Chapter 39
Safety Evaluation of Special Equipment Based on Revolutionary AHP-FCE Method

Fumin Deng, Fan Zeng, Xuedong Liang and Jian Zhang

Abstract This paper divides special equipment safety evaluation factors into indirect factors (environment and management) and direct factors (human and equipment) combined with fishbone diagram based on the factors' features of diversity, fuzziness and interference effects between layers. AHP-FCE method and DEMATEL method are adopted to determine and modify factor weights to build a special equipment safety evaluation system. Finally, a practical case is proposed to examine the effectiveness of this system which is expected to provide a practical, objective and reasonable approach for the improvement of special equipment safety evaluation.

Keywords Special equipment · Safety evaluation · Revolutionary AHP-FCE Method · DEMATEL method · Fishbone diagram

39.1 Introduction

Special equipment is playing a more and more important role in the natural economy, and its security problem has become a key factor in its development. Compared to most industrial countries, special equipment management is started late in our country which leads to the relatively immature special equipment safety evaluation system [1, 2].

Factors of special equipment safety evaluation are diversified, uncertain and have interference effects between layers. Relatively a small number of domestic scholars study the safety evaluation of the special equipment, and mainly concentrate on

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the special equipment itself and its management. Shen et al [3] divided evaluation factors into daily operational management, the basis of important equipment, transmission, braking device, safety devices and electrical control device. Miao et al [4] divided evaluation factors into Enterprise security, equipment security and human security research. Yang et al [5] divided evaluation factors into source of the inherent danger, security system and management, device management status, status of personnel management and risk control. Tang et al [6] divided evaluation factors of passenger cableway into cableway qualification, security agencies, management system, safety training, safety inspections and incident handling research. There are two problems from these established special equipment safety evaluation system: (1) Most evaluation factors are constrained to equipment itself which did not reflect the systematic features of special equipment safety evaluation. Comprehensiveness and independence of factors can hardly be guaranteed in consideration of the diversity and complexity of evaluation factors. (2) Interference effects between layers of factors were ignored which influenced the objectiveness of factor weights.

Factors set of safety evaluation are established on the basis of fishbone diagram and AHP method. Evaluation factors are divided into indirect factors and direct factors, what's more, indirect factors are divided into environment and management while direct factors are divided into human and equipment. Then DEMATEL method is adopted to modify the interference effects between layers of factors and revise the factor weights. Finally, fuzzy comprehensive method is used to establish safety evaluation system and a practical case is presented to examine the effectiveness of this system.

39.2 Factors Set of Special Equipment Safety Evaluation

Factors set of special equipment safety evaluation are established on the basis of fishbone diagram and AHP method.

39.2.1 Factors Set

Factors set U are the sets of all related factors, $U = \{u_1, u_2, \cdots, u_n\}$. u_i $(i = 1, 2, \cdots, n)$ indicates the factor which influences special equipment safety evaluation system. Factors set are built by collecting relevant data, classifying master data and expert interviews, and fishbone diagram is drawn in Fig. 39.1.

Factors set of special equipment safety evaluation are established based on fishbone diagram analysis.

Factors set consist of direct and indirect factors.

Indirect factors include "environment" and "management" which represent indirect special equipment safety risks.

