Risk Assessment of Renovation Projects of Existing Buildings in Hospitals based on Fuzzy AHP Method

TIAN, Yapeng, JIN Zhanyong
School of Economics and Management Engineering, Beijing University of Civil Engineering and Architecture, P.R. China
*Corresponding author’s e-mail: jinzhangyong@bucea.edu.cn

Abstract. Nowadays, Chinese people have a significantly increasing demand for high quality of health-care, which needs to be satisfied by renovation projects of existing Buildings. To improve the risks management skills, this paper used Fuzzy AHP Method to build a risk evaluation system. To test the effectiveness of model, “Beijing FC hospital” is introduced as study samples. The result shows that risk evaluation system based on the Fuzzy AHP was effective and the total risk of renovation project in Beijing FC hospital is medium.

1. Introduction
People’s awareness of health has changed by the changing in population structure, development of science and technology and aging population [1]. As an important part of China’s medical and health system, hospitals have played a huge role in safeguarding people’s livelihood and promoting social harmony and stability. To improve the quality of health-care, hospitals need to conduct renovation projects of existing building in hospitals. But renovation projects in hospitals are complicated, which need to strengthen the risks management to increase economic and social benefits of renovation projects [2]. Before a project conducted, it is necessary to evaluate the potential risks. Risks evaluation system can be effective in evaluating the weakness of risks management in one project [3]. Currently, researched on the hospital risk mainly take the qualitative analysis, and researchers seldom take the medical risk caused by the construction into to consideration. Based on above, this paper used Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation Method to build a risks evaluation system, and introduced an actual projects as sample.

2. Establishing the Risk Assessment Model
2.1 Expert interview to establish risk index system
Based on scientific, attainable and comprehensive principles, this paper selected evaluation index from the whole life cycle of the renovation projects of existing building in hospitals. Through expert interview, literature research and Site investigation, this paper selected 4 level B factors, including the risks of decision stage, design phase, construction stage and operation stage. In terms of Level C factors, this paper selected 16 factors totally from upper level factors. As shown in Figure 1.
2.2 Delphi method to determinate weight of risk factors

The weight of the indicator reflects the extent to which an indicator affects the overall goal. The methods for determining index weights can be roughly divided into two types: first, empirical weighting, which mainly includes expert evaluation method, pairwise comparison method, Satty weight method, etc., and its advantages are directly evaluated by experts, which is simple and easy; Weighting, also known as quantitative weighting, mainly includes fuzzy weighting method, rank sum ratio method, entropy weight method and correlation coefficient method. This paper used Analytic hierarchy process, the principle and procedure are as follow [4].

(1) Establishing weight judgment matrix by using analytic hierarchy process. Once the model is built, the Delphi method can be used to determine the weight. Take advantage of the importance of each of the risk indicators. As shown in Table 1.

Table 1. Judgment matrix

|    | A₁  | B₁   | B₂   | ... | Bₙ  |
|----|-----|------|------|-----|-----|
| B₁ | b₁₁ | b₁₂  | ...  | ... | b₁ₙ |
| B₂ | b₂₁ | b₂₂  | ...  | ... | b₂ₙ |
| ...|     |      |      |     |     |
| Bₙ | bₙ₁ | bₙ₂  | ...  | ... | bₙₙ |

(2) Weight calculation. First find the Feature vector W of the matrix, and then normalize it to
make it equal to \( \sum_{i=1}^{n} W_i = 1 \), then we can find the relative importance of \( B_i \) for \( A_m \), which means weight.

1) Calculating the product \( M_i \) of the values of each row of the matrix and calculate the n-th root of \( M_i \), as shown in the following.

\[
\bar{W}_i = \sqrt[n]{M_i} = \sqrt[n]{\prod b_{ij}}
\]

(1)

2) Normalizing the vector \( \bar{W} = [\bar{W}_1, \bar{W}_2, \ldots, \bar{W}_n]^T \), which means \( W_i = \frac{\bar{W}_i}{\sum \bar{W}_i} \), then

Judging matrix maximum eigenvalue \( \lambda_{\max} = \sum \frac{(BW)_i}{n W_i} \).

(2)

(3) **Fault tolerance judgment and error analysis.** In the evaluation process, the indicator cannot accurately determine the value of \( b_{ij} \) and can only estimate it. If there is an error in the estimation, the eigenvalues of the judgment matrix will inevitably be deviated. Therefore, after finding \( \lambda_{\max} \), a consistency check is required.

