or 11.4% caused by structural failure. There was 1 accident caused by a gas leak and 1 due to a storm or 2.9% each.

Table 3
Detail of events (Middle East).

Wks	Facility	Location	Fatality	Cause	Type	Event detail
M East						
47	Qatar I	Arabian G	20	On tow	JU	Sank
1026	AMDP-1	Persian G	0	On tow	JU	Sank
1048	W.D. Kent	Dubai	0	Storm colln.	JU	Sank
1203	Scan Bay	Persian G	0	Blowout	JU	Fire
1291	Hasbah	Persian G	19	Blowout	P	Spill
1293	Maersk Endurer	Suez	3	Blowout	JU	Collapse
1300	O Champion	Port Said	0	Storm	JU	Grounded
1417	Nowruz	Persian G	20	Fire	P	Major release
1421	Iran platform	Iran	0	Blowout	P	Spill
1829	Gulf war	Kuwait	0	Fire	P	Spill
1974	D.M. Saunders	Arabian G	0	Flooding	JU	Sank
2087	Bahram	Suez	0	On tow	JU	Sank
2310	Al Mariyah	Persian G	4	Jack failure	JU	Collapsed
2439	Arabdrill 19	Saudi	3	Blowout/fire	JU	Destroyed

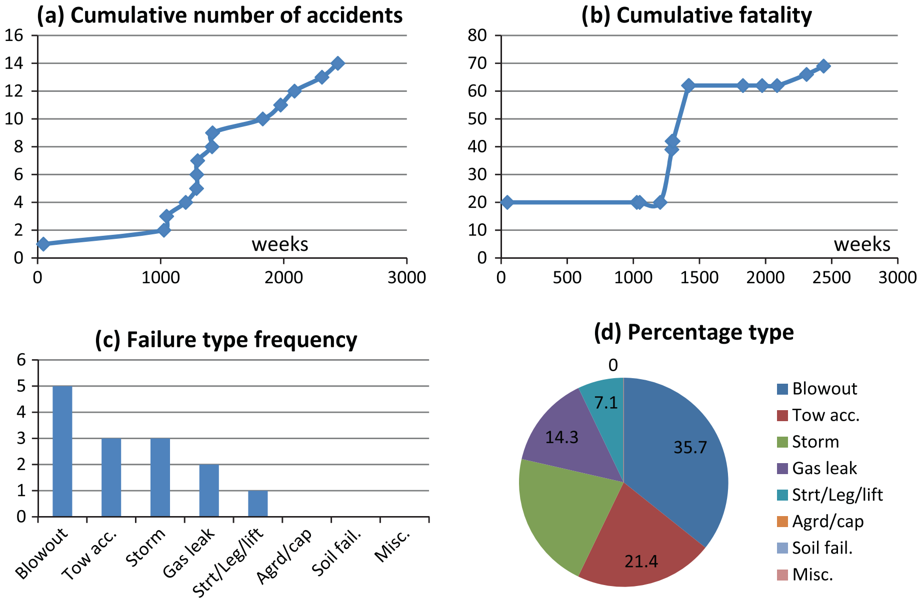

Fig. 3. Accidents type and frequency and fatality (Middle East).

Table 4
Detail of events (South America).

