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Research Article

An Assessment Model of Safety Production Management Based on Fuzzy Comprehensive Evaluation Method and Behavior-Based Safety

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To better guarantee the health and safety of employees and reduce the probability of occupational injuries and accidents, it is necessary to evaluate safety production management levels in enterprises. In this study, an evaluation index model was established for the safety production management of an oilfield enterprise. By utilizing an analytic hierarchy process (AHP) and fuzzy comprehensive evaluation (FCE), this research is based on the characteristics of the oilfield enterprise and its behavior-based safety (BBS) management. A comparison of the results of two FCEs shows that the unsafe behaviors of employees were considerably reduced, and the safety production management level was significantly increased. The results of the case study also verify that combining the FCE model and the BBS approach is effective. The combination of the AHP and FCE method with BBS management support aims to improve safety behavior and increase safety training and the identification of critical unsafe behavior, thus reducing occupational injuries and accidents.

1. Introduction

Petroleum is an important strategic resource for a country. However, the refining of petroleum can not only pollute the atmosphere and water and soil resources, but also result in the loss of materials, equipment, and casualties [1]. Petroleum refinement has undergone rapid growth over the past 15 years, owing to economic development [2, 3].

However, the working environment in an oilfield enterprise is often hot and noisy, and there is always a risk of burns [4]. Other potential risk factors include a lack of professional training, excessively heavy tasks, tight construction schedules, and work overload [5]. Every year, millions of safety production management accidents occur globally, causing immense suffering for the affected workers and their families and enormous losses to enterprises and ultimately nations [4]. Therefore, safety production management cannot be overemphasized, owing to the frequent occurrence of safety accidents resulting from problems such as a lack of effective safety education and training, low educational backgrounds of employees, and inadequate input into safety management [6]. It is self-evident that the safety production management of oilfield enterprises is improving.

As a safety management tool, behavior-based safety (BBS) can improve the emergency response capabilities of employees, reduce accidents and occupational injuries, correct unsafe behaviors of people, and improve the safety climate and performance [7, 8]. BBS typically involves measuring worker safety behaviors through peer observations or self-monitoring and providing feedback, both immediately to the individual and periodically to the group, to correct unsafe behaviors [8, 9]. The BBS approach has been observed to be effective in a wide variety of settings and industries, including dining facilities on a college campus [10], paper mills [11], oil refineries [12], fleet services [13], oil field drilling [14], and manufacturing enterprises [15], to name a few. The BBS approach was first established by Skinner, a psychologist, in the 1930s [16].

In the classic domino theory, unsafe conditions and acts of people have been viewed as root causes of industrial accidents. According to Heinrich [17], of the direct causes, 88% are unsafe acts of people, 10% unsafe conditions, and the remaining 2% unpreventable causes. Peterson [18] claims that human error often results from a management-created environment that rewards risk-taking. Nishigaki et al. [19] found that most accidents occur because of human failures. Blackmon and Gramopadhye [20] claim that 98% of incidents and occupational injuries are attributed to unsafe acts of people. HSE [21] argued that 80–90% of all occupational injuries and accidents are caused by unsafe behaviors. Many manufacturing enterprises have experienced a 40–75% reduction in their occupational injury and accident rates within a year as a direct result of applying the methods associated with BBS [22]. BBS has demonstrated effectiveness in improving worker safety behaviors and reducing occupational injuries [23]. In addition, BBS initiatives represent a trend in current research and practice efforts towards improving safety performances [24].

Owing to the high-risk working environment, oilfield enterprises need to assure safe working environments through objective and regular safety evaluations and risk analyses. Because some of the evaluation factors are inherently vague, it is necessary to utilize a tool known as fuzzy set theory. Zadeh [25] first introduced fuzzy set theory to deal with the vagueness of human thought, and the method was oriented towards the rationality of uncertainty owing to imprecision or vagueness. On the one hand, some evaluation factors cannot be defined as a precise number, but only a fuzzy concept. On the other hand, there exists no one-to-one functional relationship between disasters and the changes of various factors, which makes it impossible to establish a precise mathematical model to be solved. Fuzzy theory has a unique effect in dealing with these issues [26]. Fuzzy set theory has been applied in many systems in recent scientific research [27, 28]. Therefore, in this study an evaluation model of safety production management levels based on BBS is established using fuzzy theory [17, 29] and the analytic hierarchy process (AHP). The results show that BBS can be combined with the theory of fuzzy mathematics to improve the level of enterprise safety production management.

The remainder of this paper is arranged as follows. In Section 2, the method of AHP and fuzzy comprehensive evaluation (FCE) is introduced, and its related concepts are explained. Then, Section 3 constructs the evaluation index model of the oilfield enterprise safety production management level and calculates the factor and subfactor weights. In Section 4, the membership matrix is calculated based on survey data. In Section 5, the safety production management level of the oilfield enterprise is evaluated based on BBS management and the FCE method. Finally, a discussion of the results and conclusions of the study are provided in Sections 6 and 7, respectively.

