Offshore drilling accident analysis based on Dynamic Bayesian Network

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Abstract—Offshore drilling operations has the characteristics of far offshore, harsh environment, high risk and great technical difficulty. It is difficult to deal with offshore drilling accidents, and it is easy to cause serious social and economic problems. Based on the risk records of drilling engineering, this paper analyzes the forms and causes of offshore drilling accidents, and establishes a dynamic Bayesian network analysis model for offshore drilling accidents. With the dynamic Bayesian network, the prediction probability of drilling risk is calculated. According to the blowout accident in offshore drilling, the analysis results show that the risk of blowout accident is as high as 50.6%. The research results show that the method and the model presented in the paper is contributed to analysis and prevention of offshore drilling accidents.

1. INTRODUCTION

Offshore drilling operations are characterized by great technical difficulty, far from land, harsh operating environment and high risk level. Therefore, offshore drilling operations are easy to cause accidents, resulting in serious social, environmental and economic issue. According to the statistics of offshore drilling accidents, the main forms of accidents are kick, blowout, stuck pipe, lost circulation and so on. According to the statistics of SINTEF offshore database, from 1980 to 2016, 295 blowout accidents occurred in the Outer Continental Shelf of the US Gulf of Mexico, Norway and the North Sea of the UK, of which more than 60% occurred in the completion stage [1]. Therefore, in the process of offshore drilling operations, the rapid diagnosis technology of accidents is the very important.

In recent years, many scholars have re-searched the diagnosis of drilling and production accidents by using different methods. Xue Luning et al. [2] used the accident tree method to analyze the accident causes of offshore drilling and production blowout, established the blowout accident bow model, and verified the effect-tiveness of the model with "Deepwater Horizon" accident. Jiang Pan et al. [3] established the fault tree model of offshore drilling blowout accidents caused by human errors, and analyzed the influence of safety barriers on risks by using the bow model. Xu Zhe [4] et al. studied the drilling and production well leakage problem based on the Bayesian network, and introduced the Bayesian network to analyze the well leakage problem on drilling and improving the reliability of the prediction. The above research mainly analyzes drilling accidents under static conditions. However, offshore drilling and production accidents and equipment failures are closely related to time. Therefore,
the traditional risk and fault assessment methods cannot reflect the risk assessment under the condition of system dynamic factors with the time change.

Based on the dynamic risk factors of offshore drilling accidents, dynamic bayesian network analysis model is established in this paper. Offshore drilling blowout accident is analysis and the accident risk probability is predicted, which provides theoretical reference basis for offshore drilling accident diagnosis.

2. Theory of Dynamic Bayesian Networks
Dynamic Bayesian network can describe the system model that changes with time, which is the extension of static Bayesian network in the time domain. It inherits the ability of static Bayesian network to describe system polymorphism, complex connectivity and uncertain causality, and at the same time increases the function of time characteristics [5]. Fig. 1 describes the dynamic Bayesian network with certain causal concern and temporal relationship between node variables $X_i$, $X_2$, and $X_3$. Where, $X_i$ is the node variable, $X_3$ is the node variable $X_1$, $X_2$ at $t_{i-1}$ time, and the state in the time slice according to different transition probabilities.

![Fig. 1 dynamic Bayesian network model](image)

If the prior probability distribution of root node and the conditional probability distribution of non-root node are known, the joint probability distribution including all nodes can be obtained, as shown in Equation (1):

$$P(X_1, \ldots, X_N) = \prod_{i=1}^{N} P(X_i | Pa(X_i))$$  \hspace{1cm} (1)

Where $X_i$ is a node variable, $Pa(X_i)$ is the set of corresponding parent nodes of the node $X_i$; $P(X_i | Pa(X_i))$ is the conditional probability of the variable $X_i$. After determining the joint probability distribution of each node, the probability and predicted value of each node can be determined by Equation (2).

$$P(X_k) = \sum_{j=1}^{n} \prod_{j \neq i=1}^{n} P(X_i | Pa(X_i))$$  \hspace{1cm} (2)

3. Dynamic Bayesian Network Model
In order to describe the state change with the time, dynamic Bayesian network extends the probability distribution of fixed variable set to the time domain, and can simulate arbitrary variable set on time axis. To construct the dynamic Bayesian model of offshore drilling accident fault analysis, the prior network and transfer network should be determined firstly. Assume that the attribute set $X = \{X_1, \ldots, X_N\}$ with N attributes varies over time, $X_i^t$ representing the ith attribute value at time t. Assume that the attribute set X satisfies the Markov chain model and Markov hypothesis in the entire time series, i.e $p(X_t | X_{t-1}, \ldots, X_1) = p(X_t | X_{t-1})$. Moreover, the probability of attribute X at t time is only related to the probability of attribute X at adjacent moments, and has nothing to do with the probability of precedence.
moments. Therefore, \( p(X_i \mid X_{i+1}) \) as the transition probability of conditional transition network between two time slices has nothing to do with time [6].

