Effectiveness Evaluation of quality Management System in Construction Engineering Testing Laboratory Based on Triangle Fuzzy Analytic Hierarchy Process

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Abstract. At present, there are few evaluations on the effectiveness of the quality management system of the construction engineering testing laboratory in our country. According to the quality management system of the quality management system, a two-stage evaluation structure model of the quality management system effectiveness is established according to the Evaluation criteria for the qualification of the Laboratory. A comprehensive evaluation of the quality management system of a building engineering testing laboratory in Tangshan City was carried out by using triangular fuzzy number analytic hierarchy process (AHP), and the evaluation results were obtained in accordance with the actual situation.
Keywords: Duilding engineering testing laboratory, Quality management system, Triangular fuzzy number, Analytic hierarchy process.

1. Introduction

At present, there are few effective evaluations on the quality management system of construction engineering testing laboratory in China. In 2008, Li Han-ying set up an evaluation index system according to 25 elements of ISO/IEC 17025, and used the analytic hierarchy process (AHP) to analyze the factors affecting the operation of the system qualitatively and evaluate the effectiveness of the system quantitatively. From this, we found a weak link in the operation of quality management system, [2]. Although analytic hierarchy process canIn order to avoid the tedious process of consistency test and matrix reorganization, reduce the errors caused by uncertainty and reduce the influence of subjective factors, the factors affecting laboratory quality management system are evaluated objectively. In this paper, triangular fuzzy number analytic hierarchy process is used to evaluate the quality management system of construction engineering testing laboratory. The triangular fuzzy number analytic hierarchy process (triangular fuzzy number analytic hierarchy process) combines the triangular fuzzy number theory with the fuzzy analytic hierarchy process (FAHP). The triangular fuzzy number is used to describe the expert judgment information instead of the scale value in the traditional AHP. The fuzzy judgment matrix is formed, and the relative weight and comprehensive weight of each influencing factor can be calculated, and the evaluation index can be evaluated by Finally, the fuzzy analytic hierarchy process theory is used to realize the comprehensive evaluation of the effectiveness of its laboratory quality management system [3-5].

2. Triangular Fuzzy Number Analytic Hierarchy Process Evaluation Step

Taking a construction engineering testing laboratory in Tangshan as an example, the application process of triangular fuzzy number analytic hierarchy process in the effectiveness evaluation of

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laboratory quality management system is expounded in detail.

2.1. Establishing A Multi-Level Fuzzy Evaluation Index System

Considering that most of the construction engineering testing laboratories in China have established quality management system according to Laboratory Qualification Assessment Criteria, this paper divides the important factors affecting the quality management system of construction engineering testing laboratories into three levels by using expert consultation method according to this standard and combining with previous relevant research, and the hierarchical organization model as shown in Table 1.

Table 1. Quality management system effectiveness hierarchy evaluation model.

Index layer / Evaluation indicator / Target layer	One level indicator	Level two level index level
	Document requirements B_1	quality manual C_1 Program file C_2 Work instruction C_3 Record control C_4
	Management responsibilities B_2	quality policy and objectives C_5 Focus on customers C_6 Responsibilities, authority and communication C_7 Internal audit C_8 Management review C_9
	Resource management B_3	human resources C_{10} Instrument and equipment C_{11} Testing facilities and environmental conditions C_{12} Information network construction C_{13} Support services and procurement of supplies C_{14}
	Product realization B_4	test results implementation process planning C_{15} Correction, prevention and improvement of C_{16} Data analysis C_{17} Test report C_{18}
	Operation result B_5	product and service quality C_{19} Customer satisfaction C_{20} Financial and market results C_{21}

2.2. Constructing Fuzzy Complementary Judgement Matrix

According to the importance of each evaluation index, the relative importance of each index is determined by two-to-two comparisons. A triangular fuzzy number is introduced to construct a fuzzy complementary judgment matrix $A = (a_{ij})_{n*n}$, in which $a_{ij} = (l_i, m_i, u_i)$, $0 < L_i < M_i < U_i < 1$, a_{ij} denotes the relative importance of the first index to the second index relative to the index of the previous level. L_i, M_I and U_I respectively represent the most pessimistic, most likely, and optimistic assessment of

relative importance, and their values are based on the triangular fuzzy number scale given in Table 2 [6].

Table 2. Relative importance Triangle Fuzzy number judgment scale.

Scale class / Scale value / Language scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equally important	(1,1,1)	(1,1,1)
Slightly important	(1/2,1,3/2)	(2/3,1,2)
More important	(1,3/2,2)	(1/2,2/3,1)
Obviously important	(3/2,2,5/2)	(2/5,1/2,2/3)
Strongly important	(2,5/2,3)	(1/3,2/5,1/2)
Extremely important	(5/2,3,7/2)	(2/7,1/3,2/5)

For example, if B_1 is significantly more important than B_2 relative to target layer A, the corresponding matrix element D_{12} is (3/2, 2, 5/2), which is taken by D_{21} (2/5, 1/2, 2/3) as shown in Table 2. By analogy, the triangular fuzzy evaluation matrices of the first level index and the second level index can be established respectively, as shown in Table 3-4. For the sake of space, the judgment matrix of the other two levels is omitted.

