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Safety assessment in oil drilling work system based on empirical study and Analytic Network Process

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ABSTRACT

Safety assessment is an essential work to guarantee the safety of oil drilling. There are relations and dependencies between human factors in oil drilling work system. Therefore, the safety of oil drilling work system should be analyzed in a comprehensive way. The Human Factors Analysis and Classification System (HFACS) is applied to establish rational and applicable index system for investigating human errors. The Analytic Network Process (ANP) method is used to obtain the priorities of human factors considering the interdependences, however, the deficiency of ANP is that the obtained results are subject to experts' cognitive limitations and psychological biases. The Structural Equation Modelling (SEM) is used to form the ANP model auxiliary, which may be expected to overcome subjective opinions from experts and provide a more pertinent and practical safety strategies. A survey is conducted to explore the importance of human factors through questionnaires of which 283 pieces made up the original data. Afterwards, the human factors' weights are calculated by the ANP method. As a comparison, a frequency-based method is also used to obtain the frequencies of factors and observations causing accidents using accident reports. The causal chain and the priorities of the importance of human factors are explored by this hybrid method; the results are consistent with the experience and knowledge of safety management. We discuss the interdependencies between the human factors and the priorities in general, whilst, the specific safety requirements and recommendations in the hoisting and lifting system are also provided as an example.

1. Introduction

In recent years, safety problems in oil drilling have obtained many concerns. As the drilling industry involves complex and hazardous activities, it is of great importance to assess attendant risks in which human factors make up a large proportion. The hoisting and lifting systems are one of the most important components in oil drilling industry; measures should be taken to lower the risk of human factors (Zhou et al., 2017).

Many safety studies have been done in drilling industry. Amir-Heidari et al. (2015) carried out a case study to assess the human factors, which are identified by what-if and structured brainstorming. Zhao et al. (2011) assessed the qualification of human factor risks associated with the drilling process based on Delphi method. Strand and Lundteigen (2016) studied classification of the human factors and put forward a relative importance of assessment criteria in each risk influencing factor. Abimbola et al. (2015) analyzed the shortcomings existing in overbalanced and underbalanced drilling technique, and proposed a Bayesian network model for managed pressure drilling risk assessment. Ataallahi and Shadizadeh (2015) studied the blowout in onshore Iranian drilling industry, and provided fuzzy method to develop the consequence of blowout for Iranian onshore drilling industry. Ramzali et al. (2015) carried out a survey on a leakage event in production phase, and assessed the barriers of the initiating event by using Event Tree Analysis. Pranesh et al. (2017) analyzed the case study of deep water horizon offshore oil platform accident, in which failures in oil and gas cementing operation exists, and concluded that this tragedy is due to complete human errors and employee's poor leadership abilities. Researchers studied human factors from different views of classification, while the hierarchical and interactional study of human factors in drilling industry is still incomplete; moreover, there are rare studies in the safety assessment considering the interdependences between human factors in the hoisting and lifting system in oil drilling industry.

It has been acknowledged that accident analysis must rely on systemic and organizational models (Rasmussen, 1997; Reason, 1997). And it is essential to choose a model before starting the investigations, according to the characteristics of the system and the nature of the

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accident (Chauvin et al., 2013). Human Factors Analysis and Classification System (HFACS) is a generic human error framework originally developed for US military aviation as a tool for the analysis of the human factors aspects of accidents. The HFACS is perhaps the most widely used human factors accident analysis framework, including shipping accidents (Akyuz, 2017), mining (Patterson and Shappell, 2010), and construction (Garrett and Teizer, 2009). Wiegmann and Shappell (2001) suggested that the HFACS framework bridges the gap between theory and practice by providing safety professionals with a theoretically based tool for identifying and classifying human errors. In HFACS, factors in higher level affect factors in lower levels.

Although HFACS can provide a good capture of the complexity of the human factors systems, it cannot provide the safety-related priority of human factors. Many organizations adopt approaches such as safety checklists, Fault Tree Analysis (FTA) and Likelihood Exposure Consequence (LEC), which are built on a qualitative or semi-qualitative basis. Chen and Yang (2004) stated that the above mentioned methods cannot be used to assess the current status of safety management and the risk level of high risk operations in a quantitative way. The Analytic Hierarchy Process (AHP) method is a quantitative analysis method, which can mathematically model the decision process without much information, and it can provide a convenient way for multi-objective, multi-criteria, unstructured decision problems. The Analytic Network Process (ANP) is an extended form of the AHP. Although both the AHP and the ANP derive ratio scale priorities by making paired comparisons of elements on a criterion, differences exist between them. First, although the AHP is a special form of the ANP, the ANP can handle interdependences within a cluster (inner dependence) and among different clusters (outer dependence). The ANP method reserves the core conception of the AHP method, which divides the decision system into hierarchical structure, and believes that the criterions within lower level are dominated by the criterions of adjacent higher level. Second, the HFACS divides human factors into four levels (Li et al., 2008; Madigan et al., 2016). Human factors in the higher level affect factors in the adjacent lower level, thus they can be clustered by the hierarchical HFACS framework, which tightly aligned with the ANP method (Zhan et al., 2017). Third, the ANP is a nonlinear structure, while the AHP is hierarchical and linear, with a goal at the top level and the alternatives on the bottom level (Liou et al., 2011).

