Safety Science 92 (2017) 85–93

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Lack of dynamic leadership skills and human failure contribution analysis to manage risk in deep water horizon oil platform

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ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form 28 August 2016
Accepted 24 September 2016
Available online 5 October 2016

Keywords:
Leadership
Risk and hazards
Human errors
Human factors
AHP

ABSTRACT

This paper analyses the case study of Macondo Well Blowout and the failures of dynamic leadership skills and human contribution to process risk. The Deepwater horizon oil platform in the Gulf of Mexico was owned by Transocean and operated by British Petroleum (BP), this disaster took place on April 20, 2010 in off the coast of the Gulf of Mexico that eventually led to an oil spillage. Millions of barrels of oil flooding into the sea and beaching the shore. The analysis was executed by identifying the human factors, hazardous conditions, developing FTA, and constructing a pairwise matrix. The analytic hierarchy process (AHP) was performed to evaluate the Consistency Index (CI), Quality Index (QI), and the overall qualification of influencing factors. From the results it was observed that the least QI value was found in the factor failure to gain control of well response and the factor negative pressure test has 36% which recorded as the highest QI. On the whole, the overall qualification of influencing factors is marked as poor. Ultimately, these results demonstrate that this tragedy is due to complete human errors and it is the evidence of both Transocean and BP employee's poor leadership abilities.

1. Introduction

On April 20, 2010 the Deepwater Horizon (DWH) oil drilling platform exploded and released over the adjacent 3 months a government estimated 4.9 million barrels of oil, becoming the largest marine oil spill in the United States History (Judy et al., 2014). During the Deepwater Horizon oil spill in the Gulf of Mexico between April 20 and July 15, 2010, over 800 million liters of crude oil were gushing from the Macondo well to the water column, exerting greater adverse effects on the marine life, human health, and natural resources in the northern Gulf of Mexico (Zhou et al., 2013). The absolute mass of oil caused widespread impacts, including the oiling of approximately 796 km of Gulf Coast marshes; this included approximately 304 km of Louisiana marshes classified as moderately to be heavily oiled (Michel et al., 2013). The British Petroleum (BP) supermajor oil and gas company who was accused and took the full responsibility for this catastrophic event, BP is a British multinational oil and gas company having operations all over the globe, this Deepwater horizon rig was owned by Transocean and operated by BP. The BP oil rig team made incorrect evaluations of the drilling operations, BP contracted Halliburton an energy service company for carrying out the cementing operations in the Macondo well. The engineers at the platform wrongly made several engineering judgement and failed to perform the maintenance operations that in the end led to a devastating historical scenario. Over, 40 years the Shell-USA oil company had successfully drilled 35,000 wells in the Gulf of Mexico, they lambast and blame BP by commenting that, this unexpected incident is an act of pure human errors and poor leadership qualities (Hofmeister, 2013). In 2007, Tony Hayward replaced Mr. John Browne as CEO of BP PLC and upon swearing in ceremony, he said that, he would act as a laser in health and safety policy of this company. During the incident on 2010, he was severely criticized for his statement by the US Department of Justice. The failure of oil rig process risk analysis by identifying the human and organizational components will lead to disastrous consequences, such as the collapse of offshore structures and that in turn leads to multiple fatalities and extensive damage to property, production, and the environment (Norazahar et al., 2014).

Thus, this paper presents a framework for analyzing the Macondo well blowout issues based on human and organizational factors. The outcome of this model can be used to identify and implicate the best factor of this DWH explosion in the Gulf.

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http://dx.doi.org/10.1016/j.ssci.2016.09.013
0925-7535/

Also, good qualities for effective leadership was suggested in this paper.

1.1. Problem background

The Macondo Blowout chronology incident as follows, on April 20th the well integrity test was carried out, the negative pressure test was falsely interpreted to be successful, while carrying out the negative pressure test the BP team leader noticed that the crew are using a procedure that is not BP preferred method the operations are reconfigured to meet the requirement of the permit. The sea water was pumped into the kill line to confirm whether if it is full and this was monitored for 30 min which shows no flow. The crew started the activities for temporary abandonment of the well, but the well into an underbalanced position causing hydrocarbons to flow. The drill pipe pressure increases, but this was not noticed. The mud overflows onto the rig floor, the crew diverted the mud flow to the mud gas separator but the drill pipe pressure steadily increases. Mud and hydrocarbons discharge onto the rig and overboard. The gas alarms sound, gas entered the engine room and there was an explosion. The cables which will allow the emergency shutdown system to communicate with the BOP was damaged. The emergency shutdown was not successful and the BOP was unable to seal the well. This disaster led to the death of 11 workers and destruction to the environment and property.

While the impact due to oil spill was considered to be severe, British Petroleum (BP) made several attempts initially to cap the well, but their efforts failed. At last, on July 15, 2010 the Macondo well was capped to prevent any leak, finally on September 17, 2010 the well was permanently sealed (McAndrews, 2011). It has been estimated that 70% of the offshore blowout accidents happen due to human failures and the remaining 30% is attributed by technical failures (Cai et al., 2013). Specifically, in Macondo well blowout, there were a series of technical mistakes, wrong engineering judgements, improper maintenance and communication, lack of leadership, structure and component failures that wholeheartedly contributed to the tragedy.

2. Analysis from the angle of drilling operation

The blowout of Macondo well has unleashed serious fears on the offshore drilling safety. The Deepwater horizon drilling rig was thought to be safe and productive drilling unit since for past seven years from the incident, there were no personal injuries and technical damage, said by BP officials (Skogdalen et al., 2011). But on the 20th April 2010 night approximately 9.45 pm local time, gas exploded up the wellbore onto the oil platform deck and caught fire. Consequently, 11 crew members killed in the explosion of the rig. High pressures, high temperatures, complicated casing process, uncertain seismic, difficult formations, lack of skilled and experienced professionals, and high cost are such challenges involved in the deepwater drilling (Addison et al., 2010). Also, the well integrity plan was not properly established by the drilling crew in the rig. Well integrity is the combination of operational, technical, and organizational expertise to reduce the risk of uncontrolled flow of hydrocarbons from formation throughout the life cycle of the well (Norwegian Oil Industry Association, 2004). This eventually led to the release of kick, it's an unusual occurrence in which the phenomenon of hydrocarbon influx due to differences in the formation and hydrostatic pressure.

