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Human Error Analysis of the Macondo Well Blowout

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Abstract

The Macondo well blowout resulted in 11 fatalities and caused the largest non-intentional oil spill in history. The situation stemmed from a series of human errors through all stages of the project leading up to the blowout and subsequent explosion. These errors include faulty interpretation of signals indicating problems with well and safety system integrity, inappropriate modifications to safety systems, inadequate design of critical systems, failure to provide redundancy in the design stage, failure to adhere to administrative controls for the safe operation, failure to follow the American Petroleum Institute Recommended Practices 75 on drilling mud circulation, and others. Twenty five specific errors were identified and classified into eight categories. The results show that the majority of the errors are latent errors and caused by poor leadership in the organization or management. In order to resolve these issues it is necessary to create a safety culture in which safety is paramount in operations and facilities. The lessons learned from this incident are many, but the most important lesson is that safety must be a way of life, beginning in the design stage and carrying through the entire project life cycle.

Keywords: Macondo well; blowout; human error; latent error; incident analysis

Introduction

The Deepwater Horizon was a fifth-generation semi-submersible mobile offshore drilling unit (MODU), measuring 396 feet long and 256 feet wide, and was capable of operating in water depths of up to 8,000 feet [1]. It was owned by Transocean and leased by BP at a daily cost of $533,000 for the purpose of performing exploratory drilling operations in BP's Macando Prospect located in Mississippi Canyon Block 252 off the Gulf of Mexico [2, 3]. Other companies involved in the Macondo drilling process were Halliburton and Cameron. Halliburton performed the cementing operations for the well and well cap, and Cameron manufactured the Deepwater Horizon's blowout preventer (BOP) [4, 5].

At approximately 22:00 hours on April 20, 2010 a blowout occurred causing an explosion and ensuing a fire on the Deepwater Horizon rig, killing 11 workers, and injuring 17 others [6]. When the disaster occurred, the Macondo was undergoing a process of temporary abandonment [7]. Two days following the initial explosion, the Deepwater Horizon rig sank, breaking the riser pipe which was still attached to the blowout preventer at the wellhead on the seafloor. This resulted in the largest non-intentional oil spill in history [8]. Approximately 4.9 million bbls of oil were released into the Gulf of Mexico before the well was capped on July 15, 2010 [9].

This work used the availble news, reports and proceedings regarding the Macondo well blowout incident to identify the likely causes, especially human errors. An error clasification system was developed in order to gain a better understanding of what events preceded the incident and hence these types of events could be further studied and ultimately prevented in the future. The work summarizes some critical safety issues that need to be resolved for a safe offshore exploration and production and provides a good insight into the incident analysis of the Macondo disaster.

Methodology

Several critical events occurred in the days and hours before the Macondo disaster that culminated to allow the incident to occur. A critical event is defined as an event or action which could have directly reduced or eliminated the likelihood of the disaster if it had been performed correctly or avoided. Several critical events that have been identified in the investigation of the incident include: The annulus cement barrier did not isolate the hydrocarbons (HC); the shoe track barriers did not isolate HC; the negative-pressure test was misinterpreted; a large HC influx was not recognized until it reached the riser; well control response actions failed to regain control of the well; the design of HVAC fire and gas detection did not prevent the ignition of HC; and the BOP emergency controls failed to seal the well [7, 10].

Multiple human errors have been attributed to the cause of the above seven critical events in the Macondo well blowout. An error classification system was developed to organize errors into eight categories related to human error. The error classifications identify errors in:

- **Design**: Error resulting from a poor design that causes equipment or a process's failure to function as originally intended.
- **Maintenance/Testing:** Error resulting from a failure to follow the appropriate guidelines on maintenance and testing of equipment.
- **Policy/Procedure:** Error resulting from a failure to have and/or adhere to an adequate policy or procedure.
- **Training**: Error resulting from a lack of adequate training.
- **Decision Making**: Error resulting from a decision made in which safety was not the primary factor.
- **Organization/Management**: Error caused by poor leadership in the organization or management due to a weakness in the safety culture.