2. Fuzzy Evaluation Method

2.1. Evaluation Factor Set

$$U = \{U_1, U_2, \ldots, U_n\} \tag{1}$$

The elements U_i $(i = 1, 2, \ldots, n)$ represent different influencing factors, and these factors have different degrees of fuzziness [30].

2.2. Evaluation Result Sets. The evaluation factor set is composed of the comparison result set for the evaluation object, expressed by V.

$$V = \{V_1, V_2, \ldots V_n\} \tag{2}$$

In this study, the evaluation result can be divided into five classifications, as follows ($n = 5$): V_1: very good, V_2: good, V_3: general, V_4: bad, V_5: very bad.

2.3. Calculation of Evaluation Factor Weights Using AHP. Each individual comparison matrix represents the decision of one expert. Integration is necessary to achieve a group consensus of expert decisions. AHP is a structured technique for analyzing and integrating multiple expert opinions. It can be reasonably and accurately applied in group decision making [31]. In the application of AHP, arithmetic mean operations are generally utilized to integrate group decisions, and this is the only method that satisfies the Pareto principle (unanimity condition) and the homogeneity condition. Hence, in this work arithmetic mean operations are applied for the integration of group decisions.

2.3.1. Establishment of Factor Weight Sets. Different weights are given according to the importance of each factor, resulting in the weight set.

$$A = \{a_1, a_2, \ldots, a_n\} \tag{3}$$

There are many methods for weight determination, including expert consultation, AHP, clustering, rough-set reduction, neural networks, and gray relational analysis. Each method has its own characteristics and limitations.

2.3.2. Establishment of Comparison Matrices. In this study, the relative importance of the indexes is scored by experts, to determine the weight value of each index in the current hierarchy, and the results are used to establish the comparison matrix of the factor set [32, 33]. To this end, Saaty's 1–9 (Table 1) hierarchy marking method is employed for such pairwise comparisons [34]. Thus, a reasonable comparison matrix A is constructed.

$$\mathrm{A} = \left(a_{pq}\right)_{nn} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{4}$$

Table 1: Scales and meanings of the judgment matrix.

Scales	Meaning
1	The p_{th} factor and the q_{th} factor are equally important
3	The p_{th} factor is slightly more important than the q_{th} factor
5	The p_{th} factor is more important than the q_{th} factor
7	The p_{th} factor is strongly more important than the q_{th} factor
9	The p_{th} factor is extremely more important than the q_{th} factor
2, 4, 6, 8	The intermediate level of adjacent judgments
1/2,… …1/9	The comparative results of the p_{th} factor and the q_{th} factor for their importance are the reciprocal of the above scales

Here, a_{pq} (p, q=1, 2, …, n) refers to the importance comparison result of the p_{th} and q_{th} factors, and n is the number of factors in the evaluation factor set. The comparison matrix A satisfies $a_{pq} > 0$, $a_{qp} = 1 / a_{pq}$, and $a_{pp} = 1$.

2.3.3. Weight Calculation and Consistency Check. (1) Each row of the comparison matrix can be normalized.

$$\overline{u}_{ij} = \frac{u_{ij}}{\sum_{i,j=1}^{n} u_{ij}} \quad (i, j = 1, 2, \ldots, n) \tag{5}$$

(2) Each column of the normalized comparison matrix is summed.

$$\overline{\mathrm{W}}_i = \sum_{j=1}^{n} u_{ij} \quad (i, j = 1, 2, \ldots, n) \tag{6}$$

(3) The vector $W = (W_1, W_2, \ldots, \mathrm{W_n})$ is then normalized.

$$a_i = \frac{\overline{\mathrm{W}}_i}{\sum_{j=1}^{n} \overline{\mathrm{W}}_j} \quad (i, j = 1, 2, \ldots, n) \tag{7}$$

(4) The maximum eigenvalues of the comparison matrix are solved through the following formula.

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(BW)_i}{nW_i} \tag{8}$$

(5) The consistency index is calculated.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{9}$$

(6) The randomness and consistency of the comparison matrix are tested, to determine whether the eigenvectors are reasonable. The empirical formula for testing is as follows:

$$CR = \frac{CI}{RI} \tag{10}$$

where λ_{max} is the maximum eigenvalue of a comparison matrix, n is the dimension of the comparison matrix, and RI represents a random index, shown in Table 2. Saaty proposed that $CI \leq 0.1$ and $CR \leq 0.1$ are acceptable ranges.

If the CR of a comparison matrix is less than or equal to 0.1, this can be considered acceptable. When $CR > 0.1$, the experts are required to revise their decisions. This step is repeated for the pairwise comparisons until all of the decisions are consistent.

