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Fuzzy AHP-based Safety Risk Assessment Methodology for Tower Crane

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Abstract: Cranes and tower cranes are complex installations they constitute critical aspects of safety at construction sites. To prevent the tower crane accidents become very important. In this study, analysis of the factors affecting the safety of tower crane from four aspects of human-machine-environment-management, establish a more reasonable safety evaluation system and applying AHP to calculate the relevant safety factor weight, so as to establish the construction site crane the safety assessment model. Finally, this evaluation technique was put into practice and get a good result was obtained. It is indicated that this model has real practicability.

Key words: Analytic hierarchy process, fuzzy evaluation, risk assessment, tower crane

INTRODUCTION

The construction industry is one of the economic pillars in China which accounts for about 6.8% of Gross Domestic Product in China and about 5.45% of total working population in China (Ministry of Construction of Housing and Urban-Rural, 2012). However, on account of the complicated andconstantly changing nature of construction work, the construction industry has very high injury and fatality rates compared to other industries in China. But there are many causal factors behind these high accident rates, a lot of construction injuries and fatalities can be attributed to one ubiquitous piece of equipment: The crane (Neitzel *et al*., 2001).

Tower crane accidents also delay project progress, increase costs and damage the reputation of the contractors (Wang *et al*., 2006). From 2008-2011, 79 tower crane related accidents were recorded. Therefore, we should strengthen the management of tower cranes, analyze the possible risk factors of tower crane, establish a comprehensive safety evaluation system of tower cranes and take effective measures to reduce the tower crane accidents (Huang, 2012).

Because of the complexity of the tower crane safety evaluation of construction site, this study presents the safety evaluation of tower cranes based on fuzzy AHP and provide a theoretical basis for the relevant units of production safety.

SAFETY RISK EVALUATION INDEX SYSTEM OF TOWER CRANE

Establish the decision group: Risk assessment starts with the establishment of a risk assessment group whose members must be carefully selected. The selected experts must have different backgrounds/disciplines and essential experiences regarding the concerned project (Tam and Fung, 2011; Zeng *et al*., 2007). In order to obtain representative views, knowledge coverage and different academic viewpoint of the decision makers should be considered, the ratio of experts should be reasonably considered. In our case study, all of the experts-four project managers, three equipment managers, eight safety managers, two equipment suppliers, two equipment operator and one who held both positions-were experienced professionals.

Establish the evaluation framework and indexes: Risk identification is the process in which threats for the project concerned are investigated. The identification of risks requires a deep understanding of tower crane operation process, related professional knowledge and experience in related fields.

Besides intuitive methods, there are some tools for risk identification, such as: Checklist, influence diagrams, cause and effect diagrams, failure mode and effect analysis, etc. Detailed introduction to the methods are described by Ahmed *et al*. (2007).

The establishment of a proper index system is the basis of work safety evaluation. At the construction site

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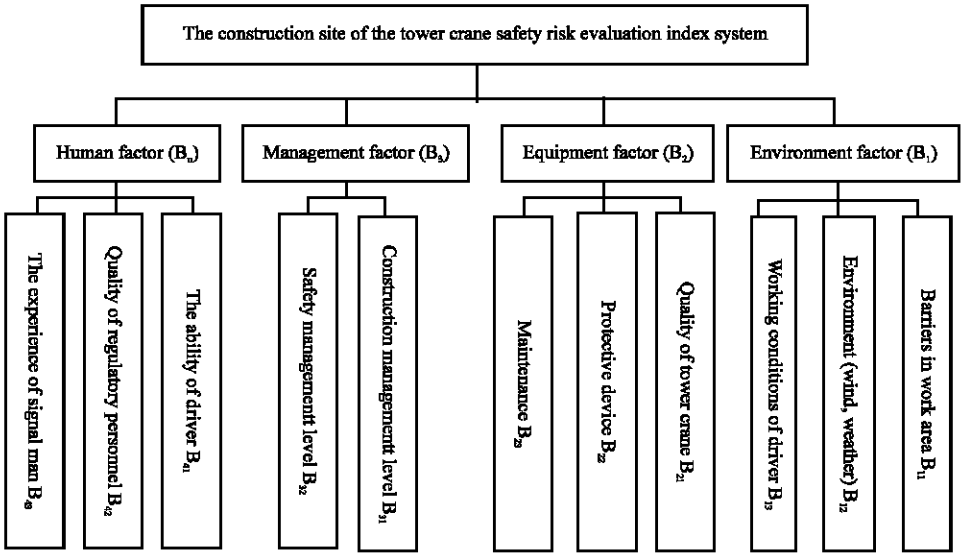