Table 3. Triangle fuzzy number judgment matrix and relative weight of target layer A.

evaluating indicator / Judgement value / evaluating indicator	B_1	B_2	B_3	B_4	B_5
B_1	(1,1,1)	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1/2,1,3/2)
B_2	(1/2,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,3/2,2)
B_3	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(2/3,1,2)	(3/2,2,5/2)
B_4	(2,5/2,3)	(3/2,2,5/2)	(1/2,1,3/2)	(1,1,1)	(2,5/2,3)
B_5	(2/3,1,2)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)

Table 4. Fuzzy judgement matrix and relative weight of B_1.

evaluating indicator / Judgement value / evaluating indicator	C_1	C_2	C_3	C_4
C_1	(1,1,1）	(1/2,1,3/2)	(2,5/2,3)	(3/2,2,5/2)
C_2	(2/3,1,2)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)
C_3	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,2)
C_4	(2/5,1/2,2/3)	(1/2,2/3,1)	(1/2,1,3/2)	(1,1,1)

2.3. Calculate the Fuzzy Comprehensive Importance Degree of Each Evaluation Index
D_i is used to represent the comprehensive importance of the first evaluation index in the judgment matrix relative to all other evaluation indexes. According to formula (1), the fuzzy comprehensive importance of each index can be calculated.

$$D_i = \sum_{j=1}^{m} M_i^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_i^j \right]^{-1}, \quad i = 1,2,3,\ldots,m, \quad j = 1,2,3,\ldots, \ n; \tag{1}$$

Take the data in Table 3 for example, the results are as follows:

D_{B1}=(2.73,3.90,5.67)$\otimes$(1/38.17,1/29.47,1/22.10)≈(0.072,0.132,0.257),

D_{B2}=(3.30,4.50,5.83)$\otimes$(1/38.17,1/29.47,1/22.10)≈(0.084,0.153,0.264), let's analogy.

2.4. Calculate Normalized Weights of Evaluation Indexes

For two triangular fuzzy numbers $D_1 = (l_1, m_1, u_1)$ and $D_2 = (l_2, m_2, u_2)$, the degree of possibility that D_1 is relatively important to D_2 is expressed as follows:

$$m_1 \geq m_2, \ S(D_1 \geq D_2) = 1; \ l_2 \geq u_1, \ S(D_1 \geq D_2) = 0; \ \text{other}, \ S(D_1 \geq D_2) = (l2-u1)/(m_1-m_2-u_1+l_2) \tag{2}$$

Take the results of Table 3 as an example:

$S(D_{B1} \geq D_{B2})$ =0.892, $S(D_{B1} \geq D_{B3})$ =0.378, $S(D_{B1} \geq D_{B4})$ =0.300, $S(D_{B1} \geq D_{B5})$ =1.000; let's analogy.

Then, according to formula (3), the probability that the first element in the same level is more important than the other elements can be calculated respectively.

$$S (D \geq D_1, D_2, D_3 \ldots, D_k) = minS(D \geq Di), i = 1, 2, 3, \ldots, k \tag{3}$$

Finally, according to formula (4), the relative weight vector of each evaluation index can be obtained.

$$W´ = (minS (D_1 \geq D_k), minS(D_1 \geq D_k), \ldots minS (D_1 \geq D_k)), k = 1, 2, 3, \ldots, k \tag{4}$$

The concrete calculation results are shown in Table 5.

2.5. Synthetic Weight

The comprehensive weights of all evaluation indexes in the n-th layer to the target layer are the relative weights of all evaluation indexes in the first (n-1) layer to the target layer multiplied by the relative weights of each evaluation index in the n-th layer to the evaluation indexes in the first (n-1) layer.

Table 5. Summary of two level evaluation index weight.

Weight category / Weight value / Two level index layer	Relative weight	Comprehensive weight
C_1	0.36	0.0396
C_2	0.35	0.0385
C_3	0.14	0.0154
C_4	0.13	0.0143
C_5	0.29	0.0348
C_6	0.16	0.0192
C_7	0.10	0.0120
C_8	0.23	0.0276
C_9	0.22	0.0264
C_{10}	0.22	0.0726
C_{11}	0.29	0.0957
C_{12}	0.29	0.0957
C_{13}	0.10	0.0330
C_{14}	0.10	0.0330
C_{15}	0.33	0.1188
C_{16}	0.16	0.0576
C_{17}	0.33	0.1188
C_{18}	0.18	0.0648
C_{19}	0.25	0.0200
C_{20}	0.50	0.0400
C_{21}	0.25	0.0200

Table 6. Summary of the weights of the first level evaluation indicators.

Weight category / First level indicator layer	Comprehensive weight
documentation requirement	0.11
Management responsibilities	0.12
resource management	0.33
Product realization	0.36
Running result	0.08

2.6. Establishing Judgement Sets

According to the operation effect of the laboratory quality management system, this paper refers to the relevant literature and consults experts to establish the evaluation index of natural language set table [7], as shown in Table 7.

Table 7. Evaluation language set and value table.