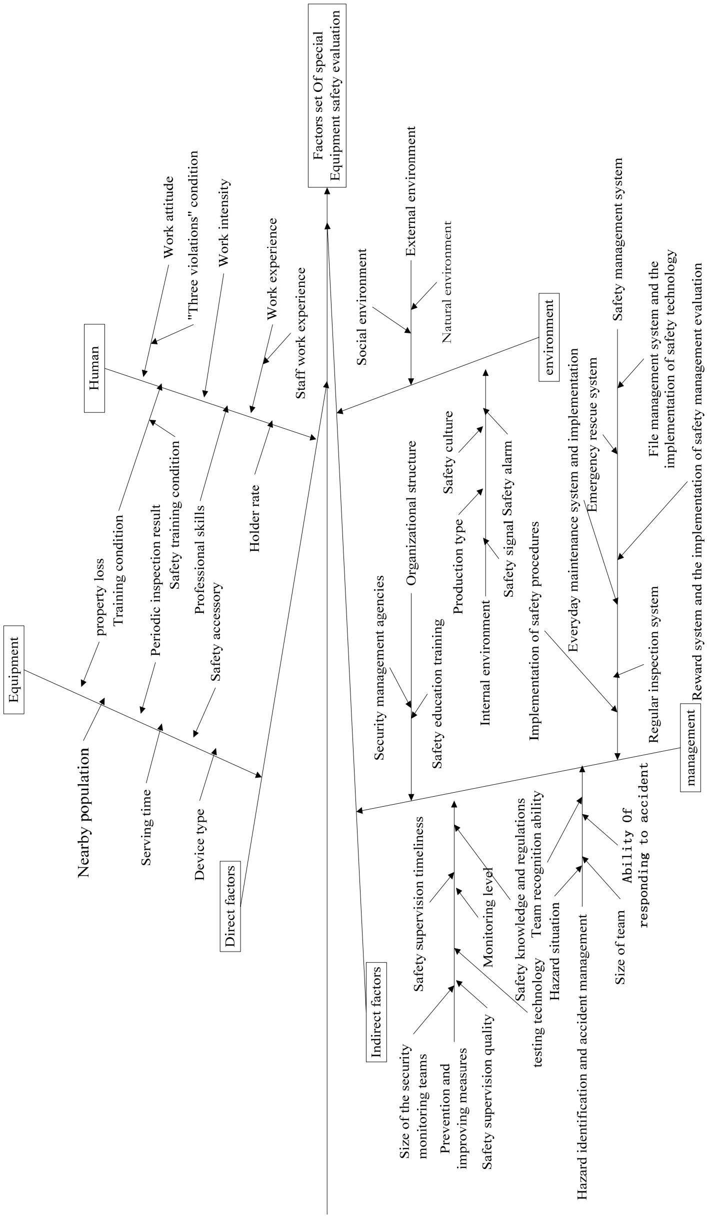

Fig. 39.1 Fishbone diagram of factors set of special equipment safety evaluation

Direct factors include “human” and “equipment” which represent indirect special equipment safety risks.

Indirect factors and direct factors are placed as criteria layer. External environment, internal environment, organizational structure, safety management system, prevention and improving measures, hazard identification and accident management, professional skills, working experience, training condition, work intensity, work attitude, device type, service life, safety accessory, periodic inspection result, headcount and property loss are placed as program layer (Fig. 39.2).

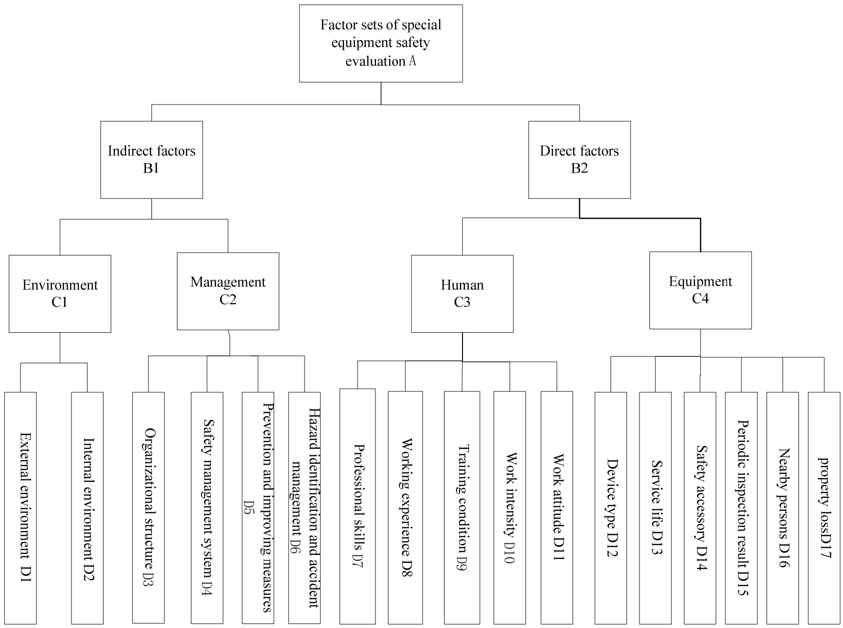

Fig. 39.2 factors set of special equipment safety evaluation

39.3 Revolutionary AHP-FCE Method

Revolutionary AHP-FCE method establishes evaluating factors set in a systematic and scientific way, which modifies factor weights between layers and builds evaluation system through fuzzy evaluation method.

