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Performance assessment system of health, safety and environment based on experts' weights and fuzzy comprehensive evaluation

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A B S T R A C T

Performance evaluation of Health, Safety and Environment (HSE) is the measurement of a company's achievement in HSE management. In order to receive a comprehensive and objective evaluation result, it is necessary to consider all evaluation factors and experts at different levels when HSE performance assessment is conducted. To improve conventional HSE performance evaluation, where weighted average method was used, a Fuzzy Comprehensive Evaluation (FCE) method is used in this study by taking experts' weights into account. Further, an HSE operating performance assessment system is designed to simplify manual and complex assessment process and generate charts and analysis reports automatically. Finally, a case of petrochemical enterprise is used to illustrate the effectiveness of the method and system.

1. Introduction

Catastrophic accidents like the Bhopal disaster in 1984 caught people's attention of safety, health and environmental management (Linhard, 2005). Since the 1990s, some international standards have been issued like ISO-9000 for quality management (ISO, 1994, 2000), BS 8800 and OHSAS 18000 for occupational safety (BSI, 1996, 2007) and the HSE guideline "Successful health and safety management" (HSE, 1997). In addition, many companies instituted their own HSE principles based on the International Chamber of Commerce (ICC) charter (Duijm et al., 2008). HSE, the acronym of safety, health and environment used by many companies (Deng, 1999), has been applied to strengthen safety management, especially in petrochemical area. The interpretation of HSE concept and its application in a large petroleum company, see (Høivik et al., 2009). Effective HSE management will result in injuries reduction, environment protection, performance improvement, and a distinctive leadership position in the world. The Health, Safety, and Environment Management Systems (HSE-MS) can promote performance and minimize the risks (Azadeh et al., 2012).

Evaluation of HSE is an important means of judging management level and continuously improving performance. It can help enterprise managers to find defects and take remedial measures. The most-used evaluation method is expert grading and weighted average, which is also the easiest. However, in the real application of HSE performance evaluation, we probably face the following three questions:

- Can managers receive a comprehensive evaluation result considering too many HSE criteria?
- Which assessment level is the evaluation object in if the score is close to boundary? (e.g., we define the object with the score of less than 0.5 is in a poor level, otherwise, it is in a good level, what about 0.499999?)
- How do managers consider different opinions of evaluation experts at different level?

To solve these problems, a comprehensive and fuzzy method should be proposed. First of all, we must consider all of the affecting factors simultaneously to conduct HSE performance evaluation because the object is affected by many elements rather than an independent unit. Second, there is no absoluteness in real world and thus we need fuzzy logic to interpret boundary questions. In many cases, the evaluation result can not just be expressed by a specific level like good or bad. But we can see it as a matter of

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degree in fuzzy logic so as to make it be in accordance with human thinking (Kacprzyk and Yager, 1985). Finally, experts with different expertise and knowledge have different opinions on evaluation object. So it is essential to have regard to all experts' views while evaluating HSE performance. Therefore, a fuzzy comprehensive evaluation considering multi-experts' weights is established to assess the HSE performance.

Besides, traditional performance evaluation of HSE is conducted by manual work. With the development of computer technology, computer-aided HSE management systems have been designed. For example, Det Norske Veritas (DNV) launched the International Safety Risk System (ISRS) to assess HSE management level in 1978. Conventionally, it usually takes several weeks to conduct an assessment and also requires lots of experts and organizations. By building models or designing computer-aided systems, the time of performance evaluation process can be saved; meanwhile, human errors can be reduced. A. Azadeh proposed an integrated HSE and ergonomics expert system to evaluate the impacts of indicators on HSE organization performance. However, they mainly put their focus on the health, safety, environment and ergonomics factors and seldom consider evaluation experts' impacts (Azadeh et al., 2008).

The development of PRIMA and STATAS audit tools for the assessment of safety management systems were described by Nick Hurst in the Health and Safety Laboratory. Through these tools, major hazard failures can be analyzed (Hurst, 1997). Unlike traditional HSE performance assessment system, the system developed in this work can obtain a fuzzy and comprehensive result of HSE performance based on experts' weights.

The rest of this article is organized as follows. In Section 2, a fuzzy comprehensive evaluation method based on experts' weights is introduced and its methodology is explained. Then a fuzzy comprehensive evaluation model of HSE performance assessment is established in Section 3. Section 4 describes the framework and modules of HSE performance assessment system. Finally, a petrochemical application example is provided to illustrate the effectiveness of the proposed system in Section 5.

