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An integrated framework of safety performance evaluation for oil and gas production plants: Application to a petroleum transportation station

Laibin Zhang [b, 1], Jian Kang [a, *, 1], Jixin Zhang [a], Jiancun Gao [a]

[a] Department of Safety Engineering, Beijing Institute of Petrochemical Technology, 102617, China
[b] China University of Petroleum (Beijing), 102249, China

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ABSTRACT

Safety performance evaluation is a significant way to ensure the safety of oil and gas production plants. Various evaluation methods have been proposed to make safety evaluation more consistent and scientific. However, a major concern is that many existing safety evaluation measurements are still subjective and are not easy to obtain in a uniform way, which can be attributed to the challenges that process plants faced such as people having different knowledge levels, equipment with dispersed locations and management with many processes. This paper aims to display the impact of risk factors on system safety level in a succinct and visual way that may be expected to overcome subjective opinions from experts and provide a more pertinent and practical safety strategies. To this end, an integrated framework is developed, which considers crucial risk factors from pipeline, static equipment, dynamic equipment and management. First, Fault tree analysis (FTA) is used to explicitly determine the crucial r risk factors. Then, a novel fuzzy cognitive map cooperating with relative degree analysis model (FCM-RDA) is proposed to deal with the weigh distribution opinions. Finally, considering the oil and gas production process is a complex system, a fuzzy comprehensive evaluation (FCE) is employed to calculate the overall safety level.

1. Introduction

Oil and gas production plant possessing large amounts of harmful substances and energy with great probability of accidental release, can pose risks to personnel, equipment facilities and environment. The accidental concerns are exacerbated with studies indicating that the safety of natural gas and oil production becomes one of the most important parts in industrial civilization, which receives more and more interest among scholars and project managers. Safety performance evaluation is an effective way to assess and manage system risk factors. Although various methods and models have been proposed to make the safety evaluation more consistent and objective, comprehensive safety evaluation is still important for guaranteeing the safety running of oil and gas production plants.

Generally, there are three parts in system performance evaluation. First, identify evaluation score or description for individual entity, which displays the local performance of the system. Second, determine weight-distribution, which represents the organization mechanism of local performances to reflect the holistic system performance. Third, the weight distribution model is applied on the scores to achieve a final evaluation score, and the final evaluation score could be compared to required standards to determine the whole system performance.

Some existing evaluation methods have become standard methods in certain fields. Fault tree analysis (FTA) is a widely used method in safety-related researches. With top-down logic analysis, FTA provides useful information for finding critical failure components and weak paths in a complex system. However, it has some shortcomings: various analysis results yield for different analysts, large calculating quantity of complex system, failure rate data required for each failure event in quantitative calculations and so on. Fuzzy cognitive maps (FCM) were first described by Bart Kosko in 1986 (http://www.sciencedirect.com/science/article/pii/S0016328714000809 Kosko, 1986), who proposed them as a mean to make qualitative cognitive maps, which had originated in social science (e.g. http://www.sciencedirect.com/science/article/

* Corresponding author.
E-mail address: kangjian0210@126.com (J. Kang).
[1] These authors contributed equally to this work.

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pii/S0016328714000809 Axelord, 1976). Recently an increasing number of publications are devoted to applications of FCM across a variety of fields, such as business planning, medicine, and environmental management (Abou, 2012; Wu et al., 2015). They frequently focus on the extension of the FCM method, among others through machine learning approaches that reveal the overall relation of system elements. FCM still lacks in in-depth research models such as on conditional probabilistic relation. Therefore, the mathematical mechanism of FCM is still not clear. Relative degree analysis (RDA) aims to discover the correlation characters existing in large data to find out the rules of how the changes of some event cause the changes of the others. Quantitative model based on RDA constantly spring up. A numerical statistical model is introduced to measure inter-individual differences in relative degree of personal disorganization and social alienation, which transfers ambiguous empirical cognitions to quantitative expressions (Lewis, 2015). Mu et al (Mu et al., 2004). used grey relative analysis, which can account for the time sequence, to analyze the relative relation among the four major factors affecting the rural household biofuels consumption of each province/region in China. Considering that the essence performance evaluations is a fuzzy concept with multiple indices, the concept of fuzzy sets describing imprecision or vagueness was introduced by Zadeh and Desoer (1965) and first applied to economic field to solve fuzzy problems, in which the object to be evaluated is affected by multiple factors, and relations among these factors. With the development of fuzzy theory, Fuzzy comprehensive evaluation (FCE) was developed and has been widely applied in decision-making and evaluation processed in imprecise situations (Zhou et al., 2013).