This is the major hazard associated with drilling operations and one the main reason behind the rig explosion. Generally, the mud engineer should prevent the kick formation in the way that the mud (drilling fluid) pressure is higher the formation pressure as this process is safe, but it is uneconomical due to formation damage and tedious work (Abimbola et al., 2014). Nowadays, in most of the offshore drilling, especially in the North Sea a different drilling technique is employed is called managed pressure drilling (MPD). It is an adaptive drilling process used for accurate control of the annular pressure profile throughout the wellbore (Frink, 2006). MPD offers a system of closed-loop circulation in which the bottom hole, pore, and formation fracture pressures are balanced and managed at the surface. Drilling fluid is added by surface backpressure, which can be adjusted soon in response to the conditions of the downhole compared with the conventional changes in mud weights (Schlumberger, 2016). Fig. 1 presents the general hydrocarbon well profile.

Rig crew has executed an improper cementing job and this being a second main reason for the blowout. The day before the tragedy, the cement had been pumped down the production casing and to wellbore surface for preventing the formation fluid entry into the wellbore. The annulus cement that was positioned across the main zone of hydrocarbon was a nitrified foam slurry of cement, which is light. This cement annulus probably undergone nitrogen breakout and migration, consequently allowing formation fluids to come in the annulus of wellbore. The accident investigation team concluded that there were weakness in the design and testing of cement, risk assessment and quality assurance (Executive Summary, 2010). Fig. 2 shows a typical cementing procedure for an oil and gas well.

The critical nature of cementing process is during the casing and cementing operation, liners are placed for lost circulation isolation. In practice, it is very difficult to get a good cementing job on a liner due to the less annular clearance between the liner and open hole section. Thereby, experiencing a difficulty in running and the cement slurry has been frequently susceptible to contamination by the drilling fluid (mud) and there is a frequent difficulty in succeeding engineering tolerance in linear movement for good placement of cement (Abimbola et al., 2016). Hence, it is evident that fossil fuel exploration activity in offshore environment is recognized by risk of kick during drilling and well control operations. Efficient measures must be taken when the kick is detected and if it ignored or failed to control this problem, a severe well blowout will occur, leading to a loss in machineries and lives (Feng et al., 2016). Therefore, this section describes on why human factors are critical in drilling operations and thus, there is the need for investigation of human and organizational factors associated with Macondo well blowout.

3. Process Hazard Analysis (PHA)

Generally, Process Hazard Analysis (PHA) is an organized attempt to identify and assess risks associated with chemical processes and operations to enable their control. This review normally involves the role of qualitative techniques to find out and evaluate the significance of hazards. The purpose of using PHA is to understand how it can be used as a technique to prevent accidents and to learn about debating the importance of determining the worst case scenarios. According to Kariuki and Löwe (2007) a typical PHA comprises of the following chart.

Fig. 3 shows the potential hazards chart associated with an offshore oil rig, these hazards were compiled by Christou and Konstantinidou (2012). In the first procedure, it indicates the identification of potential hazards that is the possible hazards involving around the oil rig should be identified. The second measure is to establish an engineering evaluation or administrative controls subjected to the process hazards. The last step is to evaluate and demonstrate the consequences of failure of the controls by using appropriate PHA methods like a hazard and operability study (HAZOP), fault tree analysis (FTA), Failure mode and effects analysis (FMEA), etc.

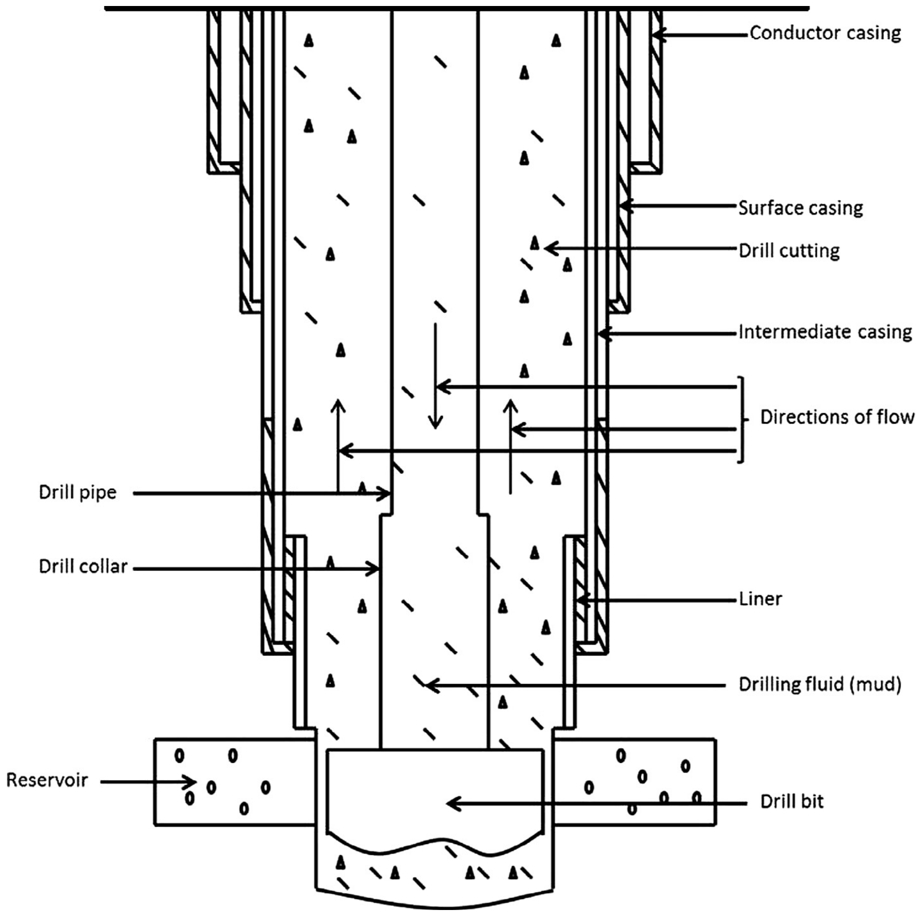

Fig. 1. A typical oil and gas well profile (Abimbola et al., 2015).

