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A dynamic Bayesian networks modeling of human factors on offshore blowouts

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A B S T R A C T

An application of dynamic Bayesian networks for quantitative risk assessment of human factors on offshore blowouts is presented. Human error is described using human factor barrier failure (HFBF), which consists of three categories of factors, including individual factor barrier failure (IFBF), organizational factor barrier failure (OFBF) and group factor barrier failure (GFBF). The structure of human factors is illustrated using pseudo-fault tree, which is defined by incorporating the intermediate options into fault tree in order to eliminate the binary restriction. A methodology of translating pseudo-fault tree into Bayesian networks and dynamic Bayesian networks taking repair into consideration is proposed and the propagation is performed. The results show that the human factor barrier failure probability only increases within the first two weeks and rapidly reaches a stable level when the repair is considered, whereas it increases continuously when the repair action is not considered. The results of mutual information show that the important degree sequences for the three categories of human factors on HFBF are: GFBF, OFBF and IFBF. In addition, each individual human factor contributes different to the HFBF, those which contribute much should given more attention in order to improve the human reliability and prevent the potential accident occurring.

1. Introduction

The accidents in offshore oil and gas industry can lead to devastating consequences. For example, the failures of subsea blowout preventer (BOP) caused an explosion aboard the deep-sea petroleum drilling rig Deepwater Horizon on April 20, 2010, which led to the largest accidental oil spill in history. It was concluded that the failure of the BOP to shear the drill pipe and seal the wellbore was caused directly by the physical location of the drill pipe near the inside wall of the wellbore, which was outside the blind shear ram cutting surface during activation (BOEMRE, 2011). However, human factors were also considered to contribute much to the failure. Extensive reviews and studies of marine and offshore accidents have clearly indicated that human failures have been responsible for over 70% of the causes in accidents, while only 30% attributes to technical failures (Reason, 1997; Wang & Trbojevic, 2007).

Many methods have been developed for the purpose of human reliability evaluation, such as Reason's Swiss cheese model, human factors analysis and classification system, systems-theoretic accident model and processes and success likelihood index methodology. Recently, Bayesian network (BN) is more and more used in human reliability analysis due to the fact that the model can perform forward or predictive analysis as well as backward or diagnostic analysis (Bobbio, Portinale, Minichino, & Ciancamerla, 2001). Ren et al. performed offshore safety assessment and situation assessment of nuclear power plant operators focusing on human and organizational factors. Reason's Swiss cheese model was used to form a generic offshore safety assessment framework, and BN was tailored to fit into the framework to construct a causal relationship model (Ren, Jenkinson, Wang, Xu, & Yang, 2008). Lee et al. proposed a computational model for situation assessment of nuclear power plant operators using a BN. The human factors significantly affecting operators' situation assessment were incorporated the model (Lee & Seong, 2009). Wang et al. presented a 6-steps accident analysis BN model, including Define, Analyze, Node, Graphic, Elicit and Reasoning, to investigate the contribution of human and organizational factors in hazardous vapor accidents (Wang, Roohi, Hu, & Xie, 2011). Trucco et al. developed a BN to model the maritime transport system, by integrating human and organizational factors into risk analysis (Trucco, Cagno, Ruggeri, & Grande, 2008). Droguett et al. developed an availability assessment model in which the system dynamics was described via

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a continuous-time semi-Markovian process. The model was integrated with a BN characterizing the cause–effect relationships among factors influencing the repairman error probability during maintenance (Droguett, Moura, Jacinto, & Silva, 2008). Vinnem et al. researched the influences of technical, human, operational, as well as organizational factors on maintenance work on major process equipment of offshore petroleum installation using BN method (Gran et al., 2012; Vinnem et al., 2012).

Bayesian network models for reliability evaluation can be achieved by converting the traditional reliability models. Torres-Toledano et al. presented a general methodology for transforming a reliability structure represented as a reliability block diagram to a BN representation, and with this, the reliability of the system can be obtained using probability propagation techniques (Torres-Toledano & Sucar, 1998). Bobbio et al. presented an algorithm to convert a fault tree (FT) or a dynamic fault tree into a BN or dynamic Bayesian network (DBN). A software tool named RADYBAN was also developed for automatic translation (Bobbio et al., 2001; Montani, Portinale, Bobbio, & Codetta-Raiteri, 2008). Weber et al. presented a methodology that help developing dynamic object oriented BN to formalize complex dynamic models as equivalent models to the Markov chains (Weber & Jouffe, 2006). Kim extended the research, and provided a method of mapping a reliability block diagram with general gates model into an equivalent BN model without losing the one to-one matching characteristic for quantitative analysis (Kim, 2011). Khakzad et al. presented a methodology to map bow-tie into BN for dynamic safety analysis of process systems (Khakzad, Khan, & Amyotte, 2013).

