Study on the identification and control of operational safety accidents in construction

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Abstract. Since the 21st century, China's urbanization process is accelerating, the construction industry has developed rapidly and become one of the pillar industries of the national economy, but the construction safety problems also follow. Although the progress of modern technology and management level can improve this problem to a certain extent, safety accidents still occur frequently in actual construction due to the complexity of construction process and the interference of many uncertain factors. Therefore, it is necessary to carry out research on the prevention and control system of construction safety accidents, which is of great significance to improve the prevention and control ability of construction safety accidents and reduce the accident rate. On the basis of a large number of literature studies, this paper establishes an evaluation model for the prevention and control of construction safety accidents, analyses four levels including the risk of equipment failure, environmental risk, the risk of personnel failure and management risk, verifies the model through AHP, and gives weight to each index to draw relevant conclusions. Combined with the current situation of construction safety accidents in construction companies in recent two years, this paper discusses and analyses the problems existing in the prevention and control of construction safety accidents in construction companies, and puts forward corresponding optimization countermeasures, in order to provide assistance for the decision-making of the prevention and control of construction safety accidents.

1. Introduction

The construction technology is complex, the process is cumbersome, the fluidity is large, and it is mostly carried out at high places and in the open air. The construction is mostly at high places and in the open air. In recent years, construction safety accidents are not uncommon, and the prevention and control of construction safety has become a major difficulty in the current construction industry. Therefore, it is of great significance to construct an indicator system for the prevention and control of construction safety accidents. It can not only provide technical support for construction safety management, prevent safety accidents during construction, but also ensure the safety of staff and is conducive to the sustainable development of construction enterprises.

Regarding the research on the prevention and control mechanism of safety accidents, in 2009, Zhao Ping et al. adopted the DS evidence theory method of information fusion technology, analysed from the four perspectives of man, machine, environment, and management, and established a building safety prediction model to prevent construction the occurrence of construction safety accidents. Subsequently, Wang Ying et al. analysed the causes of actual safety accidents, conducted safety early warning management research from four aspects of human, material, environment, and management, and constructed a construction site safety early warning system model. Chen Weike et al. (2020) analysed...
actural typical construction safety accident cases, deeply analysed the risk factors of construction safety accidents, mainly individual factors, management factors, mechanical equipment factors and on-site environmental factors, and established a multi-risk coupling analysis framework for the construction system. In-depth exploration of the deep evolution mechanism of the building construction system under the three states of "safety-risk-mutation". Therefore, this article refers to previous studies, starting from the four aspects of equipment failure, environmental risk, personnel error and management risk, and establishes an indicator system for the prevention and control of construction safety accidents.

2. Fundamental framework of influencing factor

(1) Equipment failure
The technical status of vehicles and other construction tools is a direct factor affecting accidents in the construction process, among which the steering and braking systems of construction vehicles are the most important. There are two main types of engineering vehicles for the transportation of building construction materials: semi-mounted and full-mounted. According to statistics, the structures most prone to technical failures resulting in safety accidents are the main vehicle chassis loading and unloading equipment safety facilities and containers. Driving faults can lead to traffic accidents, such as engine failure, braking problems, steering failure, old tires and flat tires. The quantity and frequency of vehicle maintenance can directly reflect the failure control of vehicles and equipment.

Failure of monitoring and measuring equipment makes it impossible to respond to emergencies, for example, safety devices on mechanical equipment, such as relief valves, pressure gauges and level gauges on pressure vessels (including gas cylinders), load travel limit device on hoisting equipment, calibration and management of temperature, pressure, flow, liquid level over limit alarm device and other instruments during the process, as well as key parts of the installation of communication devices, all of these are essential to ensure the safety of the construction of a line of defense. In addition, failure of safety facilities will also lead to failure to cope with the accident, for example, there is no high altitude protection and other safety protection, no electrostatic device and so on.

According to the relevant management system of construction safety in China, construction personnel must pass safety education before entering the construction site, and everyone should have a full understanding of the work content of the day and the possible safety risks, so that personnel involved in construction, quality inspection and management can operate carefully at work, at the same time, people must wear safety helmets and walk through safe passages to ensure the safety of construction personnel on site.

The construction process contains a lot of aerial work content, aerial work facilities are the key to ensure the safety of construction, ascending ladders must be solid, the foot of the ladder should have anti-skid measures, suspended work should have a firm foothold, and must be configured according to the specific situation of protective fence railings or other safety facilities. Construction materials contain some dangerous chemicals, the packaging of dangerous chemicals must ensure that they are complete, firm, tight no leakage and clean appearance, and must be packaged through wooden foam or special containers to ensure that they can be anti-impact, anti-vibration, anti-sun, rain and so on to a certain extent, especially when the transportation is toxic or corrosive items, the packaging should strictly comply with the requirements, and the liquid storage tanks and other supporting equipment used should also be tested at regular intervals.