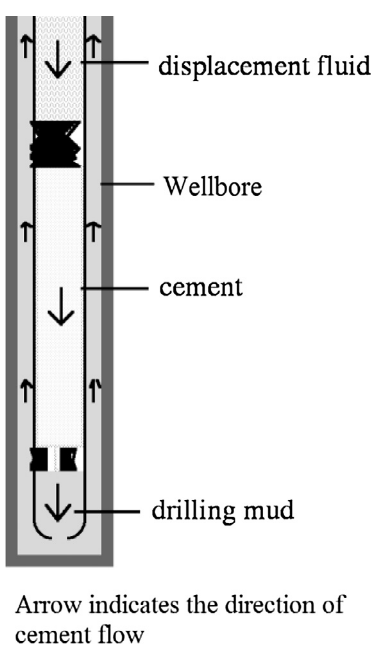

Fig. 2. A typical oil and gas cementing operation (CNX, 2016).

4. Human Factors (HF)

HF refer to the factors of environmental, organizational, job, and human, and individual characteristics, which influence behavior at work in a way that can affect health and safety (Kariuki and Löwe, 2007). Norazahar et al. (2014), developed a framework to analyze the human and organizational factors on the offshore BP drilling rig accident evacuation operations. Their framework comprises of evacuation protective and preparedness plan. Both factors were critically examined and they identified that, insufficient emergency drills, poor communication, poor safety plan, poor emergency response plan are the governing factors in the unsuccessful evacuation operations of the rig during blowout. Musharraf et al. (2013) executed an assessment of human reliability during the offshore emergency conditions. The authors studied that due to the insufficient human error in this worst case scenario most of obtainable techniques are based on the methods of expert judgement. For better understanding and analysis they have used Bayesian Network (BN) approach to evaluate and review the human reliability. This approach will minimize the uncertainty associated with existing methods. The common human failures and factors include the following.

The human failures are influenced by human factors or in other words they are responsible for the failures. The human factor is a cause and the human failure is the effect. These are of four main types as it is presented in Fig. 4. The human elements can be categorized into 3 primary types, organizational, business and individual factor. In terms of Macondo case study the underlying cause of the accident was a bad safety culture of the operator and its contractors (Christou and Konstantinidou, 2012). Baybutt (2013) guideline helps us to identify the typical human factors that cause human failures or errors, which is presented below.

(i) Insufficient skills and knowledge (OF & IF).
(ii) Fatigue (IF).

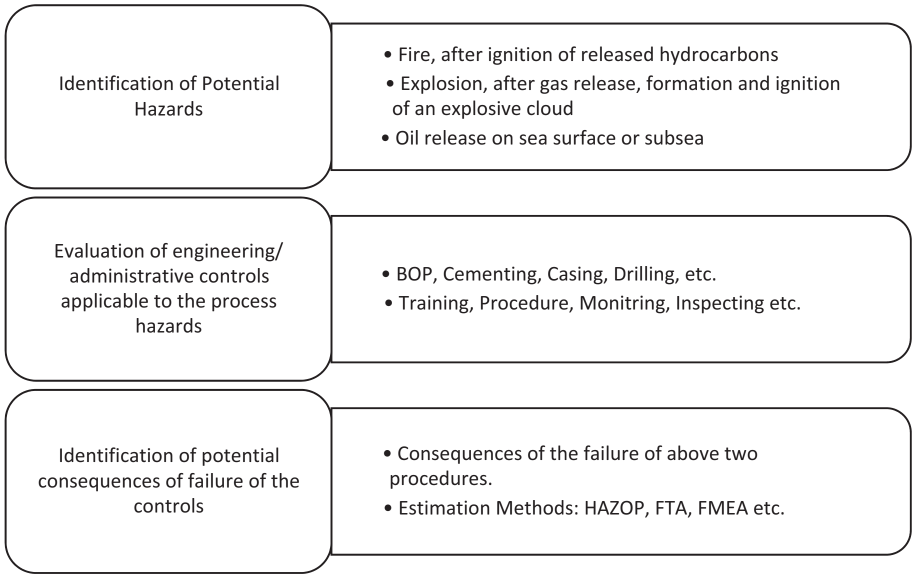

Fig. 3. PHA evaluation chart for an offshore oil rig.

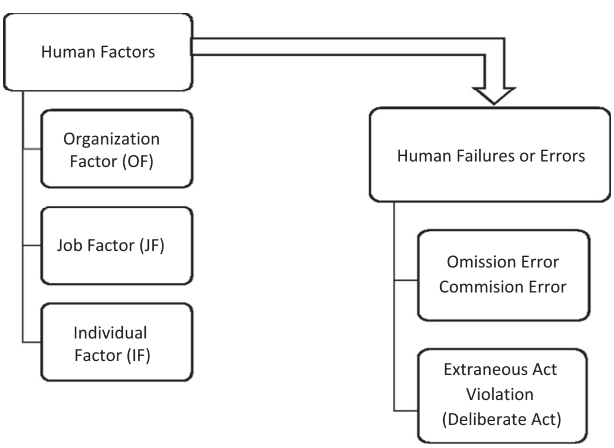

Fig. 4. Human failures and factors involved in an offshore oil platform.