Assuming that offshore drilling accident model runs indefinitely on the time axis, the dynamic Bayesian model for risk assessment and fault analysis of offshore drilling accident can be expressed by dynamic Bayesian network as: \( BN(B_1, B_n) \), where \( B_1 \) is the priori network of the root node, and \( B_n \) is the transfer network between two time slices. According to relevant theories of Bayesian inference, the probability of the transfer network is as follows:

\[
p(X_i \mid X_{i+1}) = \prod_{i=1}^{N} p(X_i \mid Pa(X_i))
\]  

(3)

Since the root node of the original Bayesian network before time extension has an unconditional probability distribution, the probability of the Bayesian network at time \( t_0 \) is \( p(X_1^{t_0}) \). The dynamic Bayesian joint probability distribution with \( T \) time slices is as follows [7]:

\[
P\left(X_1^{t_1}; N \right) = \prod_{i=1}^{n} p(X_1 \mid Pa(X_1)) \times \prod_{T=2}^{T} \prod_{i=1}^{N} p_{B \rightarrow B}(X_i^{t_i} \mid Pa(X_i^{t_i}))
\]  

(4)

4. Drilling Blowout Analysis Based on Dynamic Bayesian Network

Blowout accident of offshore drilling is a serious offshore accident. In this paper, the risk identification of blowout accident is carried out with the FMECA method. The risk factors and causes are analyzed and the logical relationship among the factors is determined. Then, the dynamic Bayesian analysis model of blowout accident is established and the prediction probability of blowout accident is computed, which supports engineer to prevent blowout accidents in offshore drilling.

4.1 Fault Factor Analysis of Blowout Accident

Blow-out accident may cause serious consequences such as fire and explosion, environmental pollution, platform damage, well abandonment and human casualties. The main causes of blowout accidents are abnormal formation pressure, excessive swabbing pressure, loss of circulation, low density of drilling fluid or equipment failure. The logical model of the fault tree of the blowout accident is established with FMECA method and the model is shown in Figure 2. In this figure, the blowout accident is as the top event of the blowout accident and the causes are as the bottom event.

![Fault Tree Model of the Blowout Accident](image-url)
4.2 Blowout Accident Analysis Based on DBN

According to the fault tree logic model of blowout accident, the fault tree model is transformed into dynamic Bayesian network. The analysis model of dynamic Bayesian network for blowout accident obtained is shown in Figure 3. After querying the SINTEF Offshore Blowout Database and DNV’s WOAD Database data and combining with the actual situation of deepwater drilling in the South China Sea, the prior probability values of drilling accident are obtained as shown in Table 1. The prior probability value of drilling accident is input into the dynamic Bayesian network analysis model of blowout accident, and the calculated probability of blowout accident is 50.6%.

Fig. 3 DBN model of the blowout accident

| NO. | Risk Factors       | failure probability (%) | NO. | Risk Factors       | failure probability (%) |
|-----|-------------------|-------------------------|-----|-------------------|-------------------------|
| 1   | Mud injection slow| 0.1                     | 8   | Elapsed Time Pumps-Off | 12                     |
| 2   | Running fast      | 7.4                     | 9   | Design defect      | 5                      |
| 3   | High Density Mud  | 8.3                     | 10  | Insufficient pre-drilling circulation | 2.5 |
| 4   | Low Density Mud   | 3.3                     | 11  | BOP fault          | 6.2                   |
5. CONCLUSION

Offshore drilling accidents have dynamic characteristics that change with time. By updating the probability of failure variables, dynamic Bayesian network can predict the values of time-varying variables, which is more suitable for drilling risk assessment. According to the limitations of traditional accident analysis models for offshore drilling accident, this paper proposes an accident prediction method based on dynamic Bayesian network, and establishes the theoretical calculation model of dynamic Bayesian network. Taking offshore drilling blowout accident as an example, the main risk factors of offshore drilling blowout accident are identified, and the occurrence probability of blowout accident is predicted and calculated.

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