Wks	Facility	Location	Fatality	Cause	Type	Event detail
S America						
782	Drill barge	Peru	7	Blowout	Drill/S	Fire, spill
886	Mariner I	Trinidad	1	Blowout	SS	Spill
918	Trinimar Marine	Venezuela	0	Blowout	P	Major release
982	Liberacion	S America	0	Flooding	JU	Sank
1252	Rig	Brazil	0	Blowout	JU	Spill
1252	Rig	Brazil	0	Blowout	JU	Spill
1252	Rig	Brazil	0	Blowout	JU	Spill
1252	Marlin 4	S America	0	Leg failure	JU	Collapsed
1304	Rig	Brazil	0	Blowout	JU	Spill
1304	Rig	Brazil	0	Blowout	JU	Spill
1356	Rig	Brazil	0	Blowout	JU	Spill
1356	Rig	Brazil	0	Blowout	JU	Spill
1356	Rig	Brazil	0	Blowout	JU	Spill
1408	Nep Gascogne	Brazil	0	Leg failure	JU	Sank
1408	Rig	Brazil	0	Blowout	JU	Spill
1408	Rig	Brazil	0	Blowout	JU	Spill
1408	Rig	Brazil	0	Blowout	JU	Spill
1460	Rig	Brazil	0	Blowout	JU	Spill
1460	Rig	Brazil	0	Blowout	JU	Spill
1493	Enchova	Brazil	42	Cable snap	P	Explosion
1512	Rig	Brazil	0	Blowout	JU	Spill
1564	Rig	Brazil	0	Blowout	JU	Spill
1564	Rig	Brazil	0	Blowout	JU	Spill
1564	Rig	Brazil	0	Blowout	JU	Spill
1564	Rig	Brazil	0	Blowout	JU	Spill
1682	Enchova	Brazil	0	Blowout	P	Destroyed
1824	Rig	Brazil	0	Blowout	JU	Spill
1980	Rig	Brazil	0	Blowout	JU	Spill
2032	Rig	Brazil	0	Blowout	JU	Spill
2136	Rig	Brazil	0	Blowout	JU	Spill
2359	Petrobras-36	Brazil	11	Explosion	P	Sank, spill
2372	Petrobras P7	Brazil	0	Blowout	P	Fire
2552	Gulfwind	Chile	0	Leg failure	JU	Destroyed
2656	Rig	Brazil	0	Blowout	JU	Spill
2760	Rig	Brazil	0	Blowout	JU	Spill

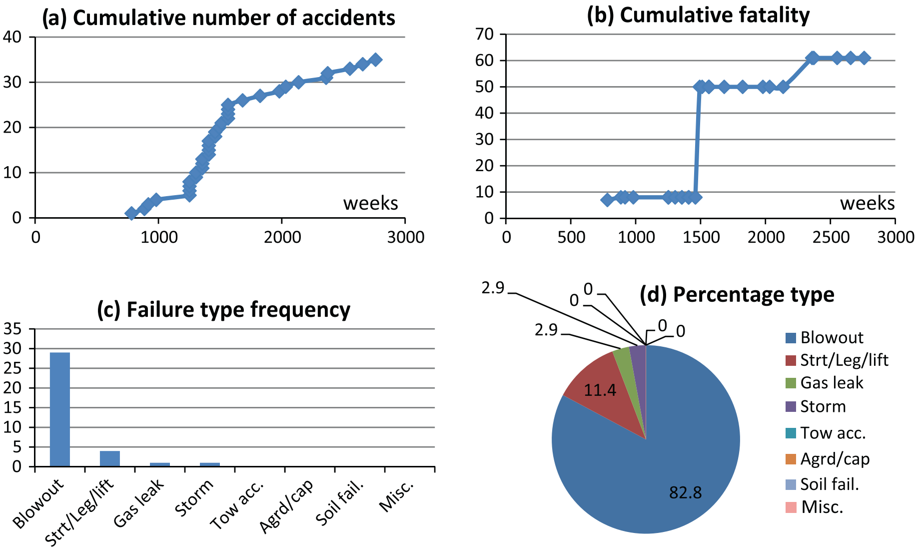

Fig. 4. Accidents type and frequency and fatality (South America).

Fig. 4d is the pie-chart showing the percentage distribution of the basic causes.

There is an indication of a presence of cycles in the frequency of accidents over the study period as indicated by periods of fairly constant slopes.

The Enchova Central platform was the location of two major incidents. In the first, on 16 August 1984, a blowout occurred followed by explosion and fire. The majority of the workers were evacuated but 42 personnel died during the evacuation of the platform. The most serious incident occurred when the lowering mechanism of a lifeboat malfunctioned, causing the bow hook to fail. The lifeboat was then left suspended vertically until the stern support broke and the lifeboat fell 10–20 m to the sea, killing 36 occupants. Six other workers were killed when they jumped 30 or 40 m from the platform to the sea.

The second incident occurred four years later on 24 April 1988 and resulted in the destruction of the platform. The well suffered a gas blowout. The blowout preventer (BOP) did not shut the well in and attempts to kill the well failed. A drill pipe was forced out of the well and struck one of the platform legs, causing sparks which ignited gas from the blowout. The fire burned for 31 days, resulting in extensive damage to the topside structure. Fortunately, a floating hotel was alongside the Enchova Central at the time and the platform was evacuated with no loss of life.