(iii) Physical and Psychological problems (JF & IF).
(iv) Lack of communication (OF & IF).
(v) Lack of leadership (OF & IF).
(vi) Poor decision making (IF).
(vii) Workplace Culture (OF).
(viii) Inadequate training and experiences, etc. (IF).
(ix) Discipline (OF & IF)

Incorporating human factors analysis into PHA helps to identify, understand, control and prevent human related failures that can ensue in an accident during the performance of a process plant (Kariuki and Löwe, 2007). The following pie chart shows an empirical data on accident causes. The human error contribution to an accident is greater than accidents due to component or natural disaster, the typical cause of any accident is due to 85% of human errors and 15% associated with the machine, structural and natural disaster (Bridges et al., 1991). The methodology for integration of human factors into PHA encompasses of computing the human factors with its several attributes. For example, the factor workplace design (WD) if required in a subject area, its all or whatsoever of the matching attributes such as facility layout (F1), workstation configuration (F2), accessibility (F3) should be taken. The theory of integration of the human factors into PHA is about finding the root causes of an event. If simply attributing to "human error" without assessing the root cause infers that the errors are inevitable, unforeseeable, and uncontrollable (Bridges et al., 1991). Fig. 5 shows the fault tree analysis for Macondo well, this emphasize the seriousness of failure sequences leading to the well blowout.

4.1. Hazardous conditions in Macondo well

Rathnayaka et al. (2013), made a risk assessment and safety critical decision making framework to a BP offshore accident in the Mexican Gulf. The authors have identified and analyzed the various engineering and safety challenges associated with the drilling rig. Failure of continuous risk assessment and decision making were emerged to be the major reasons for this catastrophic effect. Their framework assisted them to find and predict the DWH hazards and methodology for prevention. Their framework of risk assessment can be used to examine the following in the offshore oil platform:

- Different severity levels occurrence probability.
- Dynamic and aggregated risk profile.
- Safety barriers dynamic performance.
- Making critical decisions with regards to aggregated risk profile.

The identification of hazardous conditions in a workplace would be helpful in performing analytical hierarchy process (AHP), calculating the consistency and quality index.

The hazardous conditions in our workplace as follows:

- Undetected entry of high pressure/temperature hydrocarbons flowing into the wellbore.
- Improper cementing.
- Lack of Skilled Engineers.
- Inadequate maintenance.
- Inadequate inspections.
- Faulty BOP (Including faulty batteries and valves)
- Outdated computer
- Failed to create and apply a program of regulatory oversight (Government, relying on industry assertions).
- Emergency alarm failure, and
- Shut down equipment failure.

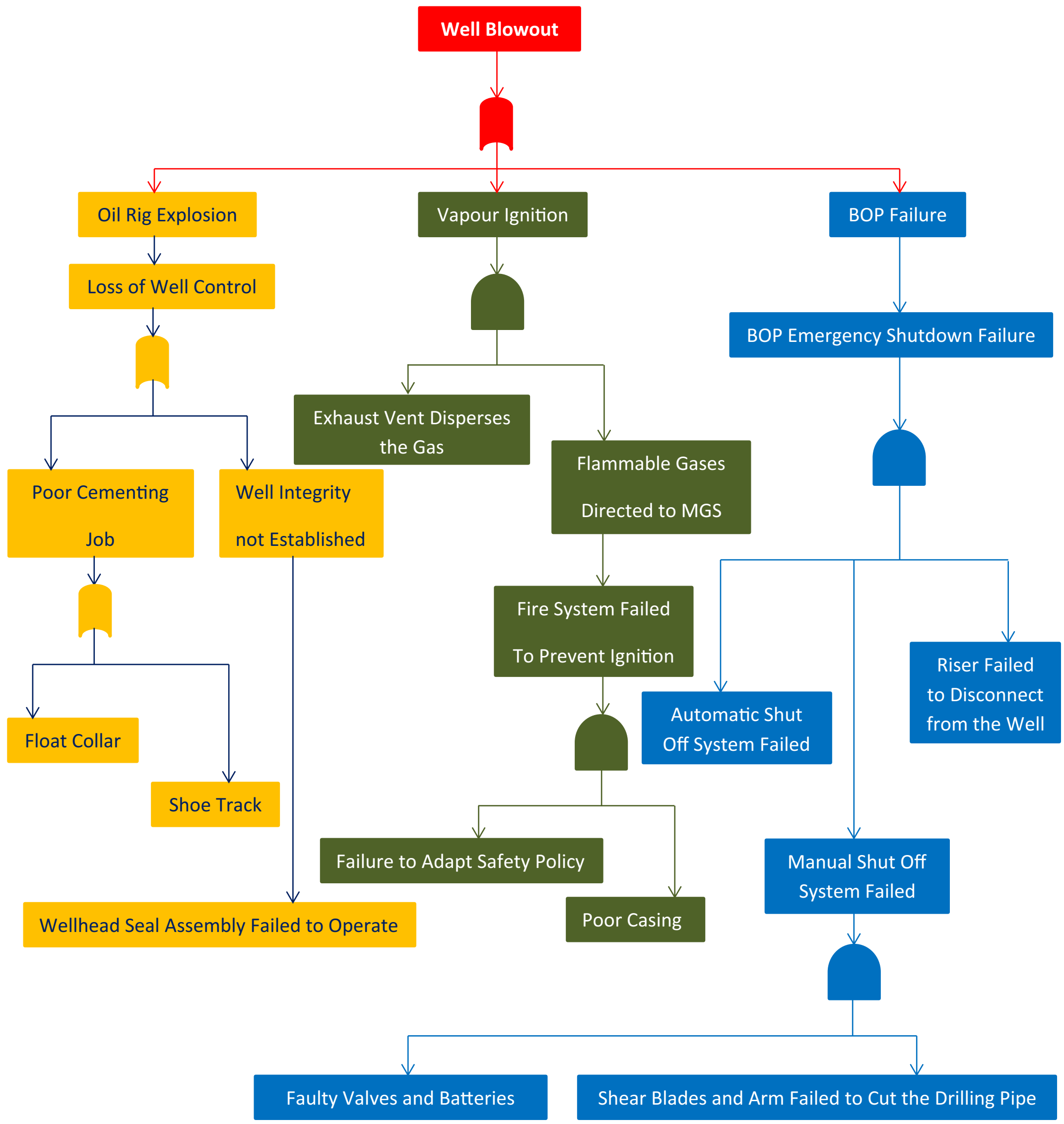

Fig. 5. Fault tree analysis for Macondo well.

