Evaluation Research on Safety Management Capability at Construction Sites of Construction projects

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Abstract—As a pillar industry in China, the construction industry is developing rapidly. However, casualties occur frequently due to such problems as unclear division of safety responsibilities, inadequate safety management at construction sites, insufficient safety education, and insufficient supporting safety resources. Considering the constraints of safety management capability at the construction sites of construction projects. Recommendations for improvement of safety management capability are made in this paper based on the results of evaluation of actual cases and analysis of causes according to actual situations of the projects by building a model using the fuzzy comprehensive evaluation method, multiplicative synthesis and combination weight method. And entropy method on the basis of the indicator system for evaluation of safety management capability at the construction sites under the three-level indicator system established.

1. Introduction
In recent years, the construction industry in China has developed rapidly, the gross output of which reached 2.484443 trillion yuan, accounting for 25.13% of GDP in 2019, and 2.25816 trillion yuan, accounting for 24.70% of GDP in 2018, offering job opportunities for more than 54 million people. It has strongly supported the healthy and stable development of the national economy from the perspective of either economic contribution or employment. Meanwhile, in the context of rural revitalization, the process of urbanization has accelerated, and a large number of infrastructures have been built. With the deepening of the strategies of "One Belt, One Road" and "Yangtze River Economic Belt", the development of construction industry in China has been pushed to a new high [1].

Nevertheless, construction safety issues also come along with the rapid development of the construction industry. The incidence of casualties in the construction industry all over the world far exceeds that in other industries and ranks only second to that in the mining industry [2]. Safety accidents are an important factor constraining the high-quality development of the construction industry because the safety accidents cause greater economic losses on the one hand, and also have great effects on the individuals and families concerned on the other hand, affecting the social stability.
Accordingly, the safety issues and emergency response capabilities in the construction industry have also been extensively concerned in various countries [3]. Based on the work safety conditions announced by the State Council Safety Committee from 2010 to 2019, the safety accidents show a rising trend. Figure 1 shows the trend of the number of construction safety accidents and that of casualties in China from 2015 to 2020. The number of accidents gradually increased from 442 in 2015 to 786 in 2020, and that of casualties increased from 621 in 2015 to 1,195 in 2020. The data indicate that the total number of construction safety accidents has continued to remain at a high level, and has gradually increased and the number of casualties has also been increasing year by year, showing a severe situation in construction safety in the construction industry [4].

![Figure 1 Number of Construction Safety Accidents and Casualties in China from 2015 to 2020](image.png)

2. Project Overview

The case project is a commercial residential community project. It is featured by a planned area of 29,000 m², a gross floor area of 18,159 m², a building area of 3,622.8 m², a plot ratio of 0.6, and a building density of 12.44%. With a greening rate of 61%, it is home to 310 households. In terms of emergency safety management at the project site, an emergency safety management team for renovation project was proposed to be established for the case project. The team was composed of safety officers of the Employer, Supervisor, and Construction Contractor. In addition, the safety management system at the project site was also used for the professional safety management at the project site, and comprehensive safety management was carried out at the project site by dynamic monitoring, timely feedback and other means.

The measures for safety management at the project site included lightning protection, fire protection, environmental protection, and equipment management and protection. Safeguards were provided through engineering design and safety measures. For the operation of professional equipment, a certificate, regular training, an operation management system, and strict implementation of maintenance regulations were required. Relevant equipment and facilities were allowed to be put into operation only after being checked and accepted by the local labor safety department. During operation, relevant personnel were required to operate various equipment and instruments in strict accordance with the operating procedures, and to attend regular trainings on work safety.

3. Acquisition of evaluation data

Based on the indicator selection principles of comprehensiveness, independence, and goal congruence, the static and dynamic capabilities were selected as the primary indicators, and the emergency management staff, emergency management input, emergency organization, safety culture and technology, operation management capability, risk management capability and safety guarantee capability were selected as the secondary indicators. 23 tertiary indicators such as the safety awareness of management staff and number of management staff were determined respectively. 20 experts engaged in the field of safety management of construction projects were invited to rate the general situation of on-site safety emergency management. In order to ensure the accuracy of evaluation
results, it was ensured that the experts were aware of the general situation of the project to a certain extent during questionnaire survey. In addition, to reduce the subjective influence caused by the positions of the experts, experts with different positions were selected for rating, including 10 experts from universities and scientific research institutions, accounting for 50%, 7 experts with senior professional titles and rich experience in safety management from the construction contractor, accounting for 35%, and 3 experts engaged in security management from government departments, accounting for 15%.