The P-36 was brought into operation in the Roncador Field off the coast of Brazil in May 2000. The unit was capable of processing 180,000 bopd and 7.2 million cubic meters of gas per day. In May 2001, the P-36 was producing around 84,000 barrels of oil and 1.3 million cubic meters of gas per day when it became destabilized by two explosions and subsequently sank.

On 15 March 2001, an explosion was recorded in the starboard aft column, thought to have been the mechanical rupturing of the starboard emergency drain tank (EDT). This caused the release of gas-saturated water and oil into the aft starboard column and caused the platform to list.

A second larger gas explosion which killed 10 members followed causing a progressive list that led to the subsequent loss of the platform.

The main causal factors were listed as alignment of the port EDT permitting entry of hydrocarbons; delay in the activation of the port EDT drainage pump, allowing the reverse flow of hydrocarbons; inadequate contingency plans and inadequate training.

3.5. Asia and Australasia

Table 5 shows details of some of the prominent accidents from the Asia and Australasia region including the time lapse in weeks after the zero hour of 1 January 1956 and the number of fatalities associated with each accident. In the current study the accident types (or causes) are grouped into blowouts, towing accidents, running aground, structural failures, gas leaks, storms, soil failures, and others. Fig. 5a shows that over the study period there were a total of 26 recorded accidents. There is an indication of a regular changing slope every 8–9 years. Fig. 5b shows a cumulative number of fatalities of 348 with a maximum of 91 recorded by the sinking of the drill ship Seacrest in a hurricane off Thailand. Despite high fatality figures in several accidents across the region over the study period, the trend in the frequency of accidents does not seem to change.

Fig. 5c shows that out of 26 accidents, 12 or 46.2% were due to blowouts and 3 or 11.5% caused by storms. There were 2 accidents caused by structural failure, towing activities and soil failures or 7.7% each. There was 1 or 3.8% accident caused by a gas leak. Fig. 5d is the pie-chart showing the percentage distribution of the basic causes.

There is an indication of a presence of cycles in the frequency of accidents over the study period as indicated by periods of fairly constant slopes.

The Montara oil spill was an oil and gas leak and subsequent slick that took place in the Montara oil field in the Timor Sea, off the northern coast of Western Australia.

Table 5
Detail of events (Asia/Australasia).

Wks	Facility	Location	Fatality	Cause	Type	Event detail
Asia/Australia						
678	Elefante	Indonesia	0	Fire	JU	Destroyed
730	Discoverer III	SC Sea	0	Blowout	Drill/S	Spill
834	TwD Rig 20	Martaban	0	Blowout	JU	Spill
834	MG Hulme	Indonesia	0	Blowout	JU	Sank
1043	Baku 2	Caspian S	0	Leg failure	JU	Sank
1097	Scan Sea	W Pacific	0	On tow	JU	Sank
1247	Bohai 2	China	72	Storm leak	JU	Flooding
1226	Nanhai II	China	0	Blowout	JU	Fire
1276	Bohai 3	China	70	Blowout	JU	Fire
1304	Bohai 6	W Pacific	0	Slipped	JU	Sank
1338	Petromar V	China Sea	0	Blowout	Drill/S	Sank
1414	Glomar Grand	Indonesia	0	Blowout	Drill/S	Fire
1443	Key Biscayne	Australia	0	Storm	JU	Sank
1444	Azerbaijan	Capsian S	5	Soil fail	JU	Sank
1451	Java Sea	S C Sea	81	Storm	Drill/S	Sank
1513	Zapata	Indinesia	0	Blowout	JU	Fire
1534	Dixilyn Field 82	Indian O	0	On tow	JU	Sank
1611	Dixilyn Field 83	Indian O	0	Leg failure	JU	Sank
1704	Viking Explorer	Borneo	4	Blowout	Drill/S	Explosion
1722	Sedco 252	India	3	Blowout	JU	Fire
1765	Seacrest	Thailand	91	Hurricane	Drill/S	Sank
1887	Fergana Valley	Uzbeck	0	Well failure	P	Spill
1930	Actinia	Vietnam	0	Blowout	SS	Major release
2132	Maersk Victory	Australia	0	Leg failure	JU	Collapsed
2586	Mumbai High	Indian O	22	Riser colln.	P	Explosion
2776	Montara	Australia	0	Blowout	P	Fire