39.3.1 Evaluation Set

Evaluation set V are sets of evaluation objects' possible evaluation results, $V = \{v_1, v_2, \cdots, v_n\}$. v_j $(j = 1, 2, \cdots, m)$ indicates the j-th level of special equipment safety evaluation. $V = v_j = \{90, 80, 70, 60, 50\}$ represents the degree of special equipment safety separately, the higher value means the safer level.

39.3.2 Evaluation Matrix

Every factor u_i $(i = 1, 2, \cdots, n)$ of factors set U is evaluated and membership degree R_i $(i = 1, 2, \cdots, n)$ of factors set is calculated, then all single factor from evaluation set U are constituted into a total evaluation set R:

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix}. \tag{39.1}$$

39.3.3 Initial Weights W_a

(1) Judgment matrix

Judgment matrix is built through $1 \sim 9$ point system by expects' questionnaire survey method [7].

(2) Initial weight W_a

Maximum eigenvalues $\lambda_{\max}$ and eigenvectors are calculated through matlab and initial weights W_a are presented.

(3) Consistency test

CI (consistency index) [8] formula is proposed as follows: $\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1}$, where CR (consistency ratio) is used to judge consistency, the formula is proposed as follows: $\mathrm{CR} = \mathrm{CI}/\mathrm{RI}$, where RI indicates average value of CI. Judgment matrix has satisfactory consistency if $\mathrm{CR} < 0.1$, or it has to be modified until it meets the demand [9].

39.3.4 DEMATEL Method to Modify Initial Weight [10]

(1) Direct impact matrix X

This paper defined $(0, 1, 2, 4)$ to indicate the degree of impact. The higher value means the higher direct impact.

$$X = \begin{pmatrix} 0 & x_{12} & \cdots & x_{1n} \\ r_{21} & 0 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & 0 \end{pmatrix} = (x_{ij}),\ 1 \le i \le n,\ 1 \le j \le n, \tag{39.2}$$

where x_{ij} indicates the impact of factor i on factor j.
(2) G is the Standardization of direct impact matrix X.

$$G = X \Big/ \max_{1 \le i \le n} \sum_{j=1}^{n} x_{ij} = (g_i j),\ 1 \le i \le n,\ 1 \le j \le n. \tag{39.3}$$

(3) Combined effect matrix T and impact weight W_b

$$T = G + G^2 + \cdots + G^n = (t_{ij})_{n \times n}. \tag{39.4}$$

$T = G(1-G)^{-1}$ when n is sufficiently large.

$$W_b = \sum_{j=1}^{n} t_{ij} W_a \Big/ \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij} W_a,\ 1 \le i \le n,\ 1 \le j \le n. \tag{39.5}$$

(4) Final weights are concluded considering initial weight and impact weight.

$$W = (W_a + W_b)/2. \tag{39.6}$$

39.3.5 Fuzzy Comprehensive Evaluation

Proper operators are adopted in fuzzy comprehensive evaluation [11] and final evaluating conclusion is drawn.

$$B = W \cdot R = (w_1 w_2 \cdots w_n) \cdot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} = (b_1 b_2 \cdots b_m). \tag{39.7}$$

39.4 Case Study

A provincial chemical company is taken as an example. A large number of industrial boilers are used during production as it is one of the largest local chemical companies. Information combined with relevant experts' investigation was collected to establish a special equipment safety evaluation factor set. Revolutionary AHP-FCE