Fig. 1: Tower crane safety risk evaluation

of tower crane operation, 4 categories-environment risk, equipment risk, management risk and human risk, including 11 risk factors, are identified by Huang (2012) as shown in Fig. 1.

FUZZY AHP EVALUATION METHOD

Establish recursive class time structure: Using AHP analyze the relations of each factor in system, then establish recursive class time structure and build the hierarchical structure model. In this situation, complex problems are made up of several elements. According to its property, these elements divided into groups, forming different layers. A certain hierarchy elements are the criterion to the next level of certain elements within a dominant, which is affected by a front layer of element the domination of the victors (Shi *et al*., 2012).

Establish the pair-wise comparison matrix: The pair-wise comparison matrix H denotes the importance degree compare between some element in the front layer and the related factor in this very layer, the pair-wise comparison matrix is shown as follows:

$$H = \begin{vmatrix} h_{11} & h_{12} & \cdots & h_{1n} \\ h_{21} & h_{22} & \cdots & h_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ h_{n1} & h_{n2} & \cdots & h_{nn} \end{vmatrix} \quad (1)$$

where, h_{ij} represents the relative importance of h_i values for h_j. In order to quantitatively describe the relative importancedegree of any two factors, quantity scale could be given by using 1~9 scale method (Table 1).

Table 1: Scale of relative importance used in the pair-wise comparison of AHP

Numerical scale	Defination
1	Equally important of the two factors
3	Low significance of one factor compared to another
5	Strongly more important of one factor compared to another
7	Very strongly more important of one factor over another
9	Extremely more important of one factor over another
2, 4, 6 and 8	Intermediate values between two neighboring levels
Reciprocals	Used to reflected dominance of the second alternative as compared with the forst

Check consistency:

- Calculate the weight. Based on the pair-wise comparison matrix H, the weights can be calculated as follows:

$$\overline{W_i} = \sqrt[n]{M_i} \quad (2)$$

Then the weights can be obtained:

$$W_i = \frac{\overline{W_i}}{\sum_{j=1}^{n} \overline{W_j}} \quad (3)$$

- Calculate the largest eigenvalue of the matrix. The largest eigenvalue of the matrix can be calculated as follows:

Table 2: Random consistency (RC) index

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(HW)_i}{nW_i} \tag{4}$$

- Consistency check. The consistency of the comparison matrix can be determined by the consistency ratio (CR), which is fined as:

$$CR = \frac{CI}{RI} \; CI = \frac{1}{n-1}(\lambda_{max} - n) \tag{5}$$

where, CI is the consistency index, RI is the random index, which is shown in Table 2, n is the matrix size. As a rule, only if CR<0.10, the consistency of the matrix is considered as acceptable, else the pair-wise comparisons need to be revised.

Second, establish a set of grade alternatives $V = \{V_1, V_2, V_3 .... V\}_n$ where n is the number of alternatives. In this study, the grades are defined as V = {1, 2, 3, 4, 5} such as, V1 is very weak influence, V_2 is weak influence, V_3 is moderate, V_4 is strong and V_5 is very strong and then establish fuzzy evaluation matrix $R = [R_1, R_2, R_3, ..., R_n]$, where, $R_i = [r_{i1}, r_{i2}, r_{i3}, ..., r_{im}]$ is the ith vector of fuzzy evaluation factors, all the single factor fuzzy evaluation vector composed of multi factor fuzzy evaluation matrix.