These ten hazardous conditions has significant contribution to the well blowout.

5. Human factor and AHP analysis

Table 1 shows the human factor analysis chart with basic events and its attributes. This table or matrix analysis is initiated to find the human failure contribution to process risk. Every factor influencing the existence of human failure is identified.

Analytic Hierarchy Process (AHP) is a technique developed by Saaty (1980) for solving complex decision problems by using a hierarchical structure, which expresses problems into some attributes. The first step in AHP is to identify the attributes that influence the decisions made. The next step is to determine the relative influence of each attribute on the performance by producing a numerical judgement scale of 1–9.

On the scale, each attribute is judged by its importance to others in a matrix pairwise comparison whereby the matrix pairwise was considering using not more than 7. People are not always consistent and this may lead to confusion in calculating eigen vectors. Saaty (1980) defined Consistency ratio as the ratio of the consistency index CI to an average consistency index RI, CR = CI/RI.

He suggested that the resulting Consistence Ratio should lie between $0 \leqslant CR \leqslant 0.1$ if otherwise the matrix is not consistent. The Random index is generated by Saaty's team by computing the mean of CI value. The Consistency index can be calculated from comparison matrix:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

where λ_{max} is the greatest eigenvalue of the matrix of pairwise comparison and n the order of the matrix. Tables 5–8 show the matrix pairwise of attributes contributing to the initiating events. The pairwise comparisons were considered using not more than 7.

The Quality Index QI is calculated from the weights w and performance measures r, of human factors behind each human error event. The r_{max} used in the calculation is 7

$$\beta = w_1 r_1 + w_2 r_2 + \ldots\ldots w_n r_n / r_{max} \ (w_1 + w_2 + \ldots\ldots + w_n), \quad (2)$$

$$\sum_{i=1}^{n} w_i r_i / r_{max} \sum_{i=1}^{n} w_i = \sum_{i=1}^{n} w_i r_i / r_{max} \quad (3)$$

Table 1
Human factor analysis chart.

Basic events	Organization	Information	Human-system interface	Workplace design	Operator characteristics	Task environment
Failure of BOP	Safety policy, organizational learning (audit and reviews)	Documentation	Equipment and valves		Attention	
Improper cementing	Safety policy	Training procedures	Design of control	Facility layout	Skills and knowledge	Temperature and pressure
Misinterpretation of the negative pressure test	Supervision, organizational learning	Procedures, communication, documentation			Skills and knowledge	Temperature and pressure
Loss of well control	Safety policy	Training, communication	Equipment and valve		Skills and knowledge	–
Fire and gas system fails to prevent ignition	Safety policy, supervision	Procedures		Facility layout	Skills and knowledge	–

β should have a maximum value of 100% or 1. The human factor analysis is better when β approaches 100%, this means that human error has been reduced. Table 2 presents the RI used in the calculating the consistency ratio.

The above Table 3 shows pairwise matrix scale developed by Saaty (1980) which is used in calculating the consistency Index and Consistency ratio. For example 'Improper cementing' the attributes identified as critical for this human error event are Safety policy, Training, communication, design of control, skills and knowledge and temperature and pressure. A pairwise matrix of 7×7 is constructed based on the level of importance of the attributes. The consistency ratio and the Quality index are then calculated based on the formula stated earlier.

The above Table 4 shows the rating used in calculating the Quality Index. It is calculated by multiplying the rate given to one attribute by the relative weight for each attribute.

In this study, we have taken 7×7 matrix to evaluate the major human factor influencing improper cementing, there are seven basic events that include, safety policy, training, communication, design of control, facility, skills and knowledge, and temperature. From the calculations of weight, it was revealed that out of seven events the training was the major contributing factor in the improper cementing job accounting for 30.2%.

Table 6 shows 7×7 matrix made to estimate the major human factor influencing misinterpretation of negative pressure test, seven basic events were taken which includes organizational learning, supervision, procedures, communication, documentation, skills and knowledge, and temperature.

From the table, it was found that out of seven events the procedure was the main contributing factor in the misinterpretation of the negative pressure test and its percentage of contribution is 30.6%, this is because the oil platform crew did not follow BP procedures properly.

In this section, we have taken 5×5 matrix to assess the major human factor influencing failure to gain control of well control response, there are five basic events which include, supervision, training, communication, equipment and valves, and skills & knowledge. With grounded on the results of the weight calculations, it was clear that out of five events, training was the major contributing factor of the event which has a weight of 31.1%, this is due to inadequate training of the crew.

In Table 8, we have taken 5×5 matrix to appraise the major human factor influencing fire and gas system failure, there are five basic events which include, safety policy, supervision, procedures, facility layout, skills and knowledge. From the interpretation of the calculations of weight, it was evaluated that out of five events the procedure was found to be 34.1%, rendering the major contributing factor in fire and gas system failure.

Table 9 shows a 5×5 matrix to compute the major human factor influencing in the failure of BOP to seal the well, there are five basic events which are, safety policy, organizational learning, documentation, equipment and valves and attention. Established on the calculations of weight, it was observed that out of five events the safety policy was the major contributing factor in the failure of BOP to seal the well test with a weight of 33.6%.

Based on the method implemented by kariuki and Löwe, 2007 the overall qualification of influencing factors can be tabulated as it is shown in Tables 10 and 11. Table 10 provides the poor grade for all factors which influencing the Macondo well, this clearly indicates this is mainly due to human error. Overall, from the analysis, it can be stated that the human negligence of hazardous

Table 3
Saaty (1980) matrix pairwise scale.