Table 2: The random consistency index.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

2.4. Fuzzy Relation Matrix R. Starting from any factor for separate evaluation, the degree of membership of each evaluation object to V is determined [35]. After the grade fuzzy subset is obtained, quantified treatment shall be conducted one-by-one on the appraised objects. In other words, each factor U_i will be quantified to further obtain the fuzzy relation matrix R. According to the evaluation grade, an evaluation object is usually scored by experts or relevant professionals or scholars. The fuzzy relation matrix can be written as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{11}$$

where R represents the fuzzy relationship between the factor set U and evaluation set V.

2.5. Comprehensive Fuzzy Evaluation. AHP is utilized to obtain the weight set W and fuzzy relation matrix R, to establish a comprehensive risk evaluation model.

$$\begin{aligned} B = A \cdot R &= (a_1, a_2, \ldots, a_m) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \\ &= (b_1, b_2, \ldots, b_n) \end{aligned} \tag{12}$$

The weight set and factor evaluation matrix are combined to perform the fuzzy matrix synthesis operation [36]. After normalization, the obtained standard evaluation result is U_i.

3. Empirical Analysis

Enterprise employees were the subjects of a questionnaire on the safety production management of an oilfield enterprise in

China. According to the statistical results, the membership frequencies of indexes to the five evaluation results (very good, good, general, bad, and very bad) can be obtained. A total of 896 employees participated in the first survey, yielding 665 usable questionnaires. Employee safety behavior was observed and guided according to the application of BBS management in the oilfield enterprise. After a period of time, a second survey was issued. A total of 962 employees participated in the second survey, yielding 726 usable questionnaires. The results of the two evaluations were compared, and the rationality of the combination of the evaluation model and the BBS management method was verified.

3.1. Established Hierarchical Structure Model. As shown in Table 3, the evaluation index model of the enterprise safety production management level can be divided into three layers [37]: a target layer, first-layer index, and second-layer index. The evaluation factor set is composed of indexes of first-order indicators. According to the structure of the evaluation index model for enterprise safety, six evaluation factor sets and 19 subfactors were established, as shown in Table 3.

3.2. Weight Calculation and Consistency Check. To obtain the factor and subfactor weights, a group of 26 experts, including enterprise managers, experienced instructors, and academic scholars, was formed. These experts were organized to participate in a deep interview and were asked to compare six factors and 19 subfactors in the evaluation model. Their opinions were obtained from the interview results. Pairwise comparisons, which were adopted to obtain the expert evaluations of the relative importance of one factor over another, were employed to establish the comparison matrices of each expert [38], obtaining the following pairwise matrix.

$$A = \begin{bmatrix} 1 & \frac{1}{3} & 4 & 4 & 3 & \frac{1}{3} \\ 3 & 1 & 4 & 6 & 5 & 2 \\ \frac{1}{4} & \frac{1}{4} & 1 & 4 & 2 & \frac{1}{2} \\ \frac{1}{4} & \frac{1}{6} & \frac{1}{4} & 1 & 3 & \frac{1}{4} \\ \frac{1}{3} & \frac{1}{5} & \frac{1}{2} & \frac{1}{3} & 1 & \frac{1}{5} \\ 3 & \frac{1}{2} & 2 & 4 & 5 & 1 \end{bmatrix} \quad (13)$$

According to the aforementioned formulas (4) and (5), the following is obtained.

$$W_{ij} = \begin{bmatrix} 0.1277 & 0.1360 & 0.3404 & 0.2069 & 0.1579 & 0.0778 \\ 0.3830 & 0.4082 & 0.3404 & 0.3104 & 0.2632 & 0.4669 \\ 0.0319 & 0.1020 & 0.0851 & 0.2069 & 0.1053 & 0.1167 \\ 0.0319 & 0.0681 & 0.0213 & 0.0517 & 0.1579 & 0.0584 \\ 0.0426 & 0.0816 & 0.0426 & 0.0172 & 0.0526 & 0.0467 \\ 0.3830 & 0.2041 & 0.1702 & 0.2069 & 0.2632 & 0.2335 \end{bmatrix} \quad (14)$$

According to (5)–(7), the weights $\overline{w}_i$ can be calculated as follows (Table 4).

$$\overline{w}_i = \begin{bmatrix} 0.1745 \\ 0.362 \\ 0.108 \\ 0.0649 \\ 0.0471 \\ 0.2435 \end{bmatrix} \quad (15)$$

$CR = 0.0937 < 0.1$ is calculated using (8)–(10). The weight distribution of the comparison matrix is reasonable, and it has satisfactory consistency.