Third, comprehensive evaluation. Fuzzy comprehensive evaluation assessment from the ground, if there is multi-level factors, then in turn to an even higher level evaluation until the evaluation to the highest level to obtain the total evaluation results. firstly evaluate the evaluation factors of secondary indexes, the result is comprehensive evaluation set B_i, B_i, can be obtained as follows:

$$B_i = A_i \circ R_i \tag{6}$$

then evaluate every factor of B in one class index, B is calculated according to Eq. 7 as follows:

$$B = A \circ R \tag{7}$$

At last, normalize the fuzzy evaluation vector and calculate the risk index F. F is calculated according to Eq. 8 as follows. This study uses the ordinary multiplication and addition operations model M (., +) calculation:

$$F = B \circ V^T \tag{8}$$

CASE STUDY

Following is a specific site case to illustrate how to use the Fuzzy AHP theory to solve the evaluation problems. Here the selected fuzzy set is V = {very weak, (V_1), weak, (V_2), moderate, (V_3), strong, (V_4), very strong, (V_5)}, the fuzzy evaluation value is V = {1, 2, 3, 4, 5}. Figure 1 shows the factor set that affect the crane safety is, $B = \{B_1, B_2, B_3, B_4\}$, $B_1 = \{B_{11}, B_{12}, B_{13}\}$, $B_2 = \{B_{21}, B_{22}, B_{23}\}$, $B_3 = \{B_{31}, B_{32}\}$, $B_4 = \{B_{41}, B_{42}, B_{43}\}$.

Index weight calculation: Indicators are constructed for each of their respective judgment matrix and then calculate the maximum eigenvalue judgment matrix and tested for consistency after calculating the corresponding feature vectors obtained theoretically relatively objective weighting factor. Four first class index importance scale and the calculation results are shown in Table 3.

Similarly available: Two level index weight:

$$A_1 = (0.\ 50, 0.28, 0.22), A_2 = (0.20, 0.30, 0.50),$$
$$A_3 = (0.60, 50.40), A_4\ (0.60, 50.20, 50.20)$$

Establish evaluation matrix:

$$R_1 = \begin{vmatrix} 0.50 & 0.25 & 0.12 & 0.10 & 0.03 \\ 0.60 & 0.23 & 0.14 & 0.03 & 0 \\ 0.40 & 0.40 & 0.10 & 0.10 & 0 \end{vmatrix}$$

$$R_2 = \begin{vmatrix} 0.70 & 0.10 & 0.10 & 0.04 & 0.06 \\ 0.60 & 0.20 & 0.15 & 0.05 & 0 \\ 0.50 & 0.30 & 0.12 & 0.06 & 0.02 \end{vmatrix}$$

$$R_3 = \begin{vmatrix} 0.43 & 0.34 & 0.20 & 0.03 & 0 \\ 0.50 & 0.30 & 0.10 & 0.07 & 0.03 \end{vmatrix}$$

$$R_4 = \begin{vmatrix} 0.80 & 0.10 & 0.10 & 0 & 0 \\ 0.30 & 0.50 & 0.12 & 0.08 & 0 \\ 0.45 & 0.35 & 0.15 & 0.05 & 0 \end{vmatrix}$$

Fuzzy comprehensive evaluation: The results show that, in whole evaluation members there 57% of the people consider that the cran safety risk is very weak, 25% consider that it = s weak, 12.5% consider that it's moderate, 4.5% consider that it's strong, 1% consider that it's very strong. The risk index is calculated according to Eq. 8 as follows:

$$F = B.V^T = (0.570, 0.250, 0.125, 0.045, 0.01).(1, 2, 3, 4, 5)$$

According the risk assessment model and evaluating steps, the calculated results by MATLAB and the comprehensive evaluation value is 1.675. Compared with the evaluation grades, "1.675" is very close to "2" (weak).

Table 3: Crane safety evaluation index first class index importane scale

i	Environment factor	Equipment factor	Management factor	Human factor	w	
Management factor	1	1/3	2	1/2	0.16	λ_{max} = 4.1128
Equipment factor	3	1	3	1/2	0.30	CR = 0.042
Management factor	1/2	1/3	1	1/5	0.10	CI= 0.0376
Human factor	2	2	5	1	0.44	

Therefore, the results show that the overall risk index of the tower crane is relatively safe.

CONCLUSION

This methodology, combining the fuzzy AHP, provides a new scientific method for safety evaluation of tower cranes and makes the evaluation results more reasonable and comprehensive. To help managers to understand and master the site safety situation, accurately find the defects in management. In order to improve their ability to control the accident.

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