	Definition	Explanation
1	Equal importance	This is when two factors are equally important
3	Moderate importance	When one factor is slightly more important than the other
5	Strong importance	One factor is strongly favoured over the other
7	Very strong importance	When one factor is very strongly favoured over the other
9	Extreme importance	When an activity is extremely favoured over another
2, 4, 6, 8	Intermediate values	When there is a need to comprise

Table 4
Rating of attributes.

Meets all/most standards	Outstanding	7
	Excellent	6
	Very good	5
	Average	4
	Below average	3
	Poor	2
Fails to meet any standards	Very poor	1

Table 2
Values for random consistency index.

N	1	2	3	4	5	6	7	8	9	10
Random index	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 5
Matrix of Pairwise and Relative weight of Human factors Influencing Improper Cementing.

Basic event	Safety Policy	Training	Communication	Design of control	Facility layout	Skills and knowledge	Temperature and pressure	Calculated weight	Rating (r)	Weighted score (w)
Safety policy	1	½	½	5	5	5	7	0.194	2	0.38814
Training	2	1	1	7	7	7	7	0.302	2	0.6036
Communication	2	1	1	5	5	5	5	0.255	2	0.5109
Design of control	1/5	1/7	1/5	1	2	1/5	5	0.059	4	0.2374
Facility	1/5	1/7	1/5	½	1	1/7	4	0.046	4	0.1858
Skills and knowledge	1/5	1/7	1/5	5	7	1	1	0.116	3	0.3475
Temperature	1/7	1/7	1/5	1/5	¼	1/5	1	0.027	4	0.1082
					CR = 0.016				QI	34%

Consistency Index (CI) = ($\lambda_{max} - n$)(n − 1) = (7.127–7)/6 = 0.022.
Consistency Ratio (CR) = CI/RI = 0.016.
Rmax = 7.
Quality Index = $\sum wr/r_{max}$ = 34.

Table 6
Matrix of pairwise and relative weight of human factors influencing misinterpretation of the negative pressure test.

Basic event	Organizational learning	Supervision	Procedures	Communication	Documentation	Skills and knowledge	Temperature	Calculative weight	Rating	Weighted score
Organizational learning	1	1	1/5	1/5	1	½	1/5	0.058	3	0.1753
Supervision	1	1	1/7	¼	1	2	4	0.103	3	0.3097
Procedures	5	7	1	1	2	4	5	0.306	2	0.6119
Communication	5	4	1	1	2	2	3	0.237	2	0.4741
Skills and knowledge	2	1/5	¼	½	1	1	3	0.10	3	0.2990
Temperature and pressure	5	¼	1/5	1/3	1/5	1/3	1	0.074	4	0.2961
							CR = 0.038			QI = 36%

Consistency Index (CI) = ($\lambda_{max} - n$)(n − 1) = (7.297–7)/6 = 0.05.
Consistency Ratio (CR) = CI/RI = 0.038.
Rmax = 7.
Quality Index = $\sum wr/r_{max}$ = 36%.

Table 7
Relative weight of human factors influencing failure to gain control of well control response.

Basic event	Supervision	Training	Communication	Equipment & valve	Skills and knowledge	Calculated weight	Rating	Weighted score
Supervision	1	½	1	3	1	0.188	3	0.5644
Training	2	1	1	5	2	0.311	2	0.6222
Communication	1	1	1	5	2	0.274	2	0.5472
Equipment & valve	1/3	¼	1/5	1	¼	0.055	3	0.1648
Skills and knowledge	1	½	½	4	1	0.172	3	0.5167
					CR = 0.016			27%

Consistency Index (CI) = ($\lambda_{max} - n$)(n − 1) = (5.072–5)/4 = 0.018.
Consistency Ratio (CR) = CI/RI = 0.016.
Quality Index = $\sum wr/r_{max}$ = 27%.

Table 8
Relative weight of human factors influencing Fire and Gas System Failure to Prevent Ignition.

Basic event	Safety policy	Supervision	Procedures	Facility layout	Skills and knowledge	Calculated weight	Rating	Weighted score
Safety policy	1	2	1	3	2	0.285	2	0.5706
Supervision	½	1	½	3	1	0.164	3	0.4922
Procedures	1	2	1	5	3	0.341	2	0.6810
Facility layout	1/3	1/3	1/5	1	½	0.071	4	0.2853
Skills and knowledge	½	1	1/3	2	1	0.139	3	0.4164
						CR = 0.012		35%

Consistency Index (CI) = ($\lambda_{max} - n$)(n − 1) = (5.056–5)/4 = 0.014.
Consistency Ratio (CR) = CI/RI = 0.012.
Quality Index = $\sum wr/r_{max}$ = 35%.

Table 9
Relative weight of Human Factors Influencing Failure of BOP to seal the well.

Basic event	Safety policy	Organizational learning	Documentation	Equipment & valve	Attention	Calculated weight	Rating	Weighted score
Safety Policy	1	2	4	5	1	0.336	2	0.67295
Organizational learning	½	1	1	3	½	0.152	3	0.4553
Documentation	¼	1	1	5	1/3	0.145	3	0.4346
Equipment & valve	1/5		1/5	1	1/5	0.052	3	0.1564
Attention	1	2	3	5	1	0.315	2	0.6295
						CR = 0.039		34%

Consistency Index (CI) = ($\lambda_{max} - n$)(n − 1) = (5.056–5)/4 = 0.044.
Consistency Ratio (CR) = CI/RI = 0.039.
Quality Index = $\sum wr/r_{max}$ = 34%.

Table 10
Overall qualification of influencing factors (Kariuki and Löwe, 2007).

Percentage score	Description of HF defenses
91% or more	Excellent
76–90%	Above average
66–75%	Good, average
46–65%	Below average
45% or less	Poor

Table 11
Overall qualification of influencing factors in the case of BP DWH disaster.

Factors	Percentage score (%)	Description of HF on Macondo well
Improper cementing job	34	Poor
Negative pressure test	36	Poor
Failure to gain control of well response	27	Poor
Fire and gas system failed to prevent ignition	35	Poor
Failure of BOP to seal the well	34	Poor

threat, and lack of knowledge and skill led to an explosion of Macondo well which is regarded as a catastrophic event in offshore petroleum industry.