Furthermore, as shown in Tables 5–10, each index passes the consistency test (the operation method is the same as that applied in Table 4), demonstrating the satisfactory consistency of the indexes. The corresponding weights of the U layers from U_1 to U_6 are shown in Tables 5–10:

$$\begin{aligned} U_1 &= [0.2114 \quad 0.6551 \quad 0.1335], \\ U_2 &= [0.2732 \quad 0.6080 \quad 0.1199], \\ U_3 &= [0.5321 \quad 0.1018 \quad 0.3661], \\ U_4 &= [0.2334 \quad 0.0749 \quad 0.5477 \quad 0.1440], \\ U_5 &= [0.6334 \quad 0.1061 \quad 0.2605], \end{aligned} \quad (16)$$

and

$$U_6 = [0.6394 \quad 0.2737 \quad 0.0869]. \quad (17)$$

4. Single-Factor Evaluation Matrix

In this study, according to the 665 and 726 valid questionnaires, the membership degrees of the safety production management indexes to the evaluation results are shown for the considered enterprise in Table 11. The membership matrix was calculated based on the survey data [39].

$$RA_1 = \begin{bmatrix} 0.6451 & 0.3188 & 0.0346 & 0.0000 & 0.0015 \\ 0.4692 & 0.4556 & 0.0737 & 0.0000 & 0.0015 \\ 0.5609 & 0.3654 & 0.0722 & 0.0000 & 0.0015 \end{bmatrix}$$

$$RA_2 = \begin{bmatrix} 0.5684 & 0.3549 & 0.0752 & 0.0000 & 0.0015 \\ 0.4902 & 0.4421 & 0.0677 & 0.0000 & 0.0000 \\ 0.3669 & 0.4917 & 0.1218 & 0.0150 & 0.0045 \end{bmatrix}$$

$$RA_3 = \begin{bmatrix} 0.4466 & 0.4376 & 0.1098 & 0.0030 & 0.0030 \\ 0.4241 & 0.4737 & 0.0737 & 0.0211 & 0.0075 \\ 0.2692 & 0.5759 & 0.1308 & 0.0180 & 0.0060 \end{bmatrix}$$

$$RA_4 = \begin{bmatrix} 0.5699 & 0.4030 & 0.0271 & 0.0000 & 0.0000 \\ 0.3549 & 0.5444 & 0.0962 & 0.0030 & 0.0015 \\ 0.3383 & 0.4842 & 0.1398 & 0.0105 & 0.0271 \\ 0.2991 & 0.5115 & 0.1805 & 0.0053 & 0.0035 \end{bmatrix}$$

$$RA_5 = \begin{bmatrix} 0.4421 & 0.4692 & 0.0842 & 0.0030 & 0.0015 \\ 0.3684 & 0.5398 & 0.0857 & 0.0060 & 0.0000 \\ 0.4647 & 0.4647 & 0.0677 & 0.0030 & 0.0000 \end{bmatrix}$$

$$RA_6 = \begin{bmatrix} 0.3895 & 0.5398 & 0.0692 & 0.0015 & 0.0000 \\ 0.4576 & 0.4892 & 0.0532 & 0.0000 & 0.0000 \\ 0.4451 & 0.5233 & 0.0301 & 0.0015 & 0.0000 \end{bmatrix}$$

$$RB_1 = \begin{bmatrix} 0.6556 & 0.3017 & 0.0427 & 0.0000 & 0.0000 \\ 0.3953 & 0.5289 & 0.0758 & 0.0000 & 0.0000 \\ 0.4917 & 0.4311 & 0.0771 & 0.0000 & 0.0000 \end{bmatrix}$$

$$RB_2 = \begin{bmatrix} 0.5482 & 0.3747 & 0.0771 & 0.0000 & 0.0000 \\ 0.4504 & 0.4780 & 0.0702 & 0.0014 & 0.0000 \\ 0.4325 & 0.4380 & 0.1226 & 0.0014 & 0.0055 \end{bmatrix}$$

$$RB_3 = \begin{bmatrix} 0.5207 & 0.4008 & 0.0744 & 0.0028 & 0.0014 \\ 0.5179 & 0.3994 & 0.0813 & 0.0014 & 0.0000 \\ 0.5344 & 0.4036 & 0.0537 & 0.0083 & 0.0000 \end{bmatrix}$$

$$RB_4 = \begin{bmatrix} 0.7190 & 0.2631 & 0.0179 & 0.0000 & 0.0000 \\ 0.4118 & 0.5275 & 0.0606 & 0.0000 & 0.0000 \\ 0.4187 & 0.5303 & 0.0455 & 0.0014 & 0.0041 \\ 0.4215 & 0.5441 & 0.0275 & 0.0041 & 0.0028 \end{bmatrix}$$

$$RB_5 = \begin{bmatrix} 0.4766 & 0.3953 & 0.1267 & 0.0000 & 0.0014 \\ 0.4573 & 0.4366 & 0.1047 & 0.0014 & 0.0000 \\ 0.4780 & 0.4587 & 0.0592 & 0.0014 & 0.0028 \end{bmatrix}$$

$$RB_6 = \begin{bmatrix} 0.4050 & 0.5358 & 0.0579 & 0.0000 & 0.0014 \\ 0.5441 & 0.3871 & 0.0689 & 0.0000 & 0.0000 \\ 0.5606 & 0.4077 & 0.0289 & 0.0000 & 0.0028 \end{bmatrix} \quad (18)$$