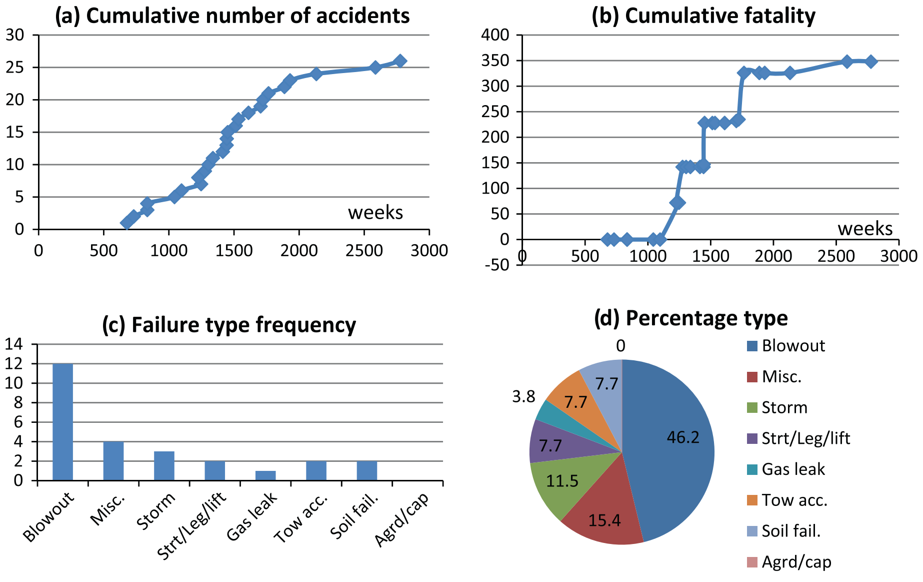

Fig. 5. Accidents type and frequency and fatality (Asia/Australasia).

The slick was released following a blowout from the Montara wellhead platform on 21 August 2009, and continued leaking for 74 days. Halliburton was involved in cementing the well. Sixty-nine workers were safely evacuated.

There was an ignition at surface, even though the whole installation was 'dead' and unmanned but there was insufficient mud available. The intense fire caused the cantilevered rig to collapse onto the platform below it and both platform and rig were extensively damaged.

The cement barrier was faulty. It was learned that not one of the Montara wells had been constructed in strict compliance with PTT's well manual.

The accommodation barge at Montara was poorly prepared for a blowout situation, though the initial emergency response to pull off station was effective. It is apparent that no party, including the regulators who reviewed the installation safety case, believed that a significant continuing hydrocarbon release was a realistic event which should be considered.

Emergency response arrangements and equipment were fundamentally sound, and the calm weather was undoubtedly another key factor in ensuring rescue after abandonment. Investigations revealed many organizational deficiencies, primarily involving clear communications and risk-based decision making. There was lack of adequate foresight on local organizational systems and procedures. It was judged that the associated risks were not so significant that work should stop until they were corrected [25].

On 25 November 1979 the Bohai 2 jack-up rig had a towing accident in a storm and sank. There were 72 deaths. The following year on 15 June the Bohai 3 had a fire as a result of blowout killing 70 crewmembers. The Seacrest drillship capsized in 1989 during Typhoon Gay, with the loss of 91 crew members. Another storm fatality, the Glomar Java Sea capsized and sank during Typhoon Lex in 1983 with the loss of all on board. A support vessel collided with Mumbai High North in 2005, rupturing a riser and causing a major fire that destroyed the platform.

3.6. Africa

Table 6 shows details of some of the prominent accidents from the African region including the time lapse in weeks after the zero hour of 1 January 1956 and the number of fatalities associated with each accident. In the current study the accident types (or causes) are grouped into blowouts, towing accidents, running aground, structural failures, gas leaks, storms, soil failures, and others. Fig. 6a shows that over the study period there were a total of 14 recorded accidents. There is an indication of a regular changing slope every 8–9 years. Fig. 6b shows a cumulative number of fatalities of 271 with a maximum of 230 recorded by the Funiwa 5 platform blowout and forest fire.