1) Calculating consistency indicator \( CI \).

\[
CI = \frac{\lambda_{\max} - n}{n - 1}
\]

(3)

For different judgment matrices, the CI values are also different. In general, the larger the order \( n \), the larger the CI value. In order to measure whether the different order judgment matrices have satisfactory consistency, the average random consistency index RI value of the judgment matrix is introduced. The RI value is a random method for \( n=1-9 \), each constructing 500 sample matrices, calculating the CI value of the consistency index, and then obtaining the RI on average, as shown in the following table.

| Matrix order | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 |
|--------------|----|----|----|----|----|----|----|----|----|----|----|
| RI           | 0  | 0  | 0.58 | 0.9 | 1.12 | 1.24 | 1.36 | 1.41 | 1.46 | 1.49 | 1.52 |

2) Calculating the consistency ratio \( CR \).

\[
CR = \frac{CI}{RI}
\]

(4)

If \( CR < 0.1 \), then the judgment matrix can be considered to have satisfactory consistency, otherwise the judgment matrix needs to be adjusted.

(4) **Combined weight calculation.** After calculating the weight of each level of indicators to the upper level indicators, we can start from the top level and find the combined weights of the indicators at all levels from the top down. According to the index layer C risk factor relative criterion layer B risk factor eigenvector set W and criterion layer B risk factor relative evaluation target A system risk eigenvector V, index layer C risk factor relative to the evaluation target A system feature vector U, as seen in the following.

\[
U = W \times V
\]

(5)

2.3 Application of Fuzzy Comprehensive Evaluation Method

There are several methods to evaluate risks of renovation projects in hospitals, such as Data Envelopment Analysis, Artificial Neural Network, etc. Through Expert Interview, this paper used Fuzzy Comprehensive Evaluation Method to evaluate risks.
2.3.1 Building risk evaluation guidelines set

In the fuzzy comprehensive evaluation, the evaluation criteria are generally not available in the form of analytical expressions, and the level of the risk system can only be directly judged by fuzzy language. Because the risk variable varies [0, 1], If the risk level is divided into n levels, the length of each interval is 1/n.

For the risk evaluation of renovation projects in hospitals, the risk level is divided into five levels, namely lower risk $r_5$, low risk $r_4$, medium risk $r_3$, high risk $r_2$ and higher risk $r_1$. The risk range is [0, 0.2], [0.2, 0.4], [0.4, 0.6], [0.6, 0.8], [0.8, 1]. The renovation projects risk evaluation criteria set as follows.

$$T=\{T_1, T_2, T_3, T_4, T_5\}$$

2.3.2 Determine the risk membership vector

The risk membership degree is the degree of subordination of each risk factor relative to each risk level in the evaluation set. Since the evaluation angles and methods of different evaluators are different, the evaluation results can only be expressed by the possible degree of the risk factor $C_i$ belonging to the evaluation set $T_j$, that is, the membership degree, $r_{ij}$, if the i-th risk factor $C_i$ by making a possible degree of membership in all evaluation criteria, a membership degree $R_i$ corresponding to $C_i$ can be obtained:

$$R_i=\begin{pmatrix} r_{i1}, r_{i2}, r_{i3}, r_{i4}, r_{i5} \end{pmatrix}$$

If all the risk factors in the risk factor set $C$ are evaluated above, the risk factor membership vector matrix can be obtained:

$$R_{n \times 5} = (r_{ij})_{n \times 5} \quad (6)$$

2.3.3 Fuzzy comprehensive evaluation model

According to fuzzy set theory and comprehensive evaluation concept, $R_{n \times 5}$ and $U$ are known, then the a comprehensive evaluation model $S$ can be obtained:

$$S = U^T \bullet R_{n \times 5} \quad (7)$$

$S$ is a vector of five rows and columns, and the result indicates that the renovation projects risk belongs to the degree of membership of each risk level. The maximum of these five numbers indicates that the renovation risk has the highest degree of membership to the standard, and the corresponding evaluation standard is the final evaluation result.

3. Case Study

3.1 Introduction of the renovation project in Beijing FC Hospital

Seismic Reinforcement and Comprehensive Reconstruction Project in Beijing FC hospital mainly involves 16 building and a total construction area of 24099.35 square meters. This project try to renovate 3 houses, outdoor pipe network, boiler equipment and establish identification guidance system, which can improve the comprehensive resilience of existing buildings. Therefore, the project is expected to have significant social benefits.