5. Fuzzy Comprehensive Evaluation

The first-layer FCE was calculated according to each second-layer indicator weight W_i and each corresponding single-factor matrix R_i of the U layer. The first-layer FCE results were then obtained using (11).

$$\begin{aligned} SA_1 = WA_1.RA_1 &= (0.2114 \ \ 0.6551 \ \ 0.1335) \begin{bmatrix} 0.6451 & 0.3188 & 0.0346 & 0.0000 & 0.0015 \\ 0.4692 & 0.4556 & 0.0737 & 0.0000 & 0.0015 \\ 0.5609 & 0.3654 & 0.0722 & 0.0000 & 0.0015 \end{bmatrix} \\ &= (0.5186 \ \ 0.4146 \ \ 0.0652 \ \ 0.0000 \ \ 0.0015) \end{aligned} \quad (19)$$

Similarly,

$$\begin{aligned} SA_2 &= (0.4973 \ \ 0.4247 \ \ 0.0763 \ \ 0.0018 \ \ 0.0009) \\ SA_3 &= (0.3794 \ \ 0.4919 \ \ 0.1138 \ \ 0.0103 \ \ 0.0046) \\ SA_4 &= (0.3880 \ \ 0.4737 \ \ 0.1161 \ \ 0.0067 \ \ 0.0155) \\ SA_5 &= (0.4402 \ \ 0.4755 \ \ 0.0801 \ \ 0.0033 \ \ 0.0010) \\ SA_6 &= (0.4130 \ \ 0.5245 \ \ 0.0614 \ \ 0.0011 \ \ 0.0000) \\ SB_1 &= (0.5129 \ \ 0.4570 \ \ 0.0301 \ \ 0.0000 \ \ 0.0000) \\ SB_2 &= (0.4755 \ \ 0.4455 \ \ 0.0784 \ \ 0.0010 \ \ 0.0007) \\ SB_3 &= (0.5254 \ \ 0.4017 \ \ 0.0675 \ \ 0.0047 \ \ 0.0007) \\ SB_4 &= (0.4887 \ \ 0.4697 \ \ 0.0376 \ \ 0.0014 \ \ 0.0026) \\ SB_5 &= (0.4749 \ \ 0.4162 \ \ 0.1068 \ \ 0.0005 \ \ 0.0016) \end{aligned} \quad (20)$$

and

$$SB_6 = (0.4566 \ \ 0.4840 \ \ 0.0584 \ \ 0.0000 \ \ 0.0011) \quad (21)$$

where $SA_{1\text{-}6}$ and $SB_{1\text{-}6}$ represent the first-layer fuzzy comprehensive results of the first and second evaluations, respectively.

According to the weight values in Tables 4–10, the result set of the second hierarchy comprehensive evaluation is as follows [38].

$$\begin{aligned} SA &= WA.RA \\ &= (0.1745, 0.3620, 0.1080, 0.0649, 0.0471, 0.2435) \\ &\quad \cdot \begin{bmatrix} 0.5186 & 0.4146 & 0.0652 & 0.0000 & 0.0015 \\ 0.4973 & 0.4247 & 0.0763 & 0.0018 & 0.0009 \\ 0.3794 & 0.4919 & 0.1138 & 0.0103 & 0.0046 \\ 0.3880 & 0.4737 & 0.1161 & 0.0067 & 0.0155 \\ 0.4402 & 0.4755 & 0.0801 & 0.0033 & 0.0010 \\ 0.4130 & 0.5245 & 0.0614 & 0.0011 & 0.0000 \end{bmatrix} \\ &= (0.4580, 0.4601, 0.0775, 0.0026, 0.0021) \\ SB &= WA.RB \\ &= (0.1745, 0.3620, 0.1080, 0.0649, 0.0471, 0.2435) \\ &\quad \cdot \begin{bmatrix} 0.5129 & 0.4570 & 0.0301 & 0.0000 & 0.0000 \\ 0.4755 & 0.4455 & 0.0784 & 0.0010 & 0.0007 \\ 0.5254 & 0.4017 & 0.0675 & 0.0047 & 0.0007 \\ 0.4887 & 0.4697 & 0.0376 & 0.0014 & 0.0026 \\ 0.4749 & 0.4162 & 0.1068 & 0.0005 & 0.0016 \\ 0.4566 & 0.4840 & 0.0584 & 0.0000 & 0.0011 \end{bmatrix} \\ &= (0.4836, 0.4523, 0.0626, 0.0010, 0.0008) \end{aligned} \quad (22)$$

Table 3: Evaluation index model of the enterprise safety production management level.