Table 39.1 Comparison matrix and the consistency test

Index	Comparison matrix B	Initial weight W_a	Consistency test
B1	1 1	0.4768	$\lambda_{\max} = 2.0000, \mathrm{CR} = \mathrm{CI}/\mathrm{RI} = 0.0000 < 0.10$
B2	1 1	0.5232	
C1	1 1/6 1/2 1/5	0.0708	$\lambda_{\max} = 2.0000, \mathrm{CR} = \mathrm{CI}/\mathrm{RI} = 0.0000 < 0.10$
C2	6 1 3 1	0.4060	
C3	2 1/3 1 1/3	0.1353	$\lambda_{\max} = 2.0000, \mathrm{CR} = \mathrm{CI}/\mathrm{RI} = 0.0000 < 0.10$
C4	5 1 3 1	0.3879	
D1	1 1/4	0.2	$\lambda_{\max} = 2.0000, \mathrm{CR} = \mathrm{CI}/\mathrm{RI} = 0.0000 < 0.10$
D2	4 1	0.8	
D3	1 1/7 1/4 1/2	0.0712	$\lambda_{\max} = 4.060, \mathrm{CR} = \mathrm{CI}/\mathrm{RI} = 0.0235 < 0.10$
D4	7 1 2 4	0.5331	
D5	4 1/2 1 2	0.2318	
D6	2 1/4 1/2 1	0.1639	
D7	1 1 1/2 3 2	0.2124	$\lambda_{\max} = 5.0173, \mathrm{CR} = \mathrm{CI}/\mathrm{RI} = 0.0039 < 0.10$
D8	1 1 1/2 3 2	0.2124	
D9	2 2 1 5 3	0.3867	
D10	1/3 1/3 1/5 1 1/2	0.0693	
D11	1/2 1/2 1/3 2 1	0.1192	
D12	1 2 1 1/2 1/2 3	0.1477	$\lambda_{\max} = 6.0599, \mathrm{CR} = \mathrm{CI}/\mathrm{RI} = 0.0095 < 0.10$
D13	1/2 1 1/2 1/4 1/3 1	0.0724	
D14	1 2 1 1/2 1/3 3	0.1380	
D15	2 4 2 1 1 6	0.2954	
D16	2 3 3 1 1 5	0.2922	
D17	1/3 1 1/3 1/6 1/5 1	0.0543	

is adopted in this paper to establish the industrial boiler safety evaluation system and to evaluate the security of the company.

39.4.1 Initial Weights W_a

Judgment matrix is proposed based on special equipment safety evaluation set, see Table 39.1.

39.4.2 DEMATEL Method of Modifying Initial Weight

The interference effects between layers of factors are analyzed through expert group survey and final weights are calculated (see Table 39.2).

Table 39.2 Revised calculation of the index weight

Index	Direct impact matrix X	Combined effect matrix T	W_a	W_b	W
B1	0 0	0 0	0.4768	0.4768	0.4768
B2	0 0	0 0	0.5232	0.5232	0.5232
C1	0 1 0 1	0.6875 0.8750 0.5625 1.1250	0.0708	0.0583	0.0646
C2	1 0 0 0	1.7500 0.8750 0.2500 1.1250	0.4060	0.4115	0.4088
C3	0 0 0 1	1.1250 0.2500 0.8750 1.7500	0.1353	0.1371	0.1362
C4	1 0 1 0	1.1250 0.5625 0.8750 1.4375	0.3879	0.3931	0.3905
D1	0 0	0 0	0.2006	0.2006	0.2006
D2	0 0	0 0	0.7994	0.7994	0.7994
D3	0 0 1 2	1.2532 0.871 1.7969 3.0785	0.0714	0.1186	0.0950
D4	0 0 1 1	0.7954 0.5491 1.0917 1.5640	0.5330	0.5060	0.5195
D5	1 1 0 1	0.9511 0.7278 0.7808 1.5398	0.2318	0.2202	0.2260
D6	2 1 1 0	1.0274 0.6254 0.9239 1.423	0.1638	0.0824	0.1231
D7	0 2 1 0 0	2 2 0.9999 0 0	0.2121	0.2360	0.2241
D8	1 0 0 0 0	3.0000 1.3334 0.6666 0 0	0.2121	0.2360	0.2241
D9	1 0 0 0 0	1 0 0 2 2	0.3865	0.4344	0.4105
D10	0 0 0 0 1	0 0 0 2 3	0.0694	0.0780	0.0737
D11	0 0 0 1 0	0 0 0 3 2	0.1190	0.0268	0.0729
D12	0 0 2 0 1 1	0.8321 0.6502 1.0765 1.1187 0.6924 1.6298	0.1477	0.1479	0.1478
D13	0 0 0 2 0 1	0.5208 0.9715 0.6091 1.7670 0.5793 1.4530	0.0724	0.0722	0.0723
D14	4 0 0 2 0 2	1.0765 0.7498 0.7455 1.3158 0.5116 1.6004	0.1379	0.1379	0.1379
D15	0 4 1 0 0 1	0.4971 1.2745 0.5847 1.4736 0.3972 1.7717	0.2954	0.2954	0.2954
D16	1 0 0 0 0 2	0.9231 0.7486 0.6821 1.1919 0.5379 1.9160	0.2911	0.2911	0.2911
D17	1 2 1 4 2 0	0.6519 1.0442 0.6401 1.5947 0.5748 1.4938	0.0544	0.0544	0.0544