There was no indication of any trend in the frequency of accidents. Fig. 6c shows that out of 14 accidents, 8 or 57.2% were due to blowouts followed by 3 or 21.4% due to towing accidents. There were 2 or 14.3% accidents caused by structural failure and 1 or 7.1% accident due to a gas leak. Fig. 6d is the pie-chart showing the percentage distribution of the basic causes.

There is an indication of a presence of cycles in the frequency of accidents over the study period as indicated by periods of fairly constant slopes.

On 9 October 1995 in West Africa the Gemini jack-up collapsed due to leg failure and killed 18 people. Oil from the 1980 Funiwa 5 blowout polluted the Niger Delta for 2 weeks, followed by fire and the eventual bridging of the well. Santa Fe's Al Baz jack-up burned and sank after a blowout in 1989 with the loss of 5 lives. A fire on the Ubit platform in Nigeria in 1996 killed 18 people.

3.7. Overall summary of failures

Basically all the stated accidents were due to human error and incompetence and equipment and instrument failures. There is no one factor that solely contributes to the accident but a host of other contributory failures that together ultimately make it happen. From the examples above it can be observed that almost all the accidents cited were routine accidents. Similar accidents have happened elsewhere sometime in the past. The question is whether people really learn from history or not. Or maybe even an apparently routine incident is unique and there are no two exactly similar ones that there is nothing much to learn from past incidents.

Fig. 7a shows the summary of the number of operating facilities as from 1991 to date and the number of accidents recorded in this study. Jack-ups represent the biggest number of operating facility type followed by platforms, semi-submersibles and drill ships. There is a corresponding trend in the frequency of accidents in relation to the numbers of facility types in operation. Fig. 7b shows the percentage of the various types of facilities in operation and the percentage of those types involved in incidents. It is apparent that jack-ups have a disproportionately higher rate of failures compared to platforms and semi-submersibles. This could be due to the less stable operating conditions for the jack-ups. Fig. 7c shows the total frequency of incidents for each type of facility involved in this study. Fig. 7d shows the frequency for various fatality ranges. The majority of accidents involved no fatalities. The trend shows the higher the range of fatality, the less

Table 6
Detail of events (Africa).

Wks	Facility	Location	Fatality	Cause	Type	Event detail
Africa						
527	Roger Butin 3	W Africa	0	Leg failure	JU	Sank
979	Gemini	W Africa	18	Leg failure	JU	Collapsed
1121	Ocean Master II	W Africa	0	On tow	JU	Sank
1252	Sea Quest	Nigeria	0	Blowout	SS	Fire
1252	Sedco 135G	Nigeria	0	Blowout	SS	Fire
1254	Funiwa 5	Nigeria	230	Blowout	P	Forest fire
1356	Banzala	Angola	0	Blowout	P	Sank
1734	Sedco J	S Africa	0	On tow	SS	Capsized
1738	Al Baz	Nigeria	5	Blowout	JU	Burned
2064	Ocean Dev.	Angola	0	On tow	SS	Sank
2087	Ubit	Nigeria	18	Gas leak	P	Explosion
2536	Adriatic IV	Egypt	0	Blowout	JU	Fire
2537	Cunningham	Egypt	0	Blowout	SS	Fire
2544	Adriatic IV	Egypt	0	Blowout	P	Destroyed

