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Safety barriers analysis of offshore drilling system by employing Fuzzy Event Tree Analysis

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ABSTRACT

In technical systems like oil and gas drilling systems, an accident sequence starts with an Initiating Event (IE) and evolves over time through the interaction of barriers in terms of success or failure. As it has been dramatically demonstrated in a variety of cases, offshore oil rigs activities have severe consequences to people, asset, environment and reputation.

A survey carried out on a leakage event in production phase. The barriers of the above IE are assessed by Event Tree Analysis (ETA) which evaluates the sequence of events in a potential accident scenario following the occurrence of an IE. In this research to calculate Failure Probability (FP) of barriers new approach is proposed. In this methodology, Reliability Block Diagram (RBD) and Fault Tree Analysis (FTA) are employed to quantify barriers FP. RBD is useful tool to quantify FP of barriers with logic diagram. FP of barriers with logic diagram is obtained by FTA. However it is often difficult to estimate precisely the FP of the components due to insufficient data. It has been reported that availability of the FP data pertaining to local conditions is surprisingly limited. In this study to overcome this problem using of expert judgment and then fuzzy logic is employed. Therefore, Fuzzy FTA (FFTA) is used to reduce uncertainty of expert judgment.

1. Introduction

Drilling phase is a key part in the oil and gas system. Success in drilling activities will depend on its ability to substantially improve the operational reliability and availability of this process. Upstream sector of the oil and gas industry which is called "exploration and production" include all oil and gas drilling activities have been accounting the highest critical injury incident rate than any other domains in petroleum industry (Quanmin et al., 2011). One of the actions which can be done to prevent and decrease the number of accidents is to increase the reliability of safety barriers. Several researches have been done to assess the risks and accidents in drilling but few researches were considered analyzing of safety barriers as an important aspect to prevent accidents.

Various industries have used Probabilistic Risk Assessment (PRA) as an essential analysis tool to identify potential accident scenarios. Several researches used ETA as an effective tool to assess safety barriers. An ETA is a bottom-up, inductive and system safety analytical technique that evaluates the sequence of events in a potential accident scenario following the occurrence of an Initiating Event (IE). Event Tree Diagram (ETD) is a visual representation of all the events which can occur in a system after a failure has occurred, and so is the 'next step' in the path mapped out in FTA (Andrews and Dunnett, 2000) and shows all possible outcomes resulting from an accidental (initiating) event, taking into account whether installed safety barriers are functioning or not, and additional events and factors (Rausand, 2005). According to Bedford and Cooke (2001), event tree is a basic modeling technique which provides an effective method of dissecting the operation of an arbitrary system or process into critical events which can then be assigned probabilities of success or failure.

Andrews and Dunnett (2000) considered analyzing of event trees where the branch point event causes are defined using fault tree structures. They suggested a new approach using Binary Decision Diagrams (BDD) which overcomes these deficiencies in other research. Peila and Guardini (2008) employed ETA to evaluate of the collective risk that can affect a road subjected to rockfalls. Xu and Dugan (2004) considered how to combine Dynamic Fault Trees (DFT) and event tree. Sun et al. (2011) used an event tree to analyze the risk of inadequate flight separation based on the Human Cognitive Reliability (HCR) model, which explored how the consequences of such an event depend on factors such as abilities and mental states of pilots and air traffic controllers, and the efficiency of human-machine interaction.

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Since the first event tree applications in the 1960s many studies have been done using event trees related to the fields of nuclear industry, chemical processing, and transportation. Also, many studies have applied quantitative analysis to assess the risk of a specific accident in offshore oil and gas production especially in drilling operations. For instance, Kasaeyan et al. (2011) employed ETA and fuzzy theory to analysis the offshore oil pipeline. Xue et al. (2013) proposed a new barrier-based accident model for drilling blowouts. The model is based on the three-level well control theory, and primary and secondary well control barriers based on Swiss cheese model.

Another method which was employed to assess the safety barriers is BORA (Barrier and Operational Risk Analysis). BORA is a relatively new method both for qualitative and quantities analysis of the risk from the scenarios. It introduces barriers and how technical human operational and organizational Risk Influencing Factors (RIFs) influence the barrier performance (Aven et al., 2006).

The objective of this research is to build a safety barrier analysis based on ETA, FTA and RBD methods for offshore drilling wells. The rest of article is organized as follows: Section 2 discusses the innovation of the study and Section 3 discusses the safety barrier analysis and introduces the concept and classification of safety barrier, and discusses barriers in a well. The proposed model, which is based on barrier analysis, is presented in Section 5. The leakage scenario in production phase is analyzed by using the proposed model in Section 6. Finally, conclusions are given in Section 7.