39.4.3 Fuzzy Comprehensive Evaluation

Matrix of every membership degree is presented through fuzzy comprehensive evaluation:

$$R_1=\begin{pmatrix}0&1&0&0&0\\0&0&0&1&0\end{pmatrix},R_2=\begin{pmatrix}1&0&0&0&0\\0&0&1&0&0\\0&0&1&0&0\\0&0&0&0&1\end{pmatrix},R_3=\begin{pmatrix}0&0&1&0&0\\0&0.5&0.5&0&0\\0&0&1&0&0\\0&1&0&0&0\\0&1&0&0&0\end{pmatrix},R_4=\begin{pmatrix}0&0&0&1&0\\0&0&1&0&0\\0&0&0&0&1\\0&1&0&0&0\\0&0&0&1&0\\0&1&0&0&0\end{pmatrix}.$$

$W_1=C_1=(0.2006\ \ 0.7994)$,
$W_2=C_2=(0.0950\ \ 0.5195\ \ 0.2260\ \ 0.1231)$,
$W_3=C_3=(0.2241\ \ 0.2241\ \ 0.4105\ \ 0.0737\ \ 0.0729)$,
$W_4=C_4=(0.1477\ \ 0.0724\ \ 0.1379\ \ 0.2954\ \ 0.2911\ \ 0.0544)$.

According to the formula: $B_i = w_i \cdot R_i$
$B_1 = (0.2006 \ \ 0.7994 \ \ 0)$,
$B_2 = (0.0950 \ \ 0.5195 \ \ 0.2260 \ \ 0.1231)$,
$B_3 = (0.2241 \ \ 0.2241 \ \ 0.4105 \ \ 0.0737 \ \ 0.0729)$,
$B_4 = (0 \ \ 0.3498 \ \ 0.0724 \ \ 0.4388 \ \ 0.1379)$.

$$\begin{aligned} B = (w \cdot R) &= (0.4768 \ \ 0.5232) \cdot \begin{pmatrix} 0.09 & 0.03 & 0.62 & 0.11 & 0.10 \\ 0 & 0.33 & 0.26 & 0.33 & 0.10 \end{pmatrix} \\ &= (0.04 \ \ 0.19 \ \ 0.43 \ \ 0.22 \ \ 0.10). \end{aligned} \tag{39.8}$$

The final evaluation result: $F = B \times V_T = (0.04\ 0.19\ 0.43\ 0.22\ 0.10) \times (90\ 80\ 70\ 60\ 50)^T = 60.50$.

According to the evaluation level, this unit belongs to the middle level.

Through revolutionary AHP-FCE method, the safety level of every factor is proposed and quick and effective information of special equipment safety management is provided. It is proposed that “hazard identification”, “device type”, “safety accessory” and “headcount” have security risks. Great attention should be drawn by relevant departments and effective measures should be taken to improve the safety condition of those factors.

39.5 Conclusions

Fishbone diagram is adopted in the classification of special equipment safety management and revolutionary AHP-FCE method is used to establish special equipment safety evaluation system. Here are the conclusions:

- In this paper, indirect and direct factors are classified in factors set of special equipment from the perspective of systematic and practical situation. Management and environment are divided in the indirect factors while human and equipment are divided in the direct factors to enhance systematization and integrality of factors set.
- In this paper, revolutionary AHP-FCE method is adopted to establish special equipment safety evaluation system. Multilevel fuzzy comprehensive evaluation method and DEMATEL method are adopted to reduce the subjective preferences of Analytic Hierarchy Process, and DEMATEL method is used to modify the weight of factors between layers to enhance the objectivity and scientific nature.
- In this paper, revolutionary AHP-FCE method is applied in specific cases to establish special equipment safety factors set and evaluation system. Weight is calculated and evaluation results are came. It reflects the practicality and effectiveness of the method.

Revolutionary AHP-FCE method is applied to build special equipment safety evaluation system; it reflects creativity and further improvement in the establishment of special equipment safety evaluation system.

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