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Failure analysis of the offshore process component considering causation dependence

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ABSTRACT

Offshore oil and gas processing equipment operating in harsh environments poses high risk. This risk is further increased by the susceptibility of the equipment to natural disasters such as hurricanes and snowstorms due to harsh environments. When equipment functionality is compromised, it can become a hazard to personnel as well as to other equipment. The key safety practice on the offshore facility is to isolate the equipment and minimize consequences associated with processing equipment failures. When and how to isolate vulnerable equipment is a challenge due to limited understanding of the equipment's susceptibility and dependency to failure causes and consequences. This paper presents a methodology to analyze potential failure scenarios considering causation dependency and also determine which parameter(s) have the most impact on the failure. The results of the analysis are used to identify most sensitive equipment and their potential failure causes. This analysis will help to develop effective risk management strategies focusing on critical equipment.

1. Introduction

Accidents in the offshore oil and gas industry are mainly caused by human factors, climatic conditions, mechanical facilities and technical lapses (Gordon, 1998). Numerous offshore accidents have taken place over the past few decades, such as the Piper Alpha incident that occurred in the North Sea on July 6, 1988. This accident was caused by a compromised gas compression module, which resulted in a massive leakage of gas condensate. The leak on ignitions caused explosions and a pool fire on the platform (Pate-Cornell, 1993). The pool fire led to the subsequent explosion and fireball that resulted in the collapse of the platform. In this accident, over 167 people were killed and 62 survived, with severe injuries, mostly burns (Pate-Cornell, 1993). A similar accident took place on March 21, 2001, in the Campos Basin, off the coast of Brazil. On the P-36 platform, two large explosions occurred. The first one occurred mainly as a result of the excessive application of pressure to the aft starboard drains storage tank, where pressure had risen to 10 bars. When the tank could no longer hold the pressure, a rupture occurred and the fluid inside the tank began to leak. The leakage was followed by a second and more intense blast that was caused by contact between the spilled gas and an ignition source. The two blasts ultimately caused the destruction and sinking of the giant platform. As a result of the accident, one worker died immediately and nine others were missing and presumed dead (ANP/DPC Investigation Comission, 2001). More recently, an incident occurred on July 27, 2005, in the Mumbai High Field. Unlike the two accidents described earlier, this one was caused by inclement weather. During the storm, equipment on board one of the platforms was damaged due to hurricane-force winds,

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leading to a gas leak and ignition. The subsequent fire devoured that platform and moved onto others. Moreover, the risers' failure led to the leakage of massive amounts of gas, such that on August 1, 2005, the first platform sank, followed a few hours later by another one. In total, the week-long event killed at least 22 workers (Mitra et al., 2008; Walker, 2005). On March 25, 2012, a gas and condensate leakage on a platform in the North Sea led to the evacuation of workers due to a fear of fire and explosion. Despite precautionary measures taken, the fire burned for five days before being extinguished (Henderson and Hainsworth, 2014). On July 23, 2013, an incident took place in the Gulf of Mexico that resulted in the burning of a rig, likely caused by a gas leak (natural gas condensate) (Romero et al., 2016). Then, on February 11, 2015, yet another accident took place in Brazil, this time on the Cidade de São Mateu on the Floating Production Storage and Offloading (FPSO). In this event, the FPSO's pump room exploded due to a leakage of condensed material and the shock between the engine room and pumps. Nine workers were reported dead (Baksh et al., 2016; ANP, 2015). On April 1, 2015, a gas leak-caused explosion ignited a fire on the Abkatun Alpha platform in the Gulf of Mexico, resulting in 4 deaths and 16 injuries (Baksh et al., 2016).

Perhaps the most well-known recent disaster in recent history is that which occurred on April 20, 2010, on the Deepwater Horizon platform in the Gulf of Mexico. The disaster caused not only the deaths of 11 workers and the near destruction of the platform, but it also led to the decimation of the seafood industry in and around the Gulf due to the unprecedented levels of toxins caused by both the leak itself and the chemicals used to clean it up. The Deep-water Horizon's oil slick spanned 80 miles off the coast of Florida and 140 miles off Mississippi, Louisiana, and Alabama states. Fifteen million gallons of oil and water mixture were recovered, but the impact of the spill is still being felt in the affected states (Levy and Gopalakrishnan, 2010; Ciavarelli, 2016).

It is evident from past accidents in the offshore process facility that equipment failure risk is strongly dependent on the harsh environment operating conditions. In offshore facility, equipment failure quickly becomes a hazard to personnel as well as to other equipment. There is limited understanding on when and how to isolate vulnerable equipment to minimize equipment failure risk. There is no work reported in the public domain that helps better understanding of the of the equipment's dependency and susceptibility to failure causes and consequences. This paper aims to fill this gap between analyzing potential failure scenarios and determining which parameters have the most impact on the failure. Sensitivity analysis is also performed to study the vulnerability of the causes and interaction of different failure scenarios. This work will help to develop effective operational risk management strategies focusing on key equipment to minimize overall facility risk.

