Safety Evaluation of Metal Structures of Quayside Container Cranes Based on Combination Weighting and Fuzzy Comprehensive Evaluation

Li Chen[a], Keqin Ding[b *]

[a]chenli111528@163.com ,[b]503718617@qq.com

China Special Equipment Inspection and Research Institute, Beijing, 10029, China

Abstract. To improve the accuracy and reliability of metal structure safety evaluation for quayside container cranes, this article constructs a fuzzy comprehensive evaluation method based on a membership function model, proposes and adopts a subjective and objective weight combination weighting method that combines CRITIC objective weight method, and AHP subjective weight method, and finally provides a system safety evaluation method for quayside container crane metal structures. Especially, the data-driven safety evaluation system for the metal structure of Quayside container cranes has been developed, which is convenient for large-scale promotion and application. At the same time, the engineering application results show that the combination weighting method reduces the extreme value impact caused by subjective judgment, and takes into account the differences and correlations between different indexes. The evaluation results obtained by this method are more accurate and safe.

Keywords: Quayside container crane, subjective and objective combination weighting, membership function model, comprehensive safety evaluation in the fuzzy mode

1 Introduction

The quayside container crane (quay bridge) is a professional lifting equipment used for container loading and unloading at port terminals. Quayside container cranes that have been in service for more than 15 years will experience a certain degree of structural fatigue damage. If they are directly scrapped and completely renewed, it is uneconomical and not in line with national conditions. Therefore, it is urgent to develop scientific and reasonable safety evaluation methods for quayside container crane metal structures.

A large amount of research has been conducted on the safety evaluation methods for cranes [1-4] such as quayside container cranes. The above studies mostly use the subjective weight determined by the AHP method and the maximum membership degree to determine the safety evaluation level for quayside container cranes, and less consider the issue of objective weight of evaluation indexes.

This article constructs a fuzzy comprehensive evaluation method based on a membership function model and proposes and adopts a subjective and objective weight combination weighting method that combines the CRITIC (Criterion Importance Through Intercredieria Correlation) method and AHP subjective weight method. On the one hand, it weakens the

PMBDA 2023, December 15-17, Nanjing, People's Republic of China

DOI 10.4108/eai.15-12-2023.2345290

extreme value impact caused by subjective weighting, making weighting more scientific and reasonable, and on the other hand, it also reasonably controls the calculation amount and difficulty, building a three-level safety evaluation model for quayside container crane metal structures, classifying the system safety evaluation results, identifying the evaluation level, improving the credibility of the evaluation results, and providing more accurate and reliable methods and means for the safety evaluation of quayside container crane metal structures.

2 Safety evaluation method for metal structure system of quayside container crane

2.1Structural hierarchy system division

As shown in Figure 1, the metal structure system of the quayside container crane consists of three evaluation levels from top to bottom: system, subsystem, and measurement index.

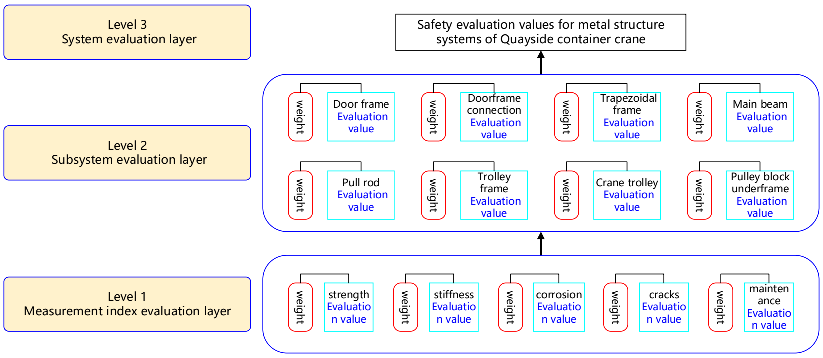


Figure 1. Hierarchy structure diagram for metal structures of quayside container cranes

The first evaluation layer for the safety evaluation of the quayside container crane metal structure system is the measurement index evaluation layer. There are five influencing factors on the evaluation layer of measurement indexes, namely strength, stiffness, corrosion, cracks, and maintenance. The second evaluation layer is the subsystem evaluation layer, which is divided into door frame, door frame connection, trapezoidal frame, main beam, pull rod, trolley frame, crane trolley, and pulley block underframe subsystem. The third evaluation layer is the metal structure system evaluation layer.

2.2Calculation framework

The process of safety evaluation of the metal structure of the quay bridge is based on the detection, monitoring, and historical record data of the quay bridge from bottom to top: (1) comprehensive evaluation of subsystems, that is, the evaluation values of subsystems such as door frames are calculated based on the evaluation values of five index such as strength and stiffness in the lowest level indexes and their corresponding weight combinations; (2) the comprehensive evaluation of the metal structure system involves combining the evaluation values of each part of the subsystem with corresponding weights to obtain the evaluation values of the subsystem.

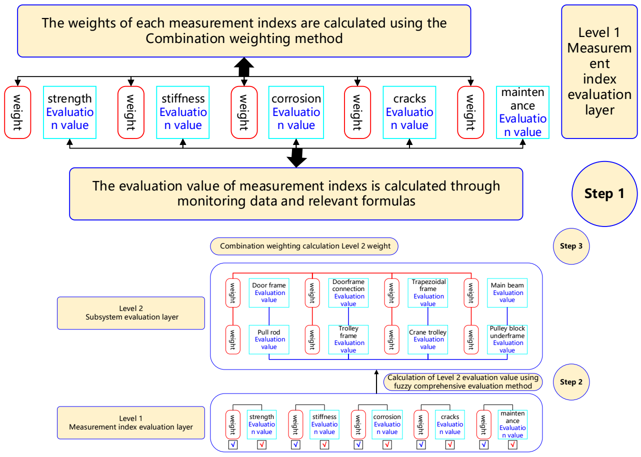


Figure 2. Computational procedure

The first step, as shown in Figure 2, calculates the weights of each measurement index based on the subjective and objective combination weighting method. This step of calculation will obtain the evaluation values of the measurement index evaluation layer and their corresponding weight combinations.

The second step, as shown in Figure 2, is to comprehensively consider the evaluation status and impact effects of the five measurement indexes. The fuzzy comprehensive evaluation method based on the membership function is used to obtain the evaluation values of the subsystem level. After the first and second steps of the calculation, the evaluation analysis from the measurement index evaluation layer to the subsystem layer is achieved.

Similarly, steps 1 and 2 are repeated to obtain the evaluation values for the subsystem and metal structure system in sequence.

3 Combination weighting method

3.1Subjective Weight Calculation - Analytic Hierarchy Process

This article uses Analytic Hierarchy Process to determine the subjective weights of indexes, which generally involves three steps to determine the weights: (1) establishing a hierarchical structure of the system; (2) constructing a 9-scale pairwise comparison judgment matrix; (3) calculating the relative weights of each index and conduct consistency testing.

3.2Objective Weights - CRITIC Method

The CRITIC [5] method comprehensively determines weights based on the conflict and intensity comparison between evaluation indexes, which not only takes into account the differences and correlations between indexes but also makes weighting more scientific and reasonable. The general calculation steps are as follows:

(1) According to the evaluation value x_{ij} of the index, the standard deviation σ_j of index x_j can be calculated.

$$\sigma_j = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(x_{ij} - \overline{x}_j\right)^2} \tag{1}$$

(2) Correlation coefficient matrix $R = \left(r_{ij}\right)_{m\times n}$ is calculated.

$$r_{ij} = \left[\sum_{i=1}^{m}\left(x_i - \overline{x}_i\right)\left(x_j - \overline{x}_j\right)\right] / \left[\sqrt{\sum_{i=1}^{m}\left(x_i - \overline{x}_i\right)^2 \sum_{i=1}^{n}\left(x_j - \overline{x}_j\right)^2}\right] \tag{2}$$

(3) Objective weights w_{Oj} is calculated.

$$w_{Oj} = \left[\sigma_j \sum_{i=1}^{m}\left(1 - r_{ij}\right)\right] / \left[\sum_{j=1}^{n}\sigma_j \sum_{i=1}^{m}\left(1 - r_{ij}\right)\right] \qquad \left(j = 1, 2, ..., n\right) \tag{3}$$