6. Discussion

The federal board of investigation into the 2010 BP oil spill says that a last ditch safety device on the underwater well had multiple failures, wasn't tested properly and still poses a risk for many offshore drilling platforms. The report issued by the US chemical safety board indicates what went wrong with the BOP and blames bas management and operations. They found faulty wiring in two places, a dead battery and a bent pipe in the hulking device. And that, they said, led to the dumping of 172 m gallons of oil into the Gulf of Mexico and the nation's worst offshore oil disaster (Federal Investigation Board, 2010). FTA is a top down, deductive failure analysis was developed in 1962 at Bell Laboratories by H. A. Watson (Ericson, 1999). The fault tree analysis was successfully executed for Macondo well blowout, it can be seen from Fig. 4 that the top event is taken as well blowout consequently three events was drawn, they are oil rig explosion, vapor Ignition, and BOP failure. The BOP is considered as a critical factor, this top event is marked by OR gate which indicates that the output occurs if any input occurs. If any event, for example the BOP failure event happened then the Macondo well will explode. The AND gate indicates that the output occurs if all the input occurs, in other words the top event will fail if all the subsequent event fails. Similarly, the FTA was performed till least possible deducted event. Although FTA can be employed to estimate the probability of an event, that is only used for illustrating the structures of human errors, but not for calculation (Cai et al., 2013). Even the BP incident investigated team used fault tree to define and classify the various scenarios of this accident and their FTA modelling had well agreed with our FTA model. They have indicated that FTA modelling will help the investigation team to rectify the accident causes soon and it will be effective for future decision making on safety policy (Executive Summary, 2010).

After FTA process the hazardous conditions in the workplace have been distinguished, then the human factor along with the analytic hierarchy process were modelled and analyzed. In Table 1 of human factor analysis (HFA) chart, in the BP offshore disaster case, 6 factors were identified to influence the basic events such as failure of BOP, improper cementing, misinterpretation of the negative pressure test, loss of well control, and fire and gas system fails to prevent ignition. It is evident from Fig. 2 that human error is always influenced or controlled by the human factor. We are associating this scenario with a multi-response optimization model, as mentioned below.

$$MROM = (L)^n \tag{4}$$

where,
MROM = Multiple Response Optimizational Matrix.
L = Number of Human Factor Variables in DWH Disaster.
n = Number of Basic Event Variables in DWH Disaster.

MROM is like a boundary condition of a problem with that we can optimize or find a dominating cause of an event. Here this HFA chart has standard 6 human factor variables and 5 basic events. By substituting these values in Eq. (4) we get

$$(6)^5 = 5 \times 6$$

Hence, within this boundary condition, we can able to take further analysis, AHP. It was applied to estimate the consistency index (CI) and Quality Index (QI), and this was performed based on a method suggested by Saaty, 1980. From the analytical results it was remarked that the QI for all the five factors go down below 45% an overall qualification of influencing factors, which is rated as poor. The factor "failure to gain control of well response" received the lowest score 27%. This is due to kick an unwanted influx of formation fluids into the wellbore as a result of loss of well control, in consequence it results in a blowout (Khakzad et al., 2013).

The cascade of deeply flawed failure and signal analysis, decision making, communicating, and organization-managerial processes, safety was compromised to the point that the blowout occurred with the disastrous effects. The study from the available evidence point out that poor decision making and dynamic leadership played crucial role in accident causation (Center for Catastrophic Risk Management, 2011). Even the national commission and senate report on BP deepwater horizon claims that BP crew carried wrong drilling operation at the beginning. Afterwards, there were many incorrect engineering judgement, poor communication, weak leadership and ignoring the risk associated with the tractor trailer. On the whole, the investigators concluded that the BP crew breached the safety regulations and this incident could be prevented if proper technical and organizational decisions were taken (Graham et al., 2011). Therefore, this paper results are well justified and there is a potential need for dynamic leadership skill and effective decision making of both engineering and management operations in a hazardous offshore environment to avoid this calamitous accident.

7. Conclusions

This paper has clearly demonstrated that, the DWH incident at Gulf of Mexico is entirely due to human errors and poor dynamic leadership skills. Improper leadership and co-ordination were prevailing in the top, middle, and lower management of the BP oil giant company. Also, an analysis was made with regards to drilling operation. The energy industries are taking up more advanced technologies to research and produce hydrocarbons in a hazardous environmental conditions. Afterwards, they neglected to implement necessary Health, Safety, and Environment (HSE) principles, due to this carelessness that leads to a severe holocaust. Based on the results of the human and organizational factor analysis, it can be implicated that, the factor failure to gain control of well response was estimated to be the least percentage score accounting for 27%. Out of five factors only negative pressure test factors were observed to be 36%, which is considered as highest percentage score. Hence, all the five factors which were taken in a study have their percentage scores below 45%, which is graded as poor, and has significant contribution to the disaster. Finally, to conclude that this incident was completely because of human errors and this report analytical finding supported this assertion. Accidents like this can be prevented by applying adequate knowledge, experience, training, good HSE policy and ultimately effective leadership skills.

Acknowledgement

We would like to thank Mr. Stephen Theophilus, Lecturer in Petroleum and Environmental Technology and Mr Mark Taylor, HSE Consultant at Coventry University for providing suggestions to improve the paper structure and content. Also, the corresponding author heartily thank two anonymous reviewers for their constructive comments which consequently improved this paper quality.

References

Abimbola, M., Khan, F., Khakzad, N., 2014. Dynamic safety risk analysis of offshore drilling. J. Loss Prev. Process Ind. 30, 74–85.

Abimbola, M., Khan, F., Khakzad, N., Butt, S., 2015. Safety and risk analysis of managed pressure drilling operation using Bayesian network. Saf. Sci. 76, 133–144.