- **Risk Perception/Risk Acceptance**: Error resulting from actions with an unacceptable level of risk due to a weakness in the safety culture.
- **Communication**: Error resulting from a failure to send or receive information.

Errors were also classified as *active or latent errors*. The effects of an active error can be seen almost immediately, and active errors are usually associated with the performance of front line operators [11, 12]. Effects of latent errors may not appear for a long time until combined with other factors to cause an incident [11]. Latent errors are most often generated by persons at the end of the system such as high-level decision makers, designers, managers, or maintenance personnel. These individuals are often located away from any of the direct hazards that are associated with the operation giving them a greater potential to introduce hazards into the system. Latent errors present the greatest threat to safety in a complex system such as drilling rig operation. While operators do make errors, they tend to more frequently inherit system defects created by inadequate design, incorrect installation, improper maintenance, and poor management decisions.

Results and Discussion

Situational Awareness (SA) and human cognition are crucial to the safe operation of complex systems. The level of Situational Awareness is often directly related to the level of safety found during an operation [13]. If workers lack an adequate understanding of their surroundings and worksite they are more likely to commit an error which may lead to an incident. It has been reported that human factors cause 70-80% of incidents in high-hazard industries [13]. During the drilling process, the occurrence of a kick or blowout is likely and extremely dangerous, and workers must maintain proper Situational Awareness and monitor well conditions to reduce the risk and/or severity of an incident.

There are three levels of Situational Awareness: 1) perception, 2) comprehension or information integration, and 3) projection [13]. Most problems with Situational Awareness occur during the first level when information and data is perceived. Some factors that affect Situational Awareness have been identified as: fatigue, stress and workload, routine tasks, weather conditions, communication, experience level, and personal problems. Some indicators of reduced awareness have been identified as change in a workers character, reduced communication, the need for repetition of instructions, reduced expressions, and a reduced work standard [13]. Situational Awareness can be improved by increased communication, an individual's removal from the situation, altering the work level, training, and discussion of events. Because surroundings on a drilling rig can change quickly and unexpectedly, maintaining a high level Situational Awareness is critical [13].

In addition to classifying each type of error, the American Petroleum Institute (API) Recommended Practice (RP) 75: Development of a Safety and Environmental Management Program for Offshore Operations and Facilities was applied to study this incident [14]. It was determined to be a viable management program which would have prevented a majority of these errors from occurring.

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Table 1 summarizes each error leading up to the Macondo disaster, its classification, and the relevant API RP 75 section. Twenty five errors have been identified in the Macondo well blowout disaster and assigned into each category. The symbol "◊" denotes that the classification of the error can be made with a high degree of certainty based upon the available evidence. The symbol "‡" denotes that the supporting evidence strongly suggests that the error should be classified as a particular error type.

Based on the data contained in Table 1, it is concluded that the majority of the errors (20 out of 25) leading up to the Macondo disaster are latent errors, and are attributable to the organization as a whole. Figure 1 summarizes the number of errors that are considered to be significant contributors to the incident. The figure shows that 19 errors can be classified to the errors in organization or management caused by poor leadership. The results indicate a weakness in the safety culture which needs to be improved immediately in the future.