(2) Environmental risk
Environmental risks mainly include meteorological risks and pollutant risks. In the process of building construction, unreasonable construction links and fatigue time will increase the occurrence of accidents, and the distance between the accident department and the accident site will affect the speed of the emergency response plan. Last, changing weather conditions and the geology of the site can affect the probability of an accident and increase its severity. Therefore, the construction site environment is also a fault mode during construction.

Weather conditions are a typical cause of safety accidents in construction, although there are weather forecasting systems that can warn of most of the weather, the false positive rate of the forecast itself,
variety, suddenness and uncontrollability of severe weather all will greatly affect the safety of the construction process. Once encountered snow, rain, hail, fog, storm and other sudden bad weather, it is easy for construction personnel to cause accidents due to improper operation or unstable facilities. Once this kind of safety accident happens, it not only affects the construction progress, but also poses a great threat to the personal safety of the construction personnel, especially in the coastal areas, typhoon and tsunami are the main meteorological problems that affect the construction, huge tsunamis and strong typhoons often slow down the construction process and seriously endanger the safety of construction.

High temperature can pose significant safety risks to the safety of construction facilities and building materials, for example, the brake bowl will expand and deform due to high temperature, resulting in out-of-control braking, there will be an increase in the chance of a flat tire on a building material transport vehicle. High temperature also will cause some aging parts and lines such as the crane circuit to spontaneously ignite and then cause damage to the crane, building materials such as spontaneous combustion and explosion or softening and deterioration due to high temperature.

Pollutant risk refers to the long-term exposure to some chemical materials or dust and other pollutants in the construction process may cause harm to the health of construction workers, chemicals such as formaldehyde and benzene may cause diseases such as leukemia, and the long-term inhalation of dust does great harm to the lungs, and pneumoconiosis accounts for 75%~80% of all occupational diseases in China. In a word, the pollution of pollutants in construction is a major safety problem that is difficult to avoid.

(3) Personnel error

According to the analysis results of relevant construction accident data, even if the system and construction equipment are ruled out, there will still be a lot of accidents unexplained, most of them are caused by the mistakes of the construction personnel. First of all, the safety awareness of relevant personnel is insufficient, in addition to management personnel, there are also construction workers, quality inspectors, loading and unloading personnel, maintenance personnel, inspection personnel and so on, these people are closely related to the safety of construction. Personnel should be proactive, or be able to identify and respond quickly to insecurities at an early stage. As long as someone's work can not avoid mistakes, only through layers of supervision and improve people's safety awareness in order to minimize the failure.

The lack of safety knowledge and skills of relevant persons also increases the risk in the construction process. If there is no technical and quality personnel to use and execute, the good construction equipment and the perfect system which is just a decoration. These problems mainly include the poor operator operating technology skill, unsafe working conditions, quality inspection personnel do not strictly follow the construction safety standards to check equipment, the loading and unloading personnel load the vehicle overweight, overfill the container, don’t make the building material container firm, maintenance personnel perform improper operation during welding, maintenance of empty tanks and omit maintenance items, etc. This also reflects the lack of knowledge and skills training of relevant employees, and the low professional quality of employees.

(4) Management risk

Management risk is a typical risk common to construction companies, especially those newly entering the construction industry. Although there is a complete construction system to coordinate a series of construction management of enterprises, in many cases, the operation is mainly focused on reducing cost and in the direction of improving construction efficiency, the risk management of construction safety has been neglected. Firstly, some construction subsidiaries have the problem of unreasonable organizational structure, which is mainly manifested in the lack of a dedicated construction safety risk prevention and control department or management system to carry out comprehensive management of construction safety. If the company does not have corresponding departments, positions and functions, the functions of departments will not be able to play.

Secondly, there is a lack of prevention and control systems and corresponding supervision mechanisms, such as the lack of preventive maintenance, inspection systems, or negligence in implementation of construction facilities, the lack of a reasonable selection mechanism for construction
time and scheduling, and the lack of inspection systems check the construction workers before and after they start work or lax inspection. Companies should formulate mandatory regular inspection and maintenance systems for construction equipment, strengthen internal dynamic management of the company, ensure construction safety, improve construction quality and efficiency, and avoid accidents.

In addition, a targeted emergency plan can ensure that emergency and rescue activities are carried out quickly and effectively. The lack of emergency plans for building construction failures, unreasonable procedures for emergency plans for accidents and slow response will lead to the risk of accidents that cannot be effectively controlled before or after the accident, which leads to the secondary expansion of losses. Improving the emergency rescue technology and information support system, cultivating high-quality emergency rescue teams, and making sure that different emergency incidