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Key factors identification and dynamic fuzzy assessment of health, safety and environment performance in petroleum enterprises

Lunjiang Yan [a,b], Laibin Zhang [a,1], Wei Liang [a,2], Weijun Li [a,*], Min Du [b]

[a] Research Center of Oil & Gas Safety Engineering Technology, College of Mechanical and Transportation Engineering, China University of Petroleum in Beijing, China
[b] CNPC Research Institute of Safety & Environment Technology, China

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ABSTRACT

Performance evaluation of Health, Safety and Environment (HSE) in large petroleum corporation is an indispensable way of strengthening safety management and promoting continuous improvement. It is also a tool for petroleum enterprises to measure their HSE performance levels. As HSE has been applied in petrochemical fields for decades, it is always time-consuming to assess HSE performance because there are so many evaluation indicators. In order to evaluate HSE performance efficiently, Spearman's correlation coefficient method is applied to identify the key HSE performance factors based on historical data for the first time. Besides, conventional scoring method is too cursory and arbitrary by simply grading according to total scores of all indicators. An improved fuzzy comprehensive evaluation method is proposed to address this problem, as well as improve the predictability of HSE performance trends based on dynamic fuzzy theory. Finally, the HSE performance evaluation of gas transmission field is chosen as a case to illustrate the effectiveness of the method and a comparison with traditional fuzzy comprehensive evaluation method is made.

1. Introduction

Health, Safety and Environment, usually referred to as HSE, is a systematic and integrative management system developed in the 1980s. In the petrochemical industries, it aims to assure safe production, reduce risks, prevent accidents and achieve sustainable development (Petroleum Safety Authority Norway, 2016). The principal of HSE is now well recognized in most petrochemical plants for its good performance (Høivik et al., 2009). Since International Organization for Standardization (ISO) began working on the formulation and development of HSE standards and systems, including ISO-9000 (ISO, 1994, 2000), ISO14001 (ISO, 1996, 2004), etc., HSE implementation has been prioritized either by both government and companies. For example, Norway's government emphasized the importance of HSE in petroleum industries. Also Chinese government promulgated some HSE standards (e.g. GB/T 24001-1996, GB/T 28001-2001, Q/SY1002.1-2007, Q/SY1002.2-2008, etc.) to enforce health, safety and environment management in high risk industries (Liu, 2009). Especially in process industries like petrochemical companies, health, safety and environment are of prime importance. For example, Chinese major petroleum enterprises have implemented HSE management system and emphasize HSE management as an important part of enterprise safety management (Zheng et al., 2006). In some European Union (EU) member states, HSE management programs have also been developed to improve their safety performance (Duijm et al., 2008). All these studies and applications have proved that HSE system is an effective tool to enforce safety management.

Initially, most efforts were put on developing or improving HSE standards and guidelines (Redinger and Levine, 1998; Robson et al., 2007). Nowadays, more attention has been given to the performance measurement methods of HSE effectiveness (Azadeh et al., 2008, 2012; Chin et al., 2003). In spite of these efforts which have been put on HSE performance management systems; there has not been any agreed standard tool for HSE performance measurement is available (Mohammadfam et al., 2012; Gholami et al., 2015). One of the most used methods to evaluate HSE performance is indexing method, which quantifies HSE indices with defined criteria (Malmasi et al., 2010). This is also called normative method.

* Corresponding author at: College of Mechanical and Transportation Engineering, China University of Petroleum in Beijing, No. 18 Fuxue Road, Changping District, Beijing, China.
E-mail addresses: zhanglb@cup.edu.cn (L. Zhang), lw@cup.edu.cn (W. Liang), weijunli2013@163.com (W. Li).
[1] Co-corresponding author at: Research Center of Oil & Gas Safety Engineering Technology, College of Mechanical and Transportation Engineering, China University of Petroleum in Beijing, No. 18 Fuxue Road, Changping District, Beijing, China.
[2] Co-corresponding author at: College of Mechanical and Transportation Engineering, China University of Petroleum in Beijing, No. 18 Fuxue Road, Changping District, Beijing, China.

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Conventional normative methods are to grade a company's HSE performance by adding scores of all HSE indicators. However, with the widespread attention and use of HSE performance assessment, issues begin to emerge.

(1) There are so many HSE performance indicators which are defined by experts (e.g. 28 indicators were defined in China National Petroleum Corporation). It requires much more resources to evaluate each fixed indicator without identifying key performance variables. Besides, according to the Pareto principle, also called the 80/20 rule, only 20% elements have significant impacts on HSE performance compared with the other 80% elements. For example, Podgórski (2015) selected 20 key performance indicators from 109 pro-active safety performance indicators with Analytic Hierarchy Process (AHP) to measure OSHMS (Occupational Safety and Health Management System) operational performance. Therefore, it is of vital importance to develop methods to identify essential performance indicators. Fortunately with the data collected from the past several decades, this issue can be addressed with statistical methods.
(2) Conventional HSE performance evaluation result is a specific value or rank. If an evaluation result is close to the boundary of two levels, for example the value is 0.49 (assuming that value less than 0.5 is at a bad level and more than 0.5 at a good level), it is too absolute and arbitrary if we conclude it at a bad level. Many fuzzy related methods have been proposed to address boundary issues (Hsiao and Ko, 2013; Guo et al., 2009; Azadeh et al., 2013). Fuzzy comprehensive evaluation (FCE) is one of them, which use membership to represent HSE performance level (Li et al., 2015).
(3) Determining performance level is not enough to measure HSE performance thoroughly and fairly. Imagine two company's HSE performances are both at good level, but one has the inclination toward a higher level while the other toward a lower level. Can we simply conclude that they are in the same level? Apparently the answer is no. In this paper, HSE performance level membership and development tendency will be obtained by introducing dynamic fuzzy set theory into traditional fuzzy comprehensive evaluation (FCE).

With more and more data being available, statistical methods could play a vital role in HSE performance evaluation. Spearman's rank correlation coefficient will be used to identify key performance indicators based on statistical data in this paper. It should be noted that indicators of HSE performance system are diverse since different countries or different enterprises can design their own criteria based on their understanding and requirements of HSE (Mahdavinejad et al., 2012; Honkasalo, 2000; Mustapha et al., 2014; Kongsvik et al., 2016). Although the HSE criteria prototype used in this research is from China National Petroleum Corporation (CNPC), and the method proposed in this research is illustrated by HSE performance evaluation of CNPC, we believe that it will be also helpful for other petroleum companies to improve their HSE performance evaluation.

2. Methodology

2.1. Spearman's rank correlation coefficient

In order to identify key performance affecting factors which contribute significantly to HSE performance, Spearman's rank correlation coefficient (Spearman, 1904) is used to measure the correlations between HSE affecting factors and HSE performance based on statistical data. A brief description of calculation steps is as follows:

(1) Choose a sample of historical data as observations. To conduct Spearman's rank correlation, there must be two sets of variables. In this research, the data is $N = 10$ pairs of HSE affecting factors' scores and HSE performance scores, which will be explained in later section.
(2) Replace the raw data by their ranks. For each pair of HSE affecting factors' scores and HSE performance scores, affecting factors' scores are ranked and marked as $X_1, X_2, X_3, \ldots, X_N$. For HSE performance scores, the ranks are represented by $Y_1, Y_2, Y_3, \ldots, Y_N$. The ranks should be in order from small to large.
(3) Calculate correlation coefficient R_s with the following formula:

$$R_s = 1 - \frac{6\sum_{i=1}^{N} d_i^2}{N(N^2 - 1)} \quad (1)$$

where d_i represents the difference between X and Y. As mentioned above, $N = 10$ in our case. For each pair of HSE affecting factor' score X and HSE performance score Y, d_i can be obtained. For example, $d_1 = Y_1 - X_1$, $d_2 = Y_2 - X_2$, $d_3 = Y_3 - X_3$, etc.
(4) Check the distribution table for the critical value of correlation coefficient R_s' provided by Zar (1972). Part of the table is provided in Appendix A. These two sets of variables are correlative if $R_s > R_s'$. In this research it means that this factor is the key HSE performance affecting factor. Repeat step 2 to step 4 for every affecting factor, then all key performance factors can be chosen.

2.2. Dynamic fuzzy comprehensive evaluation (DFCE) method

The conventional FCE is improved by introducing dynamic fuzzy sets (DFS) theory to obtain a dynamic result. The basic principle of DFS is that for any variable x, it can be represented as $x = (\overleftarrow{x}, \overrightarrow{x})$. In other words, any variable can be represented as a vector set. For dynamic membership function $(\overleftarrow{x}(\overleftarrow{u}), \overrightarrow{x}(\overrightarrow{u}))$, define a mapping $(\overleftarrow{u}, \overrightarrow{u}) \mapsto (\overleftarrow{x}(\overleftarrow{u}), \overrightarrow{x}(\overrightarrow{u}))$ $(\overleftarrow{x}(\overleftarrow{u}) \in [0, 1], \overrightarrow{x}(\overrightarrow{u}) \in [0, 1])$ to represent the membership degree of $(\overleftarrow{u}, \overrightarrow{u})$ for $(\overleftarrow{x}, \overrightarrow{x})$. The membership degree is higher if $(\overleftarrow{x}(\overleftarrow{u}), \overrightarrow{x}(\overrightarrow{u}))$ is closer to $(1, 1)$. Apparently, DFS can not only solve the boundary problem by membership but also reflect tendency by vector. Based on these definition, a dynamic fuzzy comprehensive evaluation method is established. The procedures are as follows:

(1) Determine key performance affecting factor set $U = \{u_1, u_2, \ldots, u_n\}$, where u_i represents each key performance factor obtained in Section 2.1.
(2) Determine dynamic evaluation set $V = \{(\overleftarrow{v_1}, \overrightarrow{v_1}), (\overleftarrow{v_2}, \overrightarrow{v_2}), \ldots, (\overleftarrow{v_j}, \overrightarrow{v_j}), \ldots, (\overleftarrow{v_m}, \overrightarrow{v_m})\}$, where $\overleftarrow{v_j}$ represents possible evaluation result of the evaluation objects. For example, if the fuzzy language used to describe evaluation result is "bad, good, very good", then the dynamic evaluation set should be expressed as "$(\overleftarrow{\text{bad}}, \overrightarrow{\text{bad}}), (\overleftarrow{\text{good}}, \overrightarrow{\text{good}}), (\overleftarrow{\text{very good}}, \overrightarrow{\text{very good}})$", where $\overleftarrow{\text{good}}$ represents "in good state with tendency to be bad".
(3) Determine dynamic fuzzy relation matrix. Fuzzy relation matrix is used to describe the membership degree of every affecting factor to every possible evaluation result. For u_i, its membership degree to $\overleftarrow{v_j}$ is $\overleftarrow{r_{ij}}$ $(0 \leqslant r_{ij} \leqslant 1)$. Then the