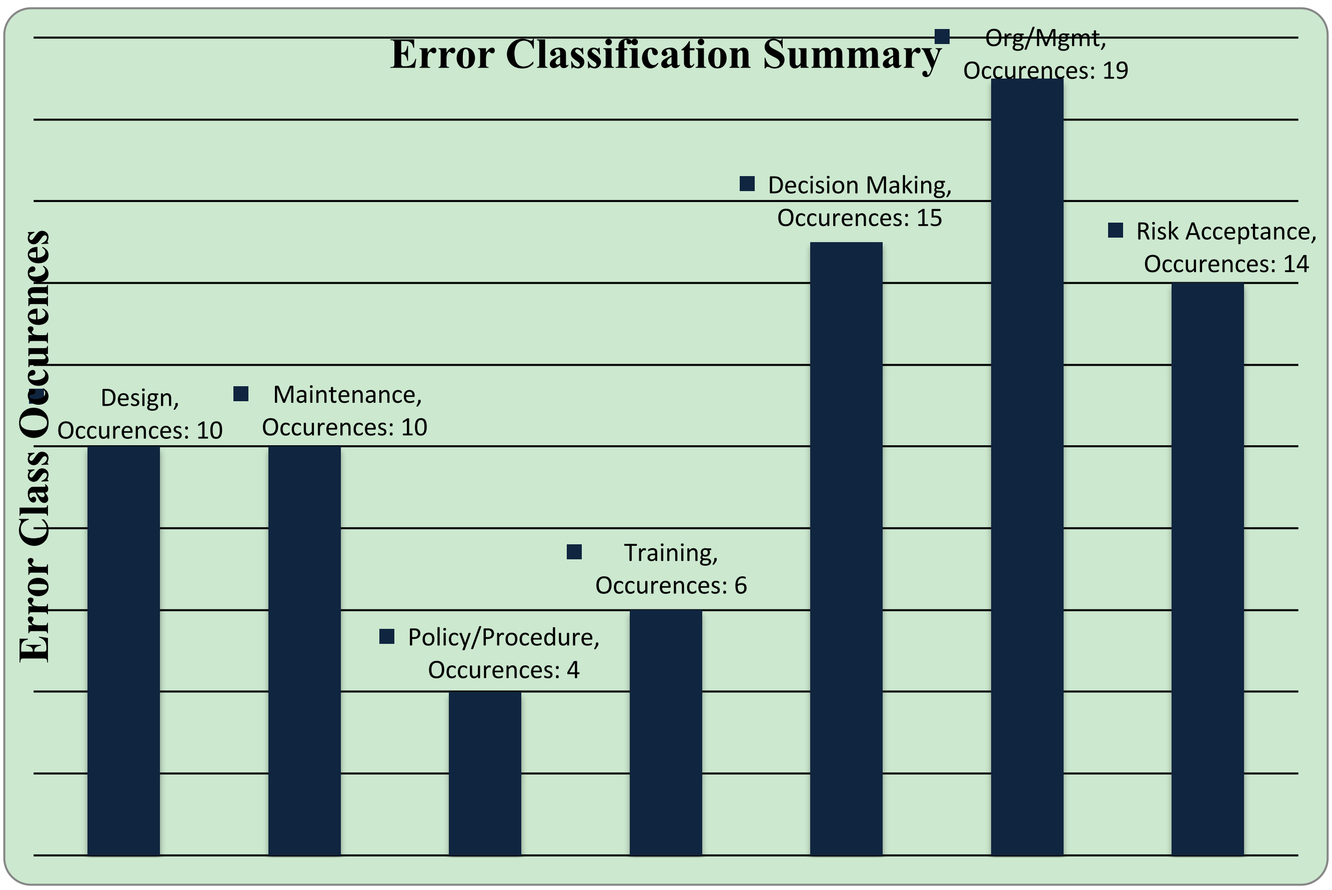

Figure 1 – Macondo Incident Error Classification Summary

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Table 1 – Macondo Incident Error Classification

Error	Type of Error									
	Design	Maintenance/ Testing	Policies/ Procedures	Training	Decision Making	Organization/ Management	Risk Perception/ Acceptance	Communi-cation	Active/ Latent	Relevant API 75 Sections
A "lessons learned" document from a well control incident on March 8, 2010 was ignored.			◊		◊	◊	◊		Latent	11
BOP testing procedures were questionable; passed function test on April 17, 2010.		◊				‡			Latent	5,7,8
A decision was made to cement the long string casing across the entire open-hole section of the well in a single operational step over multiple pressure gradients.					◊	◊	◊		Latent	3,4,5
Cement slurry was used without passing Halliburton lab tests which simulated known well conditions.		◊	◊		◊	◊	◊		Latent	3,5,6
Cement was pumped at a substandard flow ate and quantity in order to prevent increasing pressure on the formation and reduce the risk of lost returns.	◊				◊	◊	◊		Latent	3
Insufficient number of centralizers used.	◊		◊		◊	◊	◊	◊	Latent	3,4,5,6

Key

◊: Denotes that the classification of the error can be made with a high degree of certainty based upon the supporting evidence.