This paper is organised into six sections. Section 1 provides background information on the importance of safety in offshore operations, particularly the one in harsh environment. Section 2 briefly captures offshore process operation, whereas Section 3 details the research methodology. Application of the proposed methodology is discussed in Sections 4 and 5. Section 5 presents the conclusions.

1.1. *Safety analysis and risk assessment in offshore facilities*

Following the descriptions in the previous sections, it is apparent that offshore platforms bring with them extensive risks in the form of fires, explosions, and spills. Many of these accidents are caused by hydrocarbon leaks and have major impacts on operations as well as on the workers. The environmental pollution caused by these incidents is an equally compelling issue, as is the loss of power supplies and subsequent economic impacts. Most of these problems are the direct result of the absence of safety measures and safety training among platform and rig workers. Given the broad impact of these events which occur on offshore platforms but affect people thousands of kilometres away, it is essential to adopt safety measures safety measures based on the relevant information and data. This information should then be analyzed with reference to the factors that led to the critical equipment failure, which then caused the accidents.

In terms of lessons learnt, the Deep-water Horizon spill is a watershed of information. Since the occurrence of the disaster in 2010, international companies and organizations have become considerably more safety-conscious. For instance, the European Commission (Christou and Konstantinidou, 2012) has tabled a working paper calling for a concerted effort of all involved in the oil and gas industry to "meet the challenges and threats to oil and gas production platforms through the exchange of information about past disasters to prevent their recurrence in the future". The working paper has prompted several members of the EU to develop a database on accidents that take place on the continental shelf (e.g., the UK — ORION Database and Norway — Petroleum Safety Authority). There are also additional information sources, exchanges and joint coordination, such as the OGP — Well Control Incident Database, the main purpose of which is to analyze accidents (Christou and Konstantinidou, 2012). Safety analysis would lead to measures that will protect the environment (Khakzad et al., 2011). Given the death and destruction caused by accidents over the past 50 years, it is imperative that the marine industry strive for a workable balance between safety and the profits flowing from oil and gas production (Christou and Konstantinidou, 2012; Khakzad et al., 2011; Spouge, 1999).

1.2. *Techniques for safety analysis of offshore processing*

Several analysis techniques are used to analyze safety and estimate risks. These include quantitative analysis and qualitative approaches. Quantitative risk assessment (QRA) is, for the most part, a prerequisite in offshore installations in Norway, the United Kingdom, and most oil producing countries. The aim of QRA is to give the designer sufficient information to enable him/her to build a complete picture of the maritime system properties. At the same time, the quantified occurrence probability of each major failure condition and possible consequences should also be addressed. In contrast, qualitative safety evaluations set forth a series of steps that define or identify any potential risks. In this approach, information is relayed via charts, tables, fault trees, event trees and other tools. The goal here is to devise some measures to address potential safety, as highlighted by information obtained from the qualitative assessment (Rouvroye and van den Bliek, 2002). Table 1 is a list of some of the most used risk assessment tools. The qualitative ones include Analysis by experts (Domain expert knowledge) and Failure Mode and Effect Analysis while the quantitative ones are Fault Tree Analysis, Hybrid methods, Enhanced Markov Analysis and Bayesian Network.

Bayesian networks (BN) are widely used, as a probabilistic tool, in multiples domains with a significant number of applications (Wilson and Huzurbazar, 2007). Comparing to other quantitative risk analysis methods, the BN provides multi-levels and multi-states dependencies to be taken into consideration. Additionally, BN structure is easily traceable to check the way that the dependencies are described, and also if all the features are taken into consideration. In case of any feature is missing, it can be easily implemented in the network. Similarly, the implementation of new information such as the evidence on one or multiple parameters can be done on mathematical base, which is the Bayes rule.

In BN modelling, dependency is presented in two ways; vertical dependency (i.e the intermediate nodes depend on the basic or the root cause nodes), and horizontal dependency where the basic nodes are depending on each other. This horizontal dependency is what differentiates the BN from the logical diagram methods such as fault tree (FT) and event tree (ET) where the structure is based on the basic event independency. These dependencies, whether vertical or horizontal are all dictated in form of conditional probabilities table (CPT) based on the domain expert knowledge. For more details about the CPT, the reader is referred to the work of Wilson and Huzurbazar (2007).

1.3. *Equipment safety during offshore processing*

In oil and gas production, the processing of liquids is first done at the drilling sites, which in this case are offshore platforms. The product is then transferred onshore. The offshore production facility comprises six main units, namely the platform, the rig, the processing plant, the