3.3Combination weighting of subjective and objective weights

The subjective weight w_{Sj} obtained by the Analytic Hierarchy Process and the objective weight w_{Oj} obtained by the CRITIC method are fused by using the following equation to obtain the final subjective and objective combination weight W_j.

$$W_j = \sqrt{w_{Oj} w_{Sj}} / \sum_{j=1}^{n}\sqrt{w_{Oj} w_{Sj}} \qquad \left(j = 1, 2, ..., n\right) \tag{4}$$

4 Comprehensive safety evaluation in the fuzzy mode

This article divides the quay bridge into three levels and therefore adopts the multi-level fuzzy comprehensive evaluation method for comprehensive safety evaluation.

This article uses the fuzzy distribution determination method [6-8] to construct a fuzzy relationship matrix. For different evaluation objects, it is necessary to select the appropriate expression of the membership function [9-11] for fuzzy comprehensive evaluation.

The membership degree of the index evaluation value to the system evaluation set is shown in Figure 3. The initial value of the fuzzy relation matrix is the Zero matrix. After mapping to the system evaluation set, the formula for generating non-zero elements in the fuzzy relationship matrix is shown in Equations (5) to (8).

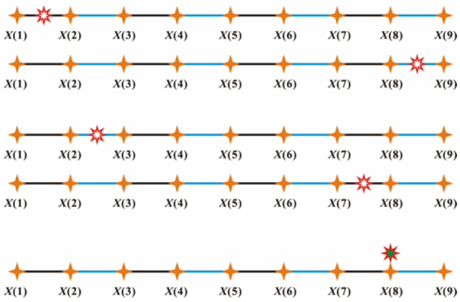


Figure 3. Generating fuzzy relationship matrix by mapping index evaluation values

As shown in Figure 3, the evaluation values of indexes located in different distribution intervals m_{v} (star-shaped symbols in Figure 3) will generate two adjacent fuzzy relationship matrix elements.

$$\begin{cases} 0 \le m_{\mathrm{v}} < \frac{1}{8}, & R(x,1) = 0.9, \quad R(x,2) = 0.1 \\ \frac{1}{8} \le m_{\mathrm{v}} < \frac{1}{4}, & R(x,1) = 1 - 4m_{\mathrm{v}}, \quad R(x,2) = 4m_{\mathrm{v}} \end{cases} \tag{5}$$

$$\begin{cases} 0 \le m_{\mathrm{v}} < \frac{1}{8}, & R(x,2) = 1 - 4\left[m_{\mathrm{v}} - X(2)\right], \quad R(x,3) = 4\left[m_{\mathrm{v}} - X(2)\right] \\ \frac{1}{4} \le m_{\mathrm{v}} < \frac{3}{8}, & R(x,3) = 1 - 4\left[m_{\mathrm{v}} - X(3)\right], \quad R(x,4) = 4\left[m_{\mathrm{v}} - X(3)\right] \end{cases} \tag{6}$$