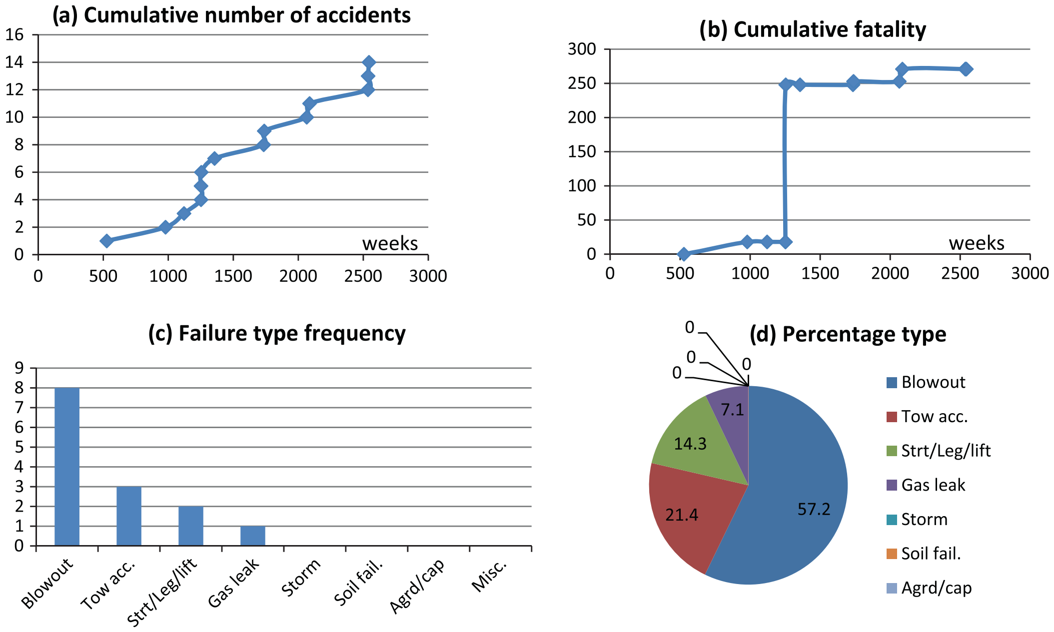

Fig. 6. Accidents type and frequency and fatality (N America).

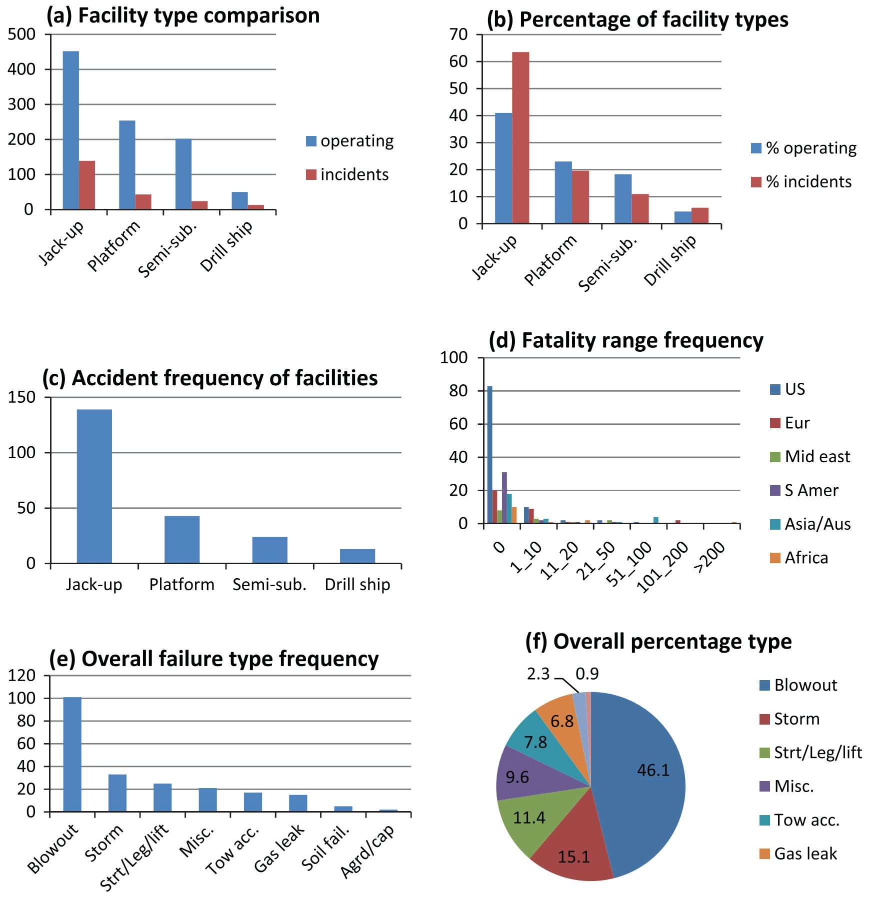

Fig. 7. Summary of overall frequencies, failure types and fatalities.

the frequency, which is to be expected. The concern is more on the double and triple fatality figures recorded by some accidents. This will be elaborated further in subsequent sections. Fig. 7e shows the overall failure type frequencies classified under blowouts, storms, structural failures, towing accidents, gas leaks, soil failures, running aground, and others. It can be observed from the figure that the most frequent accident type is a blowout followed by storm and structural failure. Fig. 7f is a pie-chart showing the percentages of the various basic causes for the accidents with blowouts representing the highest with 46.1%.