4. Determination of relative weight
As targeted experts were selected based on a small sample size during the survey, the experts with a small number are reliable to a certain extent. Owing to no extreme gap in the subjective rating of experts, the weight was obtained by the method of averaging during the survey, and processed to be indicator weight.

| Tab. 1 Combination Weight |
|---------------------------|
| Indicator                  | Subjective Weight | Objective Weight | Combination Weight |
| Safety awareness of management staff | 0.048            | 0.022            | 0.025             |
| Number of management staff  | 0.050            | 0.015            | 0.018             |
| Average education level     | 0.041            | 0.097            | 0.095             |
| Professional quality       | 0.050            | 0.015            | 0.018             |
| Total input                | 0.052            | 0.027            | 0.033             |
| Input link                 | 0.050            | 0.057            | 0.068             |
| Output effect              | 0.040            | 0.163            | 0.155             |
| Emergency resource status  | 0.036            | 0.047            | 0.040             |
| Emergency plan system      | 0.043            | 0.017            | 0.017             |
| Emergency organization establishment and responsibilities | 0.057            | 0.028            | 0.038             |
| Degree of mechanization     | 0.045            | 0.041            | 0.044             |
| Intelligent analysis method | 0.024            | 0.032            | 0.018             |
| Emergency management network | 0.041            | 0.031            | 0.030             |
| Emergency information platform construction | 0.051            | 0.041            | 0.050             |
| Safety warning             | 0.030            | 0.022            | 0.016             |
| Flexible resource mobilization | 0.019            | 0.061            | 0.028             |
| Emergency preparedness and response | 0.053            | 0.044            | 0.055             |
| On-site safety meeting     | 0.039            | 0.044            | 0.041             |
| Safety monitoring          | 0.043            | 0.030            | 0.031             |
| Risk control               | 0.046            | 0.071            | 0.078             |
| Logistics support and personnel protection | 0.043            | 0.057            | 0.058             |
| Accident investigation     | 0.047            | 0.022            | 0.025             |
| Emergency education and training | 0.052            | 0.016            | 0.020             |

Due to the hierarchical characteristics of the fuzzy comprehensive evaluation method, the relative weight of each level of indicator relative to the superior indicator is involved in the specific application. Accordingly, the relative weight of each level of indicator is required to be calculated separately, and the calculation results are shown in the table below.
Tab. 2 Weight of Tertiary Indicators Relative to Secondary Indicators

| Secondary Indicator          | Tertiary Indicator                        | Relative Weight |
|-----------------------------|------------------------------------------|-----------------|
| Emergency management staff  | Safety awareness of management staff      | 0.162           |
|                             | Number of management staff               | 0.115           |
|                             | Average education level                  | 0.609           |
|                             | Professional quality                     | 0.115           |
|                             | Total input                              | 0.130           |
|                             | Input link                               | 0.265           |
|                             | Output effect                            | 0.605           |
|                             | Emergency resource status                | 0.511           |
|                             | Emergency plan system                    | 0.185           |
| Emergency organization      | Emergency organization establishment and responsibilities | 0.304           |
| Safety culture and technology | Degree of mechanization                | 0.475           |
|                             | Intelligent analysis method              | 0.186           |
|                             | Emergency management network             | 0.316           |
|                             | Emergency information platform construction | 0.263           |
| Operation management capability | Safety warning                      | 0.083           |
|                             | Flexible resource mobilization           | 0.146           |
| Risk management capability  | Emergency preparedness and response      | 0.293           |
|                             | On-site safety meeting                   | 0.216           |
| Risk management capability  | Safety monitoring                        | 0.283           |
| Safety guarantee capability | Risk control                             | 0.717           |
|                             | Logistics support and personnel protection | 0.568           |
|                             | Accident investigation                   | 0.240           |
|                             | Emergency education and training         | 0.193           |

Tab. 3 Weight of Secondary Indicators Relative to Primary Indicators

| Primary Indicator          | Secondary Indicator                        | Relative Weight |
|---------------------------|-------------------------------------------|-----------------|
| Emergency management staff| Safety awareness of management staff      | 0.251           |
| Emergency management input| Number of management staff               | 0.251           |
| Emergency organization   | Average education level                  | 0.251           |
| Safety culture and technology | Degree of mechanization                | 0.246           |
| Operation management capability | Emergency preparedness and response     | 0.333           |
| Risk management capability| Risk control                             | 0.333           |
| Safety guarantee capability| Logistics support and personnel protection | 0.333           |

5. Evaluation by fuzzy comprehensive evaluation method

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

The calculation steps for evaluation of the safety control at the construction site using the fuzzy comprehensive evaluation method are as follows:

The first step is to set the factor set and comment set.