2. Methodology

FCE, the acronym of fuzzy comprehensive evaluation, is a comprehensive decision-making methodology of a multivariable problem solving complex decision process (Bai et al., 2009). Particularly, it is the process that many related factors are considered comprehensively and that multiple objectives are taken into account together to obtain a fuzzy evaluation result (Guo et al., 2009). FCE has the following features and capabilities: First, it should be applied in complex systems with multi-factors. Second, it considers different experts' opinions at different level and defines experts' weights. Third, its result is a fuzzy set rather than an absolute number. Thus, FCE will be an effective method to evaluate the performance of HSE. To conduct the FCE of HSE performance, five steps are briefly introduced as follows:

Step 1:

An affecting factor set is made up with various factors affecting the evaluation objective. It usually depends on existing evaluation standards or indexes or expert experience (Chen et al., 2014; Cho and Lee, 2013). The affecting factor set U can be described as

$$U = \{u_1, u_2, u_3, \cdots, u_m\} \quad (1)$$

in which $u_i\,(i = 1, 2,\ldots, m)$ is called the affecting factor of evaluation object.

Step 2:

Different factors have different affects on evaluation objective. A weight factor is used to account for the relative importance of all affecting factors. A factor weight set is composed of all weights of affecting factors for evaluation object. The factor weight set A can be described as

$$A = \{a_1, a_2, a_3, \cdots, a_m\} \quad (2)$$

where $a_i\,(i = 1, 2,\ldots, m)$ is called the weight of affecting factor u_i for evaluation result. Specially, the weight of each factor should satisfy the following equation:

$$\sum_{i=1}^{m} a_i = 1, 0 \le a_i \le 1, (i = 1, 2, 3, \cdots, m) \quad (3)$$

The weight factor can be determined by weighting coefficient method, Analytic Hierarchy Process (AHP), or subjectively determined according to the requirements of actual issues.

Step 3:

An evaluation set consists of various possible evaluation results given for the evaluation objects, which is usually expressed by fuzzy language. The aim of FCE is to calculate the membership degrees of evaluative subject to every kind of possible evaluation results. For example, if the evaluation results can be qualitatively divided into three classifications: high possibility, medium possibility and low possibility, the evaluation set can be described as $V = \{v_1, v_2, v_3\}$, where v_i $(i = 1, 2, 3)$ represents the three possible evaluation classifications.

Step 4:

To obtain the membership degrees of evaluative subject, which is affected by many factors, as mentioned above, we should first calculate the membership of every affecting factor to every possible evaluation result.

As to factor $u_i\,(i = 1, 2,\ldots, m)$ in factor set U, we assume that the membership of u_i to evaluation result $v_i\,(i = 1, 2,\ldots, n)$ in evaluation set V is r_{ij}, then the evaluation set of u_i can be expressed as

$$R_i = \{r_{i1}, r_{i2}, \cdots, r_{in}\}\ (i = 1,\ 2,\ \ldots,\ m) \quad (4)$$

This computational process is called single factor evaluation. Usually, r_{ij} is determined by experts. Specifically, if forty percent of the total experts ascribe u_i as evaluation classification v_i, the value of r_{ij} is 0.4. After all of the memberships of affecting factor in set U are calculated by the method above, a single factor evaluation matrix is determined, represented as

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_i \\ \vdots \\ R_m \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1j} & \ldots & r_{1n} \\ r_{21} & r_{22} & \ldots & r_{1j} & \ldots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & r_{i2} & \ldots & r_{ij} & \ldots & r_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \ldots & r_{mj} & \ldots & r_{mn} \end{bmatrix} \quad (5)$$

Step 5:

Based on evaluation matrix R and factor weight set A, the membership degree of evaluation object to evaluation set can be synthesized by fuzzy composite operator. The comprehensive evaluation results can be calculated by the following equation:

$$B = A \cdot R = \{b_1, b_2, \cdots, b_i, \cdots b_n\} \quad (6)$$

where b_i represents the probability of evaluation object to be evaluation classification v_i. The symbol "•" represents fuzzy composition between weighted fuzzy matrix A and factor evaluation matrix R. Some composite methods have been proposed to obtain evaluation results (Hsiao and Ko, 2013), including $M(\wedge,\vee)$, $M(\bullet,\vee)$, $M(\wedge,+)$, $M(+,\bullet)$ and so on. The $M(+,\bullet)$ method can consider and retain each factor's contribution to the evaluation results and is