Technical risk and organizational risk should take into consideration when the project was conduct. Technical risk mainly comes from the contacts between the poor condition of old building and the standard specification. Organizational risk means that the construction can play a negative influence on the daily medical activity. In order to control the risk effectively, FC hospital establish professional project management team which are responsible to supervise, check and accept. In addition, the team pay much attention to the pre-design work, trying to reduce the potential risks.
3.2 Determination of the weight of evaluation indicators for Beijing FC project

On the basis of risk analysis, the company adopts the Delphi method, which requires experts to compare the importance of the risk factors of the target layer and the indicator layer with respect to the two layers of the criterion layer. After statistical analysis, we can get the weight of each index, as shown in the table 3.

3.3 Risk evaluation for the renovation project in Beijing FC hospital

As mentioned in 2.3, By using the form survey method, the experts give the number of subordinates of each risk factor in the index layer relative to each risk level in the evaluation set T. After sorting, the evaluation results are shown in the following table.

| Level A | Level B | Weights of level B | Level C | Weights of level C | Comment Set |
|---------|---------|--------------------|---------|--------------------|-------------|
|         |         |                    |         |                  | t₁  t₂  t₃  t₄  t₅ |
| Decision Stage B₁ | 0.1150 | Functional Positioning | 0.0474 | 1 2 3 2 2 |
|         |         | Scale Calculation | 0.0387 | 2 4 2 1 1 |
|         |         | Social Stability | 0.0168 | 2 2 3 2 1 |
|         |         | Government Approval | 0.0121 | 2 2 4 2 0 |
| Design Stage B₂ | 0.2649 | Design Basis | 0.0532 | 1 3 3 2 1 |
|         |         | Designer Quality | 0.0209 | 3 2 3 1 1 |
|         |         | Professional Coordination | 0.1376 | 2 1 2 2 2 |
|         |         | Deepen Design | 0.0532 | 1 2 4 2 1 |
| Construction Stage B₃ | 0.5346 | Construction Organization | 0.1822 | 2 2 3 1 2 |
|         |         | Medical Dispute | 0.0780 | 2 2 2 1 3 |
|         |         | Force Majeure | 0.0320 | 2 0 5 2 1 |
|         |         | Security Risk | 0.1945 | 1 3 2 2 2 |
|         |         | Staff Quality | 0.0569 | 3 2 3 2 0 |
| Operating Stage B₄ | 0.0765 | Management System | 0.0064 | 3 0 2 2 2 |
|         |         | Property Management | 0.0553 | 3 2 2 2 1 |
|         |         | Financial Management | 0.0148 | 3 2 5 0 0 |

From table 3 we can get risk factor membership vector matrix, as shown in the following.
Calculating project risk. Risk membership matrix of Seismic Reinforcement and Comprehensive Reconstruction Project in Beijing FC hospital as shown in the following:

\[
S = U^T \bullet R_{16x5} = \begin{bmatrix}
0.1806 & 0.21107 & 0.26486 & 0.16506 & 0.16403
\end{bmatrix}
\]

Result analysis, 0.26484>0.21107>0.1806>0.16506>0.16403. Therefore, the risk level of the hospital project belongs to the risk level t5. We can draw a conclusion that the project risk level is medium.

4. Conclusion
Hospital renovation projects are complicated because of medical activity. Identifying project risk factors according to the stage of the life cycle can comprehensively and systematically analyze the risks existing in hospital infrastructure projects, and has guided significance for risk management in actual work. The risk was evaluated using the analytic hierarchy process and the fuzzy comprehensive evaluation method. This model can assess the risk of renovation project in hospital effectively, risk level of the Beijing hospital project belongs to the medium level, which mainly lie in design and construction stage.

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References
[1] Cao Y, Li M, Guo Y. Analysis of the design and renovation of mid-sized hospital's local area network]. [J]. Chinese Journal of Medical Instrumentation, 2011, 35(6):465.
[2] Yi-Kai J, Yu-Ching C, Yeng-Horng P, et al. Optimal Decision Model for Sustainable Hospital Building Renovation—A Case Study of a Vacant School Building Converting into a Community Public Hospital[J]. International Journal of Environmental Research and Public Health, 2016, 13(7):630.
[3] Islam M S, Nepal M P, Skitmore M, et al. Current research trends and application areas of fuzzy and hybrid methods to the risk assessment of construction projects[J]. Advanced Engineering Informatics, 2017, 33:112-131.

[4] Taylan O, Bafail A O, Abdulaal R M S, et al. Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies[J]. Applied Soft Computing Journal, 2014, 17(4):105-116.