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 qualification of the Laboratory, 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: Building 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 can 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
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.

| Index | One level indicator | Level two level index level |
|-------|---------------------|-----------------------------|
|       |                     | quality manual C<sub>1</sub> |
|       |                     | Program file C<sub>2</sub>   |
| B<sub>1</sub> | Document requirements | Work instruction C<sub>3</sub> |
|       |                     | Record control C<sub>4</sub> |
| B<sub>2</sub> | Management responsibilities | quality policy and objectives C<sub>5</sub> |
|       |                     | Focus on customers C<sub>6</sub> |
|       |                     | Responsibilities, authority and communication C<sub>7</sub> |
|       |                     | Internal audit C<sub>8</sub> |
|       |                     | Management review C<sub>9</sub> |
| B<sub>3</sub> | Resource management | human resources C<sub>10</sub> |
|       |                     | Instrument and equipment C<sub>11</sub> |
|       |                     | Testing facilities and environmental conditions C<sub>12</sub> |
|       |                     | Information network construction C<sub>13</sub> |
|       |                     | Support services and procurement of supplies C<sub>14</sub> |
| B<sub>4</sub> | Product realization | test results implementation process planning C<sub>15</sub> |
|       |                     | Correction, prevention and improvement of C<sub>16</sub> |
|       |                     | Data analysis C<sub>17</sub> |
|       |                     | Test report C<sub>18</sub> |
| B<sub>5</sub> | Operation result | product and service quality C<sub>19</sub> |
|       |                     | Customer satisfaction C<sub>20</sub> |
|       |                     | Financial and market results C<sub>21</sub> |

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<sub>ij</sub>)<sub>n x n</sub>, in which a<sub>ij</sub> = (li, mi, ui), 0 < L<sub>i</sub> < M<sub>i</sub> < U<sub>i</sub> < 1, a<sub>ij</sub> denotes the relative importance of the first index to the second index relative to the index of the previous level. Li, MI and UI 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                  | 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 | $B_1$       | $B_2$       | $B_3$       | $B_4$       | $B_5$       |
|----------------------|-----------------|-------------|-------------|-------------|-------------|-------------|
| $B_1$                | (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)     |
| $B_3$                | (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)       | (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)       |

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

| evaluating indicator | Judgement value | $C_1$       | $C_2$       | $C_3$       | $C_4$       |
|----------------------|-----------------|-------------|-------------|-------------|-------------|
| $C_1$                | (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)       |

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.
Take the data in Table 3 for example, the results are as follows:
\[ D_{B1} = (2.73, 3.90, 5.67) \otimes (1/38.17, 1/29.47, 1/22.10) \approx (0.072, 0.132, 0.257) \],
\[ D_{B2} = (3.30, 4.50, 5.83) \otimes (1/38.17, 1/29.47, 1/22.10) \approx (0.084, 0.153, 0.264) \], 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:
\[ m_1 \geq m_2, \ S(D_1 \geq D_2) = 1; \ l_2 \geq u_1, \ S(D_1 \geq D_2) = 0; \ \text{other,} \ S(D_1 \geq D_2) = (l_2 - u_1)/(m_1 - m_2 - u_1 + l_2) \] (2)

Take the results of Table 3 as an example:
\[ S(D_{B1} \geq D_{B2}) = 0.892, \ S(D_{B1} \geq D_{B3}) = 0.378, \ S(D_{B1} \geq D_{B4}) = 0.300, \ S(D_{B1} \geq D_{B5}) = 1.000; \ \text{let’s analogy.} \]
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.
\[ S(D \geq D_i, D_2, D_3, \ldots, D_k) = \min S(D \geq D_i), i = 1, 2, 3, \ldots, k \] (3)

Finally, according to formula (4), the relative weight vector of each evaluation index can be obtained.
\[ W = (\min S(D \geq D_1), \min S(D \geq D_2), \ldots, \min S(D \geq D_k)), k = 1, 2, 3, \ldots, k \] (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.

| Two level index layer | Weight value | 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.

| 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.

| 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. B_{1i}, B_{2i} and B_{3i} respectively represent the evaluation result matrix of the level 2 index C_{ij} of the level 1 index B_i by three experts, such as:

B_{1i} = \[(0.5,0.75,1),(0.5,0.75,1),(0.75,1,1),(0.5,0.75,1)\];
B_{2i} = \[(0.75,1,1),(0.5,0.75,1),(0.25,0.5,0.75),(0.5,0.75,1)\];
B_{3i} = \[(0.5,0.75,1),(0.25,0.5,0.75),(0.75,1,1),(0.5,0.75,1)\];

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 \quad (5)

e = (l + 2m + u) / 4 \quad (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 \cdot 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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