Abimbola, M., Khan, F., Khakzad, N., 2016. Risk-based safety analysis of well integrity operations. Saf. Sci. 84, 149–160.

Addison, F., Kennelley, K., Botros, F., 2010. SS: Thunder Horse and Atlantis deepwater frontier developments in the Gulf of Mexico: future challenges for deepwater developments. In: Offshore Technology Conference. Held 2010 at Houston, Texas, USA. SPE, pp. 1–5.

Baybutt, P., 2013. The role of people and human factors in performing process hazard analysis and layers of protection analysis. J. Loss Prev. Process Ind. 26 (6), 1352–1365.

Bridges, W., Lorenzo, D., Kirkman, J., 1991. Addressing human errors during process hazard analyses. In: PSM Symposium Held 1991 at Knoxville, Tennessee, USA. CCPS/AIChE, pp. 1–8.

Cai, B., Liu, Y., Zhang, Y., Fan, Q., Liu, Z., Tian, X., 2013. A dynamic Bayesian networks modeling of human factors on offshore blowouts. J. Loss Prev. Process Ind. 26 (4), 639–649.

Center for Catastrophic Risk Management (CCRM), 2011. Final Report on the Investigation of the Macondo Well Blowout. The University of California Berkely, Berkely, California, USA.

Christou, M., Konstantinidou, M., 2012. Safety of Offshore Oil and Gas Operations: Lessons from Past Accident Analysis. JRC Scientific and Policy Reports, Luxembourg.

Ericson, C., 1999. Fault tree analysis - a history. In held 1999. In: Proceedings of the 17th International Systems Safety Conference.

Executive Summary, 2010. Deepwater Horizon Accident Investigation Report. BP, Houston.

Federal Board Investigation, 2010. Investigation into 2010 BP Oil Spill finds Failures, Poor Testing and Ongoing Risks. Available from <https://www.theguardian.com/environment/2014/jun/05/bp-deepwater-horizon-spill-report-failures-risks> (26 August 2016).

Feng, J., Fu, J., Chen, P., Luo, J., Liu, Z., Wei, H., 2016. An advanced Driller's method simulator for deepwater well control. J. Loss Prev. Process Ind. 39, 131–140.

Frink, P., 2006. Managed Pressure Drilling — What's In A Name? In: SPE/IADC Managed Pressure Drilling & Underbalanced Operations Conference & Exhibition. Held 2006 at Galveston, Texas, USA. SPE & IADC, pp. 1–3.

Graham, B., Reilly, W., Beinecke, F., Boesch, D., Garcia, T., Murray, C., Ulmer, F., 2011. Deep Water the Gulf Oil Disaster and the Future of Offshore Drilling, Report to the President. National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Washington DC, USA.

Hofmeister, J., 2013. Lafayette Chamber of Commerce "Business for Business". Held 2013 Louisiana.

Judy, C., Graham, S., Lin, Q., Hou, A., Mendelssohn, I., 2014. Impacts of Macondo oil from Deepwater Horizon Spill on the growth response of the common reed Phragmites Australis: a mesocosm study. Mar. Pollut. Bull. 79 (1–2), 69–76.

Kariuki, S., Löwe, K., 2007. Integrating human factors into process hazard analysis. Reliab. Eng. Syst. Safe. 92 (12), 1764–1773.

Khakzad, N., Khan, F., Amyotte, P., 2013. Quantitative risk analysis of offshore drilling operations: a Bayesian approach. Saf. Sci. 57, 108–117.

Managed Pressure Drilling, 2016/Schlumberger. Available from <http://www.slb.com/services/drilling/drilling_services_systems/mpd-services-and-equipment.aspx> (28 August 2016).

McAndrews, K., 2011. Consequence of Macondo: A Summary of Recently Proposed and Enacted Changes to U.S. Offshore Drilling Safety and Environmental Regulation. In: E&P Health, Safety, Security and Environment Conference, Held 2011 in Houston, Texas. Society of Petroleum Engineers (1 to 9 available from <http://www.jsg.utexas.edu/news/files/mcandrews_spe_143718-pp.pdf> [14 March 2015]).

Michel, J., Owens, E., Zengel, S., Graham, A., Nixon, Z., Allard, T., Holton, W., Reimer, P., Lamarche, A., White, M., Rutherford, N., Childs, C., Mauseth, G., Challenger, G., Taylor, T., 2013. Extent and Degree of Shoreline Oiling: Deepwater Horizon Oil Spill, Gulf of Mexico. US National Library of Medicine National Institutes of Health, USA (Supplemental Information).

Musharraf, M., Hassan, J., Khan, F., Veitch, B., MacKinnon, S., Imtiaz, S., 2013. Human reliability assessment during offshore emergency conditions. Saf. Sci. 59, 19–27.

Norazahar, N., Khan, F., Veitch, B., MacKinnon, S., 2014. Human and organizational factors assessment of the evacuation operation of BP deepwater horizon accident. Saf. Sci. 70, 41–49.

Norwegian Oil Industry Association, 2004. Well Integrity in Drilling and Well Operations. NORSOK STANDARD. Norwegian Petroleum Industry, Oslo, Norway.

Openstax CNX. Available from <https://cnx.org/contents/fdf20769-4331-4bd9-9227-acfafca1e914@10> [27 August 2016].

Rathnayaka, S., Khan, F., Amayotte, P., 2013. Accident modeling and risk assessment framework for safety critical decision-making: application to deepwater drilling operation. Proc. Inst. Mech. Eng. O: J. Risk Reliab. 227 (1), 86–105.

Saaty, T., 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.

Skogdalen, J., Utne, I., Vinnem, J., 2011. Developing safety indicators for preventing offshore oil and gas deepwater drilling blowouts. Saf. Sci. 49 (8–9), 1187–1199.

Zhou, Z., Liu, Z., Guo, L., 2013. Chemical evolution of Macondo crude oil during laboratory degradation as characterized by fluorescence EEMS and hydrocarbon composition. Mar. Pollut. Bull. 66 (1–2), 164–175.