NO.	First-layer index	Second- layer index	Indicator code
1		Personal attention at work	U_{11}
2	Employees' psychological behavior (U_1)	Personal psychological quality	U_{12}
3		Fatigue degree at work	U_{13}
4	Safety education (U_2)	Corporate frequency and intensity of safety training	U_{21}
5		Knowledge degree about current position's risks and dangers	U_{22}
6		Awareness degree of safety regulations	U_{23}
7	Working atmosphere (U_3)	Performance of workers in daily safety production	U_{31}
8		Corporate atmosphere of safety culture	U_{32}
9		Comfort level of working space	U_{33}
10	Management factors (U_4)	Corporate improvement degree of safety production plans	U_{41}
11		Improvement degree of safety production regulations	U_{42}
12		Corporate supervision of safety production	U_{43}
13		Corporate reward and punishment of safety production	U_{44}
14	Equipment factors (U_5)	Abrasion of manufacturing facilities	U_{51}
15		Cognition degree of following safety operation	U_{52}
16		Corporate funding investment in safety production	U_{53}
17	Employee's comprehensive quality (U_6)	Personal working experience	U_{61}
18		Personal physical health	U_{62}
19		Proficiency degree in safety operation	U_{63}

Table 4: The scoring of first level factors.

U	U_1	U_2	U_3	U_4	U_5	U_6	weight
U_1	1	1/3	4	4	3	1/3	0.1745
U_2	3	1	4	6	5	2	0.3620
U_3	1/4	1/4	1	4	2	1/2	0.1080
U_4	1/4	1/6	1/4	1	3	1/4	0.0649
U_5	1/3	1/5	1/2	1/3	1	1/5	0.0471
U_6	3	1/2	2	4	5	1	0.2435

Table 5: U_1 layer subordinate indicators weight.

U_1	U_{11}	U_{12}	U_{13}	Weight
U_{11}	1	1/4	2	0.2114
U_{12}	4	1	4	0.6551
U_{13}	1/2	1/4	1	0.1335

Table 6: U_2 layer subordinate indicators weight.

U_2	U_{21}	U_{22}	U_{23}	Weight
U_{21}	1	1/3	3	0.2721
U_{22}	3	1	4	0.6080
U_{23}	1/3	1/4	1	0.1199

Table 7: U_3 layer subordinate indicators weight.

U_3	U_{31}	U_{32}	U_{33}	Weight
U_{31}	1	4	2	0.5321
U_{32}	1/4	1	1/5	0.1018
U_{33}	1/2	5	1	0.3661

Table 8: U_4 layer subordinate indicators weight.

U_4	U_{41}	U_{42}	U_{43}	U_{44}	weight
U_{41}	1	3	1/4	3	0.2334
U_{42}	1/3	1	1/5	1/3	0.0749
U_{43}	4	5	1	4	0.5477
U_{44}	1/3	3	1/4	1	0.1440

Table 9: U_5 layer subordinate indicators weight.

U_5	U_{51}	U_{52}	U_{53}	Weight
U_{51}	1	5	3	0.6334
U_{52}	1/5	1	1/3	0.1061
U_{52}	1/3	3	1	0.2605

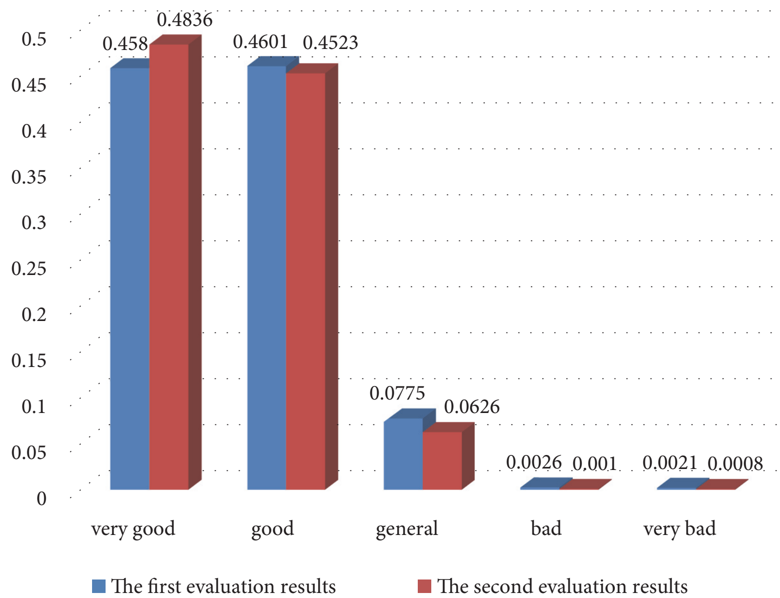

Figure 1: Histogram of the safety production management level fuzzy evaluation.

Table 10: U_6 layer subordinate indicators weight.

U_6	U_{61}	U_{62}	U_{63}	Weight
U_{61}	1	3	6	0.6394
U_{62}	1/3	1	4	0.2737
U_{63}	1/6	1/4	1	0.0869

Here, *SA* and *SB* represent the fuzzy comprehensive results of the first and second evaluations, respectively.