2. Innovation of the study

The goal of ETA is to determine the probability of all the possible outcomes resulting from the occurrence of an IE. By analyzing all possible outcomes, it is possible to determine the percentage of outcomes that lead to the desired result and the percentage of outcomes that lead to the undesired result. To calculate the probability of consequences, the FP of each barrier should be quantified. Therefore, it is necessary to quantify FP of each barrier. In the case where quantitative data is not available, expert judgment possibilities are then used. In order to calculate FP of barrier, a new approach is proposed. Generally, FTA is employed as an efficient tool to obtain FP of barriers. One of the most reliable tools for calculating reliability of system with logic diagram is RBD. In FTA and/or gates is defined by human and there is probability of fault. To overcome this problem using of RBD is proposed. The new contribution is to use RBD and Fuzzy FTA simultaneously. Barriers are divided in two groups (Barriers with logic diagram and without logic diagram). FPs of barriers with logic diagram are quantified by employing RBD. FPs of barriers without logic diagram are obtained by employing FFTA.

3. Safety barrier analysis

The theories utilized in barrier analysis were originally based on the successive works of Hienrich's domino theory (1930s), Haddon (1966) and Gibson (1961), which developed the concept of an accident as an abnormal or unexpected release of energy (Livingston et al., 2001). Barrier can be defined in various ways. For instance, barrier was defined as "physical and/or non-physical means planned to prevent, control or mitigate undesired events or accidents" by Sklet (2006). Taylor (1988) defined barrier as "equipment, constructions, or rules that can stop the development of an accident".

As there are various definition of barrier, different classification of barriers were suggested. Physical and non-physical classification is suggested by Sklet (2006). Rausand (2011) suggested Primary and Secondary barrier. Hollnagel (2004) considered four barrirs as follows: physical or material, functional, symbolic and incorporeal barrier systems. One of the first systems to describe the differences in barrier function was developed in the early 1970s. Haddon (1973) described 10 strategies for countering energy damage. This was one of the first categorizations of barrier functions and it would have a lot of influence on later categorizations. Sklet (2006) introduced classification of barrier function based on the classification which can be seen in Fig. 1.

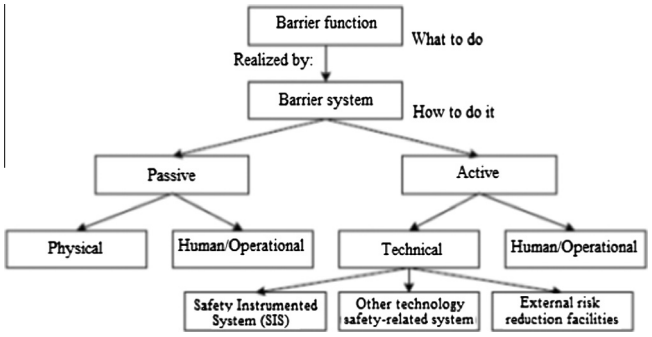

Fig. 1. Classification of safety barriers (Sklet, 2006).

Barrier analysis provides a structured way to consider the events related to a safety system failure (Livingston et al., 2001). Duijm (2009) discussed how safety-barrier diagram can be effective in safety management. A main advantage of safety-barrier is to prevent or mitigate accidents. Safety barrier directly show the issues that are the primary concern of safety management.

4. Fuzzy ETA

To manage uncertainty in ETA a lot of researches were done based on fuzzy logic in various industries. Chun and Ahn (1992) studied the use of ETA in the area of fault propagation; they employed the fuzzy set theory to develop the model of accident progression event trees. However, it is unrealistic to evaluate the occurrence of each event by using a crisp value without considering the inherent uncertainty and imprecision.

Other research areas of uncertainty in ETA have done by Baraldi and Zio (2008). They considered a hybrid method that jointly propagates probabilistic and possibilistic uncertainties and compared with pure probabilistic and pure fuzzy methods for uncertainty propagation. The uncertainties in ETA have been discussed by Ferdous et al. (2009). They suggested two approaches to address data uncertainties, namely, fuzzy sets and evidence theory, and compared the results with Monte Carlo simulations. A fuzzy-based approach was used by other researchers such as Kenarangui (1991), Patra et al. (1995), Huang et al. (2001), Dumitrescu and Munteanu (2001), and Jin et al. (2003) addressed the uncertainty issues involved in an ETA using the fuzzy set-based approach.

Another research which again discussed about uncertainty has done by Ferdous et al. (2013). They tried to accommodate the expert's knowledge to overcome missing data and incorporate fuzzy set and evidence theory to assess the uncertainties. Further, dependency coefficient-based fuzzy and evidence theory approaches have been developed to address the model uncertainty for bow-tie analysis.

5. Methodology

FTA can be used to calculate the Failure Probability (FP) of barriers in ETA model. A new method is proposed to calculate FP. The proposed method is combination of Fuzzy, RBD and FTA. Fuzzy