Category Value scale Serial number	Evaluating linguistic variables	Triangular fuzzy numbers
1	excellent	(0.75,1,1)
2	good	(0.5,0.75,1)
3	commonly	(0.25,0.5,0.75)
4	Poor	(0,0.25,0.5)
5	difference	(0,0,0.25)

2.7. Single Factor Evaluation

Taking a construction engineering testing institution in Tangshan as an example, three experts, including peers, external auditors and internal auditors, were invited to evaluate the level 2 index C_{ij} of the level 1 index B_i of the laboratory with reference to Tables 1 and 11. B1 i, B2 i and B3 i respectively represent the evaluation result matrix of the level 2 index Cij of the level 1 index Bi by three experts, such as:

B1 1= [(0.5,0.75,1), (0.5,0.75,1), (0.75,1,1), (0.5,0.75,1)];
B2 1= [(0.75,1,1), (0.5,0.75,1), (0.25,0.5,0.75), (0.5,0.75,1)];
B3 1= [(0.5,0.75,1), (0.25,0.5,0.75), (0.75,1,1), (0.5,0.75,1)]
B1 2= [(0.25,0.5,0.75), (0.5,0.75,1), (0.25,0.5,0.75), (0.25,0.5,0.75), (0.5,0.75,1)];
B2 2= [(0.5,0.75,1), (0.5,0.75,1), (0.25,0.5,0.75), (0.5,0.75,1), (0.25,0.5,0.75)];
B3 2= [(0.5,0.75,1), (0.25,0.5,0.75), (0.5,0.75,1), (0.25,0.5,0.75), (0.5,0.75,1)];
B1 3= [(0.5,0.75,1), (0.75,1,1), (0.25,0.5,0.75), (0.5,0.75,1), (0.5,0.75,1)];
B2 3= [(0.5,0.75,1), (0.75,1,1), (0.5,0.75,1), (0.5,0.75,1), (0.25,0.5,0.75)];
B3 3= [(0.5,0.75,1), (0.5,0.75,1), (0.75,1,1), (0.25,0.5,0.75), (0.5,0.75,1)];
B1 4= [(0.5,0.75,1), (0.25,0.5,0.75), (0.25,0.5,0.75), (0.5,0.75,1)]
B2 4= [(0.25,0.5,0.75), (0.5,0.75,1), (0.25,0.5,0.75), (0.5,0.75,1)];
B3 4= [(0.5,0.75,1), (0.25,0.5,0.75), (0.5,0.75,1), (0.25,0.5,0.75)]
B1 5= [(0.5,0.75,1), (0.25,0.5,0.75), (0.5,0.75,1)]
B2 5= [(0.75,1,1), (0.5,0.75,1), (0.75,1,1)];
B3 5= [(0.5,0.75,1), (0.5,0.75,1), (0.25,0.5,0.75)]

2.8. Fuzzy Comprehensive Evaluation

2.8.1 Fuzzy Number of First Level Evaluation Index The evaluation result matrix of the second-level index in the first-level index B_i and the corresponding relative weight matrix are fuzzily calculated according to the formula (5). The fuzzy number H_i of the evaluation result of the first-level index B_i is obtained. If there are many experts to evaluate the average value of the fuzzy number H_i. Finally, according to the de-fuzzy value formula of triangular fuzzy number E (l, m, u), as shown in Eq. (6), the de-fuzzy value h_i of the evaluation result can be calculated.

$$H_i = B_i \cdot W_i \qquad (5)$$

$$e = (l + 2m + u)/4 \qquad (6)$$

2.8.2 Comprehensive Evaluation Results The triangular fuzzy number matrix H and the comprehensive weight matrix W of the first grade index are fuzzily calculated. The fuzzy number T = H. W = (0.4792, 0.7500, 0.9375) can be obtained from Table 5, which shows that W = (0.11, 0.12, 0.33, 0.36, 0.08) T. Finally, the t=0.7292 of the comprehensive evaluation result can be obtained by calculating the defuzzification value of T.

According to the results of calculation and the theory of triangular fuzzy number and the principle of maximum membership degree, the quality management system of the construction engineering

testing laboratory runs well in the application example. However, there are still many deficiencies in the management responsibility and product realization, which seriously affect the efficient operation of laboratory quality management system, and need to be further improved and improved.

3. Conclusion

The effectiveness evaluation of the laboratory quality management system is an important guarantee for the efficient operation of the quality management system of the construction engineering testing laboratory, and provides a reliable basis for the continuous improvement of the laboratory. This paper establishes a hierarchical structure model for evaluating the effectiveness of the laboratory quality management system according to the Laboratory Qualification Assessment Criteria, and evaluates a construction engineering testing laboratory in Tangshan City by using triangular fuzzy number analytic hierarchy process, and finds out the weak links in the operation process of the quality management system. Triangular fuzzy number theory and fuzzy analytic hierarchy process are introduced to make the evaluation result more objective and accurate, and the calculation process is simpler, so it has better practicability. Through the application of examples, the evaluation results are basically consistent with the actual situation of the laboratory, which fully proves the feasibility of triangular fuzzy number analytic hierarchy process in the evaluation of quality management system of construction engineering testing laboratory.

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