6. Discussion of Results

6.1. Discussion of Fuzzy Comprehensive Evaluation Results. The results of the first evaluation show that the “very good” probability of the safety production management level is 0.4580, and the probabilities of “good,” “general,” “bad,” and “very bad” are 0.4601, 0.0775, 0.0026, and 0.0021, respectively. In line with the maximum membership degree principle [16], the comprehensive evaluation result for the safety production management level is good. However, the enterprise safety evaluation level requires further improvement. The result for the second evaluation shows that the “very good” probability of the safety production management level is 0.4836, and the probabilities of “good,” “general,” “bad,” and “very bad” are 0.4523, 0.0626, 0.0010, and 0.0008, respectively. In line with the maximum membership degree principle [16], the comprehensive evaluation result for the safety production management level is very good. The FCE results are illustrated in Figure 1.

By comparing the fuzzy evaluation results, Figure 1 shows that the safety production management level of the second evaluation result is superior to that of the first evaluation, based on the maximum membership degree principle. In addition, the safety awareness levels and operations of the enterprise employees improved following the BBS reinforcement. Although fluctuations continued, safety preintervention levels were higher than for the first investigation results, while safety postintervention levels were lower. In fact, the numbers of injuries and days away from work reduced following the safety intervention.

6.2. Questionnaire Score Comparison. The average score results from the two questionnaires were calculated and are presented on a radar chart in Figure 2, where the subscripts from U_{11} to U_{19} represent the 19 subfactors of the safety production management level evaluation index model.

Figure 2 illustrates the average score results for the initial investigation into the oilfield enterprise undertaken by the research team. The second averaged score results for a series of BBS studies, undertaken by groups consisting of scholars, leaders, and supervisors within the same oilfield enterprise, are also presented in the figure. By comparing the two average score results, it is observed that BBS management not only improved the second averaged score results, but also reduced unsafe acts and accidents in the same oilfield enterprise.

6.3. Weights Discussion. The combined results for the factor and subfactor weights were calculated using the AHP method [5]. As shown in Figure 3, safety education (U_2) represents the highest impact percentage on the safety production management level among all six factors (U_2 has the highest level in the global weight), followed by employee comprehension qualities (U_6), employee psychological behavior (U_1), working atmosphere (U_3), management factors (U_4), and equipment factors (U_5). Therefore, safety education (U_2) and employee’s comprehension qualities (U_6) are the key factors that should be considered concerning safety production

Table 11: Evaluation results of single factor membership.

Second-Grade	Evaluation Decision Sets				
Indicator	Very good (100)	Good (90)	Medium (80)	Bad (70)	very bad (60)
U_{11}	429/476	212/219	23/31	0/0	1/0
U_{12}	312/342	303/372	49/12	0/0	1/0
U_{13}	373/357	243/313	48/56	0/0	1/0
U_{21}	378/398	236/272	50/56	0/0	1/0
U_{22}	326/327	294/347	45/51	0/1	0/0
U_{23}	244/314	327/318	81/89	10/1	3/4
U_{31}	297/378	291/291	73/54	2/2	2/1
U_{32}	282/376	315/290	49/59	14/1	5/0
U_{33}	179/388	383/293	87/39	12/6	4/0
U_{41}	379/522	268/191	18/13	0/0	0/0
U_{42}	236/299	362/383	64/44	2/0	1/0
U_{43}	225/304	322/385	93/33	7/1	18/3
U_{44}	169/306	389/395	102/20	3/3	2/2
U_{51}	294/346	312/287	56/92	2/0	1/1
U_{52}	245/332	359/317	57/76	4/1	0/0
U_{53}	309/347	309/333	45/43	2/1	0/2
U_{61}	259/294	359/389	46/42	1/0	0/1
U_{62}	318/395	310/281	37/50	0/0	0/0
U_{63}	296/407	348/296	20/21	1/0	0/2

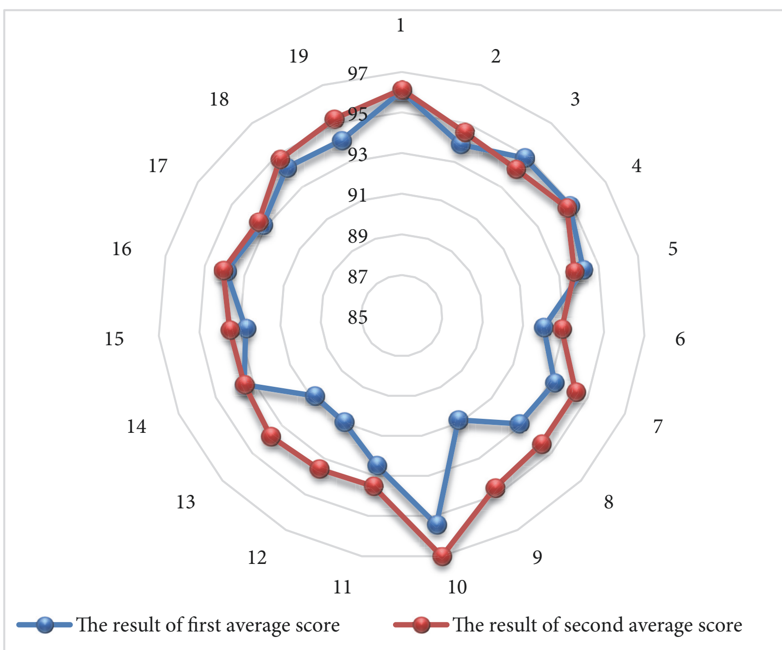

Figure 2: Comparison of average scores.

management levels. Meanwhile, Figure 3 also illustrates the fairly intuitive precedence of (U_i, i=1, 2, . . ., 6).