According to the evaluation model built above, the corresponding factor set is established hierarchically. Supposing that there are 5 possible comments, i.e., "extremely bad", "bad", "moderate", "good", and "excellent", these comments are respectively denoted as \( v_i (i=1,2,\ldots,5) \). If the corresponding comment set is \( v \), the correspondence is as follows:

\[
v = \{v_1, v_2, v_3, v_4, v_5\}
\]

Where: \( v_1 \) corresponds to "extremely bad", \( v_2 \) corresponds to "bad", \( v_3 \) corresponds to "moderate", \( v_4 \) corresponds to "good", and \( v_5 \) corresponds to "excellent".
The second step is to evaluate every single factor.

The membership relationship between the factor \( u^{(k)}(k = 1,2, \cdots, 4; i = 1,2, \cdots, m) \) and the comment element \( v_j(j = 1,2,\cdots, n) \) is established to obtain the single-factor evaluation set \( r^{(k)}(k = 1,2,\cdots, 4) \), also known as the fuzzy subset of the comment set, which is expressed as follows:

\[
r^{(k)} = (r^{(k)}_{11}, r^{(k)}_{12}, \cdots, r^{(k)}_{in})
\]

The third step is to build a tertiary indicator judgment matrix.

The evaluation sets for the tertiary indicators, \( r^{(k)}(k = 1,2,\cdots, 4; i = 1,2,\cdots, m) \), are integrated to obtain a judgment matrix \( R^{(k)}(k = 1,2,\cdots, 4) \) corresponding to the tertiary indicators \([5]\), which is expressed as follows:

\[
R^{(k)} = \begin{bmatrix}
r^{(k)}_{11} & r^{(k)}_{12} & \cdots & r^{(k)}_{1n} \\
r^{(k)}_{21} & r^{(k)}_{22} & \cdots & r^{(k)}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
r^{(k)}_{m1} & r^{(k)}_{m2} & \cdots & r^{(k)}_{mn}
\end{bmatrix}
\]

\( R^{(k)} \) is the comprehensive judgment matrix obtained by rating the tertiary indicator subset. \( U^{(k)} = \{u_1, u_2, \cdots, u_l\}(l = 1,2,\cdots, m) \).

The fourth step is to determine the fuzzy set of the importance of the factors.

1) Primary importance matrix

\( a^{(k)}(k = 1,2,\cdots, 7; i = 1,2,\cdots, m) \) is obtained according to the weight of tertiary indicators determined based on the previous combination weight method, and the corresponding primary importance matrix \( A_1^{(k)} \) is formed, with the correspondence as follows:

\[
A_1^{(k)} = (a^{(k)}_1, a^{(k)}_2, \cdots, a^{(k)}_m)
\]

2) Secondary importance matrix

\( a^{(l)}(l = 1,2; i = 1,2,\cdots, n) \) is obtained according to the weight of secondary indicators determined based on the combination weight method, and the corresponding secondary importance matrix \( A_2^{(l)}(l = 1,2) \) is formed, with the correspondence as follows:

\[
A_2^{(l)} = (a^{(l)}_{21}, a^{(l)}_{22}, \cdots, a^{(l)}_{2n})
\]

3) Tertiary importance matrix

\( a_3(l = 1,2,\cdots, o) \) is obtained according to the weight of primary indicators determined based on the combination weight method, and the corresponding tertiary importance matrix \( A_3 \) is formed, with the correspondence as follows:

\[
A_3 = (a_{21}, a_{22}, \cdots, a_{2o})
\]

The fifth step is to comprehensively evaluate the secondary indicators.

After the fuzzy relationship judgment matrix \( R^{(k)}(k = 1,2,\cdots, 4) \) of the first factor subset \( U^{(k)} = \{u_1, u_2, \cdots, u_l\}(l = 1,2,\cdots, 4) \) against the comment set \( v \), the following fuzzy transformation can be obtained by making use of \( R^{(k)(k)}(k = 1,2,\cdots, 4) \):

\[
T_p: F(U) \rightarrow F(V)
\]

Based on the above transformation, the comprehensive evaluation result \( B^{(k)}(k = 1,2,\cdots, 4) \) can be obtained \([6]\) by the following specific formula:

\[
B^{(k)} = A_1^{(k)}, R^{(k)}
\]
The sixth step is to comprehensively evaluate the primary indicators.

After the fuzzy relationship judgment matrix \( R^{(k)}(k = 1,2) \) of the second factor subset \( u^{(k)} = \{u_1, u_2, \cdots, u_l\} \) against the comment set \( V \), the following fuzzy transformation can be obtained by making use of \( R^{(k)}(k = 1,2) \):

\[
T_R : F(U) \rightarrow F(V)
\]

Based on the above transformation, the comprehensive evaluation result \( B_2^{(k)}(k = 1,2) \) can be obtained by the following specific formula:

\[
B_3^{(k)} = A_2^{(k)} \cdot B_2^{(k)}
\]

The seventh step is to comprehensively judge the general objective.