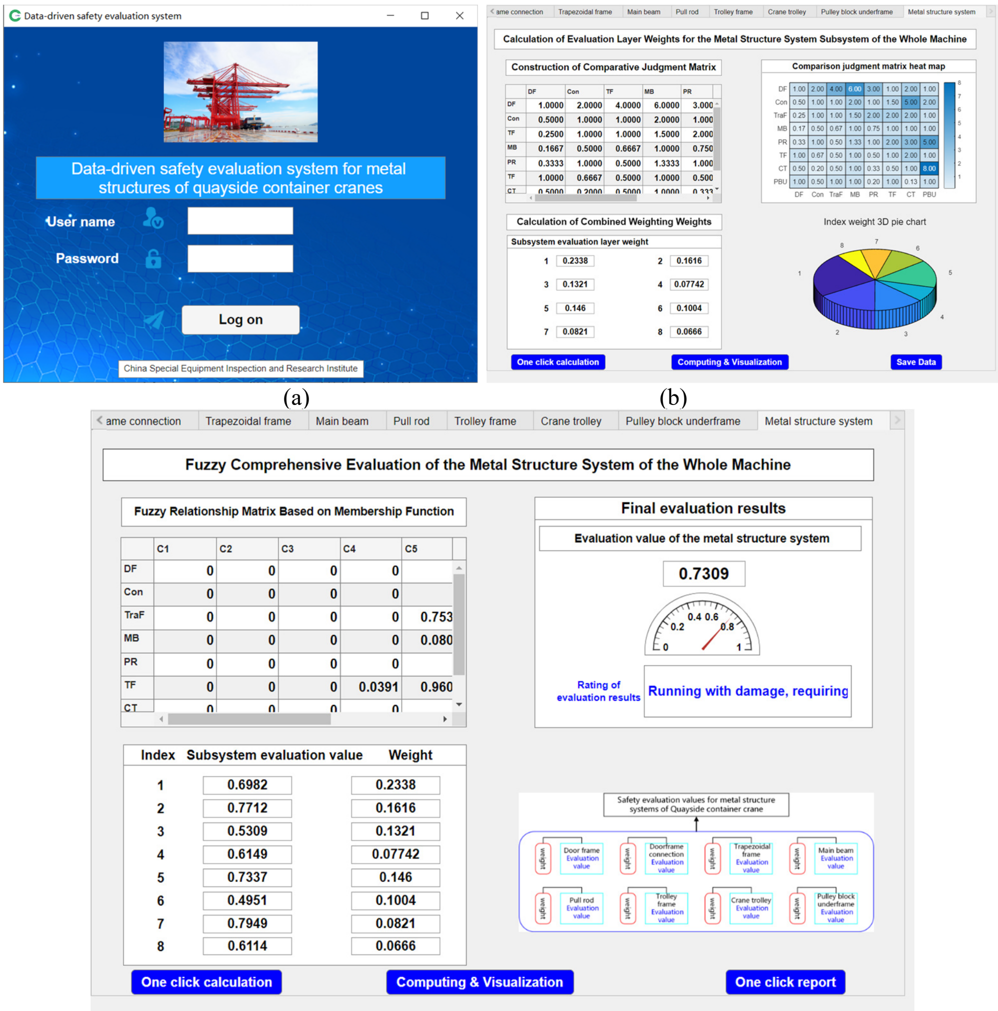
$$\begin{cases} \frac{1}{2} \le m_{\mathrm{v}} < \frac{5}{8}, & R(x,4) = 1 - 4\left[m_{\mathrm{v}} - X(4)\right], \quad R(x,5) = 4\left[m_{\mathrm{v}} - X(4)\right] \\ \frac{5}{8} \le m_{\mathrm{v}} < \frac{3}{4}, & R(x,5) = 1 - 4\left[m_{\mathrm{v}} - X(5)\right], \quad R(x,6) = 4\left[m_{\mathrm{v}} - X(5)\right] \\ \frac{3}{4} \le m_{\mathrm{v}} < \frac{7}{8}, & R(x,6) = 1 - 4\left[m_{\mathrm{v}} - X(6)\right], \quad R(x,7) = 4\left[m_{\mathrm{v}} - X(6)\right] \end{cases} \tag{7}$$

$$\begin{cases} \frac{7}{8} = m_{\mathrm{v}}, & R(x,7) = 0.5, \quad R(x,8) = 0.5 \\ \frac{7}{8} < m_{\mathrm{v}} \le 1, & R(x,7) = 0.1, \quad R(x,8) = 0.9 \end{cases} \tag{8}$$

5 Platform Development and Engineering Applications

5.1Platform Development

The interface of the safety evaluation system is shown in Figure 4. (a) Login interface; (b) Performing subjective and objective combination weighting calculation; (c) By using a multi-level fuzzy comprehensive evaluation method, the safety evaluation values of subsystems and metal structure systems are obtained.