Based on Figure 2 the weight ranking, it is clear that equipment factors (U_5) and management factors (U_4) are sufficiently weak that there may be a high probability of occupational injuries and accidents in the considered oilfield enterprise. Thus, it is necessary to apply a BBS approach to improve key aspects in this enterprise, such as abrasion of manufacturing facilities (U_{51}), cognition degrees of following safety operations (U_{52}), corporate funding investment in safety production (U_{53}), and the corporate improvement degree of safety production plans (U_{41}).

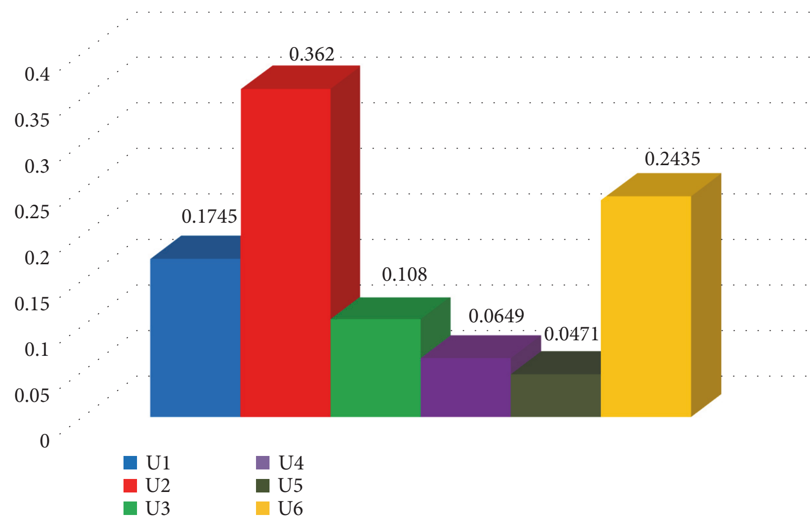

Figure 3: Global weights of factors.

7. Conclusion

Preventing safety-related incidents using behavioral science requires objective assessment and education. A new evaluation method for oilfield enterprise safety production management is proposed in this study, based on BBS theory and the FCE method. The proposed method can help employees to recognize factors that should be improved to guarantee their safe behavior. For this purpose, this study first developed an evaluation index model for safety production management. The AHP was utilized to determine the weights of factors and subfactors, because this method can make the weights determined in the evaluation index model more rational and reasonable. Second, as observers of the enterprise, we visited the enterprise, conducted some interviews with employees, distributed questionnaires to employees, issued the first FCE results, and provided feedback to the related managers, operators, and scholars. Finally, according to the analysis of the first evaluation results, we focused on employee praise and recognition when they operated safely or improved their unsafe behaviors. Following a period of time, a second round of questionnaires were distributed, and the second evaluation results were obtained. The compared results of the two evaluations showed that the unsafe behaviors of employees were considerably reduced. It was also observed that the FCE method not only gives consistent membership distributions, but also provides safety dynamic results to help enterprise leaders and researchers forecast safety risk tendencies. The comparison results also illustrated the effectiveness and reliability of the proposed approach.

From the same comparison results, it could also be verified that the combination of the evaluation model with BBS management is a rational approach. Therefore, the FCE model can be applied to evaluate safety production management and prevent potential risks in an oilfield enterprise. Furthermore, the evaluation results can be continuously adjusted based on the time interval of data collection in this field application. As a result, the analysis of the evaluation results indeed provides scientific and reasonable advice for related managers, operators, and scholars. Moreover, the proposed approach can also be expected to apply to safety production management evaluations of other enterprises and areas.

Owing to research limitations, first, the evaluation model is relatively simple and cannot include all characteristics of potential risks and human factors. Second, the fuzzy evaluation results are calculated through a large amount of data statistics, questionnaire analyses, and artificial calculations, which are time-consuming, and the weight determination is mainly dependent on the subjective experience of scholars and experts. Finally, this study only applied AHP, the FCE method, and BBS management to implement safety production management evaluation research and has not compared the results with other assessment methods, such as the extent analysis fuzzy AHP method [40], fuzzy TOPSIS-AHP methods [41], and fuzzy inference systems [42]. As a result, we should consider a variety of advanced evaluation methods and choose a combination of reasonable methods to evaluate safety production management levels in an enterprise.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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