When a fault occurs for a system, repair is required, which can improve the availability of system significantly. Few researches about BN or DBN for reliability evaluation taking repair action into consideration were reported. Flammini et al. presented both a failure model for voting architectures based on BN and a maintenance model based on continuous time Markov chains, and proposed to combine them according to a compositional multiformalism modeling approach in order to analyze the impact of imperfect maintenance on the system safety (Flammini, Marrone, Mazzocca, & Vittorini, 2009). Neil et al. presented a hybrid BN framework to model the availability of renewable systems. They used an approximate inference algorithm for hybrid BN that involves dynamically discretizing the domain of all continuous variables and used this to obtain accurate approximations for the renewal or repair time distributions for a system (Neil & Marquez, 2012). Portinale et al. presented an approach to reliability modeling and analysis based on the automatic conversion of dynamic fault tree or series and parallel modules into BN taking repair into consideration (Codetta-Raiteri, Bobbil, Montani, & Portinale, 2012; Portinale, Raiteri, & Montani, 2010).

The work proposes a conversion algorithm from defined pseudo-fault tree (PFT) into dynamic Bayesian networks, taking account of repair actions, and researches the reliability of human factors on offshore blowouts. The paper is structured as follows: Section 2 defines a PFT for illustrating the structure of human factors on offshore blowouts. In Section 3, the PFT of human factors is translated into BN or DBN. In Section 4, the probability of human factors barrier failure with and without repair is investigated, and a sensitivity analysis is done. Section 5 summarizes the paper.

2. Pseudo-fault tree

2.1. Human factors in offshore drilling

We visited the ultra-deepwater rig West Hercules in South China Sea when the subsea BOP stack was pulled on August, 2009. The operators control all functions associated with BOP stack via driller's panel, which serves as primary control station, as shown in Fig. 1. Human factors play an extremely important role in providing security assurances. Human error may cause a catastrophic accident.

The underlying human factors which affect the safety on offshore blowouts have been defined as three main categories: individual factors, organizational factors and group factors. At the individual level, competence level, stress, motivation and human system interface may affect a person's performance, which affect the operations in offshore oil and gas industry due to the fact offshore environments are among the most stressful and harshest work environments in the world. At the organizational level, company polices, company standards, and system and procedures have the potential to influence the safety of operations. At the group level, various factors may contribute to an increase in human error, including management, supervision and crew (Gordon, 1998; Gordon, Flin, & Mearns, 2005).

2.2. Pseudo-fault tree of safety barriers

Fault tree analysis is one of the most commonly used techniques for risk and reliability studies. It is a logic diagram that displays the interrelationships between a potential critical event in a system and the causes for this event. FT has a binary restriction due to that all events are only assumed either to occur or not to occur, while there are no intermediate options (Rausand & Hoyland, 2004). However, intermediate options exist largely for reliability analysis of human factors. Therefore, a pseudo-fault tree (PFT) is defined by incorporating the intermediate options into FT in this paper. Although FT can be used to calculate the probability of event, the defined PFT is only used for illustrating the structures of human factors, but not for analysis or calculation. Just like the translation from FT to BN (Bobbio et al., 2001), the BN and DBN of human factors can be obtained by translating PFT, taking account of repair action.

A safety barrier is a physical or engineered system, or human action based on procedures. It is a means to prevent, control or mitigate undesired events or incidents (Deacon, Amyotte, & Khan, 2010). PFT is used to establish the causal relationships leading to failure of each safety barrier. The top event denotes the failure of the safety barrier. The second layer is linked with the failure of sub-safety barriers. Failures of the sub-safety barriers can be caused by the failure of subsequent third class sub-safety barriers, which are caused by causal factors rather than safety elements.

Fig. 1. Operations of subsea BOP in a drilling rig.