Fig. 8 shows the summary of the frequencies as percentages of the total global figure of the various types of accidents on a regional basis. The figure shows that N America is top in all types of accidents. The plots are consistent to the number of operating facilities in the various regions.

3.8. Remedial measures

Accidents drain the human and other resources. Lives, reserves and equipment are lost; production is discontinued and market goodwill is negatively affected production, while there could be untold damage to the environment. It is to the interest of all stakeholders to ensure that accidents are reduced or eliminated. Remedial measures have to be found and implemented. Responsibility, authority and accountability must be properly assigned.

3.8.1. Human factor

DeCola and Fletcher [26] stated that human factors – either individual errors or organizational failures – have been reported to cause as much as 80% of accidents. Accidents in the oil and gas industry can be reduced through healthy industrial and environmental safety practices. Leadership who can maintain a level head during crises must be properly selected. An open, trusting work environment has to be developed [27]. Adequate resources must be provided for industrial and environmental safety training. Training and emergency preparedness, safety equipment, evacuation procedures, availability and effectiveness of rescue parties all have an influence on the overall impact of accidents.

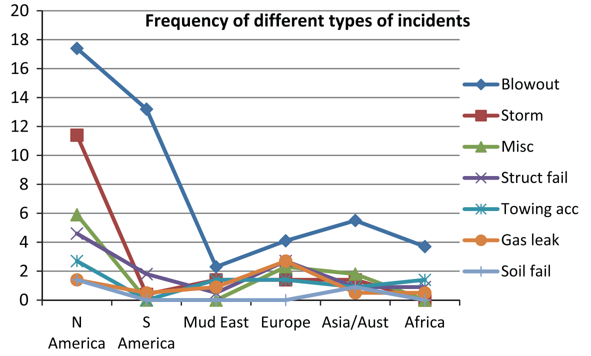

Fig. 8. Frequencies as percent of total global figure of accidents: by region.

The industrial and environmental safety conditions can be improved through positive efforts. This was demonstrated in Brazil. Prior to 1988 Brazil E&P activities were experiencing about three blowouts per year. The major reasons were identified as inattention to operations, inadequate supervision, improper maintenance, improper installation and inspection, improper planning, improper procedures and improper documentation. A program was then introduced which proposed the promotion of better well controlled industrial and environmental safety through training and certification, monitoring operational activities, elaborating standards and operational procedures, and doing research. This resulted in an almost ten-year period without a blowout event in drilling operations. Advances in technology play an important role in enhancing the skills of the operators to be more prepared to carry-out the functions of operating, maintaining and surveillance of facilities through simulator training, better graphics and animation and other aids.

Managers are important figures in an organization. Their job organization, attitudes and accident prevention approaches are vital in ensuring a safe work place and a satisfied workforce [28]. Studies have been conducted among presidents, vice-presidents and managers in the industrial company Norsk Hydro to analyze the associations between attitudes, behavioral intentions and behavior. The sample consisted of 210 respondents and the data were collected in 1997 and 1998 among participants at the Hydro Management safety Training Workshops, which is a safety course for the managers employed by the company. Managers' attitudes are interesting because they may affect behavioral intentions and the managers' behavior related to the achievement of safe working practices. Eight attitudinal dimensions explained up to nearly 40% of the variance in behavior. The study shows that industrial and environmental safety attitudes may be an important causal factor for managers' behavioral intentions as well as behavior. High management commitment, low fatalism, high industrial and environmental safety priority, and high risk awareness were found to be particularly important attitudes for managers [29]. Human reliability index based on 64 API-770 performance factors could be effectively employed to best suit the man to the job [30].