‡: The symbol "‡" denotes that the classification of the error is strongly supported by the supporting evidence.

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Error	Type of Error									
	Design	Maintenance/ Testing	Policies/ Procedures	Training	Decision Making	Organization/ Management	Risk Perception/ Acceptance	Communi-cation	Active/ Latent	Relevant API 75 Sections
API RP for mud circulation was not followed.			◊		◊	◊	◊		Latent	3,5,6
Cement was not allowed to set for an appropriate amount of time before the negative pressure test was performed			◊		◊	◊	◊		Latent	3,5
Guidelines provided for performing the negative pressure test were inadequate.			◊			◊			Latent	3,6
No flow exited the kill line during the negative pressure test; system may have been lined up incorrectly; valve may have been left closed.			◊	◊					Latent	5,7,9
Results of the negative pressure test were misinterpreted.				◊	◊				Active	5,7
An unapproved technique was used instead of CBL to determine successful cement placement.			◊		◊	◊	◊		Latent	3,4,5,6

Key

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Error	Type of Error									
	Design	**Maintenance/ Testing**	**Policies/ Procedures**	**Training**	**Decision Making**	**Organization/ Management**	**Risk Perception/ Acceptance**	**Communi-cation**	**Active/ Latent**	**Relevant API 75 Sections**
Lockdown sleeve was not used to secure the wellhead.	◊		◊		◊	◊	◊		Latent	3,4,5,6
Simultaneous end-of-well activities distracted rig crew and mud loggers from monitoring the well.			◊	◊		◊			Active	5,6,7
Mud loggers were told to stop monitoring well at 13:28 and were not notified when to begin monitoring again. Pits went unmonitored until 21:10.			◊		◊	◊	◊	◊	Active	5,6,7
Dangerous well conditions were unrecognized.				◊		◊		◊	Active	5,6,7
Transocean's shut-in protocols did not fully address how to respond in high flow emergency situations after well control had been lost.			◊	◊		◊			Latent	3,6,7
Incorrect well control response was taken by crew.			◊		◊				Active	5,7

Key

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Error	Type of Error									
	Design	**Maintenance/ Testing**	**Policies/ Procedures**	**Training**	**Decision Making**	**Organization/ Management**	**Risk Perception/ Acceptance**	**Communi-cation**	**Active/ Latent**	**Relevant API 75 Sections**
Electrical classification chosen for certain areas of the rig may not have been adequate.	◊					◊	◊		Latent	3,8,9
Inadequate power supply to reliably operate both HVAC fans and the thruster system.	◊								Latent	3, 8
Design of HVAC fan was changed to require manual activation.	◊				◊	◊	◊		Latent	3,4,8
BOP had modification and design problems.	◊	◊	◊		◊	◊	◊	◊	Latent	3,4,6,8
Inadequate maintenance on AMF system; One pod's batteries were dead and the other had a failed solenoid valve.	◊	◊	◊	‡	◊	◊	◊		Latent	3,5,6,8
Design problem with the AMF system; only activates when all three lines connecting BOP to rig are severed.	◊								Latent	3,8
MUX cables were damaged in the explosion preventing ESD from operating.	◊								Latent	3

Key

◊: Denotes that the classification of the error can be made with a high degree of certainty based upon the supporting evidence.

‡: The symbol "‡" denotes that the classification of the error is strongly supported by the supporting evidence.

Conclusions

The Macondo well blowout disaster was preventable and resulted from a combination of multiple human errors arising from all levels of the drilling organizations. During the course of this error analysis, it was determined that the majority of the errors leading to the Macondo disaster were of the latent type. It is evident that there was a total safety system breakdown starting with the project's conceptual stage and continuing through the design/implementation stages and the disaster itself that occurred on April 20, 2010. Evidence of this total safety system breakdown can be seen in the lack of maintenance on critical systems, a failure to follow industry guidelines, and the management's continuous decisions to sacrifice safety by cutting corners to save time and money. The events leading to this disaster should be studied further so that lessons learned can be used to prevent similar events from occurring in the future.

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