The primary comprehensive evaluation result \( B_3 = \{B_3^{(1)}, B_3^{(2)}\} \) is used as the tertiary comprehensive evaluation matrix, and the secondary importance matrix \( A_2 \) is substituted into the calculation to obtain the secondary evaluation result \( B = A_3 \cdot B_3 \).

The calculation result is as follows:

\[
B = \{248.6\}
\]

Based on a comparison with the corresponding comment set, it can be concluded that the evaluation conclusion of on-site safety emergency management of the construction project is good.

6. Evaluation by fuzzy comprehensive evaluation method

6.1. Results

Based on fuzzy comprehensive evaluation, it is believed that the emergency response capability of the case project is relatively good, and based on the observation of the membership of each indicator in the calculation, it can be concluded that in terms of primary indicators, the static capability of the project is good, while the dynamic capability is general. In terms of secondary indicators, the score for the emergency management input is high, which is related to the emergency management input of the project because the project manager paid more attention to emergency management, set up a corresponding emergency management team, and made a relatively high investment in corresponding emergency equipment and facilities, while the score for the safety culture and technology is low because no information management methods were adopted for the emergency management of the project and the emergency management training for construction workers and management staff also needs to be strengthened. In terms of tertiary indicators, the score for emergency organization establishment and responsibilities is low because although a special emergency management team was set up for the project, the organizational structure needs to be improved, and it is necessary to establish a corresponding on-site safety emergency management system and identify the division of responsibilities of each management staff rather than to carry out simple emergency management through one or two professionals. However, the input link and output effect of the project are relatively good because corresponding emergency safety management input was made for the project, and no safety accident occurred during the construction.
6.2. Recommendations and Countermeasures

1. Improve the on-site safety and emergency management plan

To improve the emergency response capability for a construction project, the emergency management system should be optimized first and the emergency management concept that can keep up with the high-quality development of the construction industry should be introduced. Based on observation of the performance of the operators, the emergency management rules in the construction process should be refined in a targeted manner, and the emergency management system should be implemented to ensure that all operators can strictly follow the safety management system. In addition, to ensure the smooth progress of safety supervision of construction projects, the organizational framework of emergency management should also be improved to ensure the quality of safety management of construction projects. If the scale of a project is particularly large, the management mode should be optimized, the construction process should be regulated according to different positions, and special staff should be assigned to supervise the operators to reduce the probability of safety accidents.

2. Provide emergency protection facilities

Different projects should be dealt with differently, and protective facilities for operators should be provided according to the actual needs of construction operations. Compared with the past, safety investment should be appropriately increased, and emergency facilities and protective facilities of good quality should be purchased. In addition, special emergency facility control points should be set up, and safety facilities should be provided in a targeted manner according to the construction schedule. Meanwhile, explanations should be given the operators to ensure that they can be aware of the safety and danger areas, standardized management should be strengthened, and the level of emergency response capability for construction projects should be improved. Special staff should be assigned to manage the placement of emergency equipment, and control the usage of various materials to avoid waste.

3. Improve the emergency awareness

The management staff should regularly train operators to deepen their knowledge about project safety and emergency response, and improve their emergency response awareness and capabilities. The training on safety awareness and emergency capability should be provided in advance before the operators formally enter the construction site so that the operators are familiar with the safe operation procedures of various tasks to a certain extent. For the special types of work, the operators should pass the corresponding national tests and hold the certificates. The training on emergency response capability of operators should be comprehensively intensified, and the safe operation and handling capabilities of the operators should be increased.

4. Strengthen the inspection and supervision

In the era of informatization and intelligence, informatization means should be used to build an intelligent and digital system for on-site safety and emergency management. To avoid the formalization and superficiality of the emergency capability management system for construction safety, all-round monitoring and timely feedback and processing should be ensured. The supervision of construction safety status and emergency response capability should be strengthened, the awareness of responsibility of safety management staff of construction projects should be enhanced, the rights and responsibilities and reward and punishment mechanisms should be identified, and absence of safety status and emergency management for construction projects should be avoided.

7. conclusion

This paper evaluates the safety management ability of the construction project through the actual case, and comes to the conclusion that the safety emergency ability of the construction project is better. Combined with the actual situation of the project, the evaluation results of the project are more consistent with the actual situation, and the evaluation model and index system have certain rationality and feasibility. However, this paper still deserves further research. On the one hand, in terms of the diversity of evaluation methods, this paper selects and uses the more mature fuzzy comprehensive
evaluation method, which has its advantages and disadvantages compared with other evaluation methods. Based on the principle of multiple research methods, the follow-up research can select research methods with different characteristics for evaluation research. On the other hand, in terms of the optimization and updating of the index system, the on-site safety emergency capacity of engineering projects in China has developed rapidly, and the timeliness of the index system constructed based on the standard may change. In the subsequent application, the index system should be adjusted accordingly according to the actual development and actual needs.

Fund project
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