On the account of inter-dependencies among the human factors in oil and gas drilling operations, it could prioritize among different influences by using the ANP method. ANP method has already been applied in safety assessment areas by many researchers. For instance, Jin et al. (2014) designed an assessment system for secondary task driving safety by using ANP. Dağdeviren et al. (2008) employed the ANP to determine the weights of factors and sub-factors necessary to calculate the faulty behavior risks. Zhan et al. (2017) combined the ANP method with fuzzy decision making trail and assessment method to find out leading casual factors in railway accidents.

Although ANP is a powerful method in safety assessment areas, it has some limitations. In the ANP, the most important work is to establish the reciprocal pairwise comparison matrices. Comparisons between the two given alternatives are carried out using experts' judgments, feelings, experience, and intuition (Saaty and Vargas, 2012). As ANP heavily relies on expert judgment, the results obtained are subject to experts' cognitive limitations and psychological biases. Experts might be inherently optimistic in some cases, inherently pessimistic in other cases, or inherently overconfident in still other cases (McKay and Meyer, 2000). Such cognitive limitations can produce biased results; thereby guide the conclusions of the analyses into a sub-optimal precaution.

It is suggested that statistical methods should be used to generate more accurately dependent relationship among factors (Metin et al., 2008). Structural Equation Modelling (SEM) is a family of statistical techniques used to specify, estimate, and test hypothesized theoretical relationships among variables that are organized and connected in substantively meaningful models (Fan and Wang, 1998). SEM developed by Jöreskog and Yang (1996) is a comprehensive statistical technique which is used to test casual relationships between observed and latent variables (Yuluğkural et al., 2013), which is one of the most popular research methods in the social sciences. Tomas et al. (1999) established a structural equation model of accidents and discussed the safety variables in the model. Krajangsri and Pongpeng (2016) used SEM to inform how sustainable infrastructure assessments affect construction project success and provided a guideline for developing sustainable infrastructure projects. Zhang et al. (2016) used SEM to examine the interactions between the contributory factors of coal mine accidents.

We integrate SEM with ANP to reduce experts' subjective biases. More specially, we use the relationship between the human factors obtained from SEM to form the structure of the ANP model, and use regression coefficients obtained from SEM to establish reciprocal pairwise comparison matrixes (Dangol et al., 2015). However, there are some important differences between the study of Dangol et al. and ours. First, the application of ANP in their study serves for the formation of SEM to search the relationship between factors, while, in our study, the application of SEM serves for the formation of ANP to conduct safety assessment. Second, the factors in our study are more complex and hierarchical than theirs, thus we divide the human factors in the four levels into 13 separate SEM diagrams, which not only coincides with the interdependences between the factors, but also simplifies the test and modification during the modelling process.

In all, we hope to establish a more precise research method to reduce the errors, which may be caused by subjective judgment. At last, to analyze the causes of an accident and confirm the results of this empirical method, case statistical analysis using the frequency-based method is carried out to compare with it. We also conduct the safety assessment in hoisting and lifting system as an example.

The rest of this paper is organized as follows: In Section 2, the methodology of this empirical method is proposed and the basic concepts of empirical study and ANP are reviewed. In Section 3, the implementation using the proposed method is presented on the case study of hoisting and lifting system; also the results of frequency-based method are given. Based on the results of two different methods, discussion and recommendations are given aiming at the safety improvement of activities on hoisting and lifting system. Section 4 gives a review and conclusion of the whole work.

2. Methodology

The aim of this study is to evaluate the importance of human factors by the hybrid method of ANP and SEM and provide safety recommendations in oil drilling work systems. Empirical study based on SEM and questionnaires could collect a lot of expert advices. We applied the SEM model to construct the ANP model, which can reduce the biases of experts in ANP evaluation. This research was divided into six phases illustrated in Fig. 1. Human error taxonomy based on HFACS frameworks is used to establish index system. Based on the index system, questionnaires are carried out to get the empirical data, which acts as the import to the SEM method. The structure of the SEM can be built according to the HFACS framework; the regression coefficients obtained from SEM can be used to build the pairwise comparisons in the ANP method. Correspondingly, the structure of ANP also can be built according to the relationship of variables in SEM. The weight of each human factor can be obtained from the results of ANP. Furthermore, we can compare the results of frequency-based methods with the results of the SEM-ANP method and verify the validity of the latter method. At last, the results given by the empirical study and ANP are also useful to provide practical recommendations on improving the safety goal in drilling industry.