3.8.2. Equipment and instruments

In the Piper Alpha accident the compressor header pipe gave way because of overpressure giving rise to a rupture and release of the flammable and explosive contents. One out of two vital compressors producing power for the entire complex was down for overhaul. A single safety valve on the header was taken out for repair and a blind plate fixed in its place rendering the system unsafe to operate. Repair work was simultaneously carried out on the deluge pump for automatic fire-fighting system. Shutdown procedures and limits of operational authority were also unclear to operators.

Technology is available to prevent over-pressure through relief valves and thus prevent disastrous rupture, Inspection and to a limited extent, repair, is possible while the equipment is running. This reduces the need to overhaul. Unfortunately it is the human urge to take chances oftentimes becomes the cruxial weakness.

3.8.3. Systems and procedures

Communication failure is another contributory cause of accidents. Breaks in the chain-of-command e.g. waiting for instructions which never come because the ones to issue the command are dead and replacements are not appointed. Interface problems like shift changeover duty and missing vital safety documents are common. Language problems where several workers come from different nationalities have also been known to contribute to accidents. There is often inadequate training on procedures not only for the on-site workers but also the casual contractor's workers. New recruits combined with inadequate supervision by inexperienced supervisors and replacements are other contributory causes to accidents. Safety management systems need to be implemented [31]. Systems for performance evaluation and corrective action cannot be overlooked by management [32].

Procedures need to be continually reviewed, and operators well-trained in carrying them out. However, systems involving hardware can be improved through technology development. Monitoring systems, emergency shut-down systems and fail-dafe systems are examples of these.

3.8.4. Design

In several cases victims are placed in what can be referred to as getting 'from the frying pan into the fire' or entrapment. People are trapped between the raging fire and the icy cold waters. They just jump several hundred feet into the icy waters of the sea just to perish in order to escape the raging fire on the platform. In other cases people seek shelter in gas-filled confined spaces like poorly designed control rooms waiting for disaster to strike because there are no other places to run to. Fail-safe, redundant and idiot-proof designs must be adopted. A design which works perfectly in one region need not always be suitable for other regions. Soil conditions could be different, environmental conditions could be different and the workers attitudes could also be different. System design must be site specific. Opt for safer processing alternatives and utilize concept of greener technology through materials reduction, replacement and less use of hazardous materials [33]. The number of workers required to be within the explosive limits at any one time must be minimized through proper design.

It may be possible to design facilities and systems approaching 100% safe, but the cost would be prohibitive. The normal approach is to design to as high a level of safety as possible taking into consideration the cost. This is backed-up with effective operating procedures. As a last measure, 'fire-fighting' approach is adopted where operators are trained to handle the incident when it happens.

3.8.5. Environment

Several notable accidents are caused by natural episodes like rain-storms and hurricanes, volcanic activities and lava-flows and mud-flows, earth-quakes and tsunamis which are beyond anybody's control. In these cases the sensible things to do are to heed the warnings, avoid them if possible, and reduce the impact through better awareness and state of readiness [34]. Technology advances in weather forecasting by satellites, monitoring of volcanic activities and others can assist to achieve this state of readiness.

4. Conclusions and recommendations

All the accidents examined showed that basically they were due to human error and incompetence and equipment and instrument failures. It is apparent that jack-ups have a disproportionately higher rate of failures compared to platforms and semi-submersibles. There is a corresponding trend in the frequency of accidents in relation to the numbers of facility types in operation. The frequency for various fatality ranges with the majority of accidents involving no fatalities.

In the preparation of guidelines related to industrial and environmental safety there is a need to maintain good coordination and understanding between Federal and State agencies and the private sector in order to avoid discrepancies in implementation. Good communication across all levels must be maintained with special emphasis at the interfaces. Full scale drill exercises must be conducted regularly to assess the logistics and essential supply requirements. Potential problems in the systems and procedures like evacuation procedures could be debugged. Safety training and refresher courses designed and implemented. In cases of shared common facilities there must be more cooperation across company lines to maintain and repair these facilities. For each region there is an indication of a presence of cycles in the frequency of accidents over the study period as indicated by periods of fairly constant slopes. The recurring pattern of accidents cycles may be used as a guide to anticipate incidents and to be better prepared for them.

Acknowledgements

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