Some new methods have been developed in recent years. An assessing model for equipment risk management was developed, which was based on detailed examination of qualitative and quantitative system factors (Huang et al., 2012). This method has its advantages in multiple dimensions, but the variety of equipment categories challenges the comprehensive decision-making. A kind of monitoring method for operation states of a critical sub-system was developed to detect the potential dangers (Yuan et al., 2001). However, due to the neglect of external interference that may impact on inner sub-systems, this method will provoke a high probability of misdiagnosis. MFM-HAZOP is the method of Hazard and operability analysis (HAZOP) that includes the idea of multilevel flow model (MFM), which makes the analysis process more targeted (Lind and Zhang, 2014). It is a goal-oriented system modeling method. Within the prescribed time and specified conditions, it can describe the functions of the system elements and their relations to achieve the design goals (Wang et al., 2012). MFM helps to prevent modeler from making errors and make modeler more efficient in using previous experience.

The above methods and some other classical evaluation methods provide useful ways for safety evaluation. However, in many studies, the hierarchy of evaluation system and the weight assignment of indicators are not clearly explained. A safety evaluation system usually contains various indexes, so it is possible to process the expert opinions for each index to form a scientific weight distribution model. Recently, different weighting methods are presented for different kinds of evaluation information such as quantitative data and ambiguous languages. A general conclusion of these studies is that subjective weighting model is established by comparing the importance of each index (such as sequence close analysis method), and objective weighting model is built by comparing the difference of each index (such as entropy evaluation method). Though these provided some advanced guidelines for the development of weight distribution. There still lacks an integrated scheme to comprehensively handle subjective and objective opinions at one time. In addition, since safety and risk is a relative fuzzy concept, the application of fuzzy math is a better way to quantity the fuzzy concepts to have a definite safety level. In recent years this problem has been given considerable attention among researchers. These work inspired some development of multiple indicator fusion and multiple layer analysis (Wang et al., 2011and Mercurio et al., 2009).

This work presents an integrated framework for the comprehensive safety evaluation of a process plant. FTA method combing leveled and classified thought is used to abstract all the crucial risk factors contributing to the system failure. Then a weight distribution model that can overcome the constraints of weight subjectivity and better handle the expert opinions is proposed to assign the weight for each evaluation index. FCE is employed to calculate the safety level of the system. Since the petroleum transportation station contains massive dynamic and static equipments with the objective of gathering, processing and distributing oil from original stations to refinery factories, cities and users, which plays an important role in oil and gas production plants, it is adopted as an applied objection of the proposed method.

2. Brief description of the integrated framework

The schematic structure of the proposed approach is intended to be used as a step by step guidance tool of risk assessment and safety evaluation. It is easy to build with Web/SQL server, and ready to apply for current industrial projects. In general, three basic steps are included. The flowchart of proposed framework is shown by Fig. 1.

Step one: FTA is implemented for acquiring all possible risk factors deriving from the equipment and management of the system. For large sample sizes, equipment classification is initially established and revised based on expert opinions collected via reviewing documents and reports as well as interviewing supervisors and workers on the operation. Structural importance degree analysis is used to analyze the impact degree from each basic risk factor on the top event, and for each category of equipment, basic risk factors are arranged by structural importance degree.
Step two: A weight distribution model is developed based on FCM and RDA. FCM, a knowledge driven method, is applied to determine weight assignment from the view of linguistic evaluation information, and RDA is employed to distill the obtained knowledge to establish data-driven weights, the results of which are used to review the FCM model to modify some linguistic description.
Step three: Considering the complexity and uncertainty involved in safety evaluation, the FCE, using fuzzy judgments than crisp comparisons, is proposed as a new decision-making method that is particularly useful in multivariable circumstances. The most important aspect is that the impact degree of the influence factors on the evaluation objective is considered by membership functions in fuzzy set theory, and this is more reasonable than the other traditional evaluation methods. The safety level of the oil and gas production plant could be obtained via FCE model.

The logical thinking behind this framework, initially, is to explicitly explore all the basic risk factors of system based on the background knowledge. Since the most prevalent method to hazard identification is the expert knowledge, FTA is used to obtain all the basic risk factors. After the acquisition of basic risk factors, FCE concerning with imprecise information is used to process evaluation data and yield a comprehensive safety level. Here, weight distribution model is of particular interest because the reasonability of weight assignment contributes mostly to the credibility of