(a) (b)

(c)

Figure 4. Safety Evaluation System Platform for Metal Structures of Quayside container cranes

5.2Engineering application results and analysis

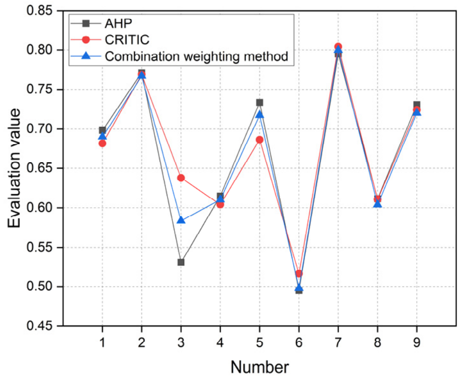


Figure 5. Comparison of evaluation results of quayside container crane subsystems and systems obtained using different weight calculation methods

As shown in Figure 5, a comparison of the evaluation values of the quayside container crane subsystem and system obtained by AHP, CRITIC method, and subjective and objective weight combination weighting method is presented. For the subsystem evaluation values represented by numbers 1 to 8, the evaluation values obtained by the combination weighting method are generally bounded between the evaluation values obtained by the AHP and CRITIC methods. The analysis results indicate that the combination weighting method reduces the extreme value impact caused by subjective judgment, and takes into account the differences and correlations between different indexes. At the same time, the evaluation value of the metal structure system represented by number 9 is lower than the evaluation value obtained by using AHP and CRITIC methods, indicating that the evaluation value obtained by using the combination weighting method is safer.

6 Conclusion

This article is based on the hierarchical system division of the quayside container crane system, using the combination of the CRITIC objective weight method and AHP subjective weight method to assign subjective and objective weights. A fuzzy comprehensive evaluation method based on the membership function model is constructed, and a multi-level safety evaluation method for the metal structure of the quayside container crane is provided. Moreover, this method also has significant reference value for the safety evaluation of different research objects in other fields.

This article proposes a membership function model that can programmatically generate a fuzzy relationship matrix. Especially, the data-driven safety evaluation system for the metal structure of quayside container cranes has been developed, which is convenient for large-scale promotion and application. At the same time, the engineering application results show that the combination weighting method reduces the extreme value impact caused by subjective judgment, and takes into account the differences and correlations between different indexes. The evaluation results obtained by this method are more accurate and safer.

Acknowledgments. This research was supported by the Technical Support Special Project of the State Administration for Market Regulation 2022YJ39.

References

[1] Xu, G. N. and F. Jiang 2010. Safety assessment on the crane based on FAHP. Journal of Safety and Environment 10 (02): 196-200.

[2] Saeidi, N., et al. 2013. Application of a Fuzzy Topsis Approach Based on Subjective and Objective Weights in the Container Terminals Risks Assessment. Applied Mathematics in Engineering Management and Technology 1 (4): 360-368.

[3] Chen, Z., et al. 2018. Safety Assessment Method of Bridge Crane Based on Cluster Analysis and Neural Network. Procedia Computer Science 131: 477-484.

[4] Li, C., et al. 2018. Research on System Safety Assessment Method for Crane Based on Membership Function Model. Hoisting and Conveying Machinery (12): 87-94.

[5] Zhang, Y. and H. B. Wei 2012. A Combination Weighting Method for Multiple Attribute Decision Making Based on CRITIC. Statistics Decision (16): 75-77.

[6] Bai, S. M. and S. M. Chen 2008. Automatically constructing grade membership functions of fuzzy rules for students' evaluation. Expert Systems with Applications 35 (3): 1408-1414.

[7] Guarracino, M. R., et al. 2013. Fuzzy regularized generalized eigenvalue classifier with a novel membership function. Information Sciences 245: 53-62.

[8] Ibarra, L., et al. 2015. A new approach to uncertainty description through accomplishment membership functions. Expert Systems with Applications 42 (21): 7895-7904.

[9] Hao, T., et al. 2009. Fuzzy Support Vector Machine with a New Fuzzy Membership Function. Journal Of Xi An Jiaotong University 43 (07): 40-43.

[10] Xing, Q. H. and F. X. Liu 2009. Method of determining membership and nonmembership function in intuitionistic fuzzy sets. Control and Decision 24 (3): 393-397.

[11] Kaufmann, M., et al. 2015. IFC-Filter: Membership function generation for inductive fuzzy classification. Expert Systems with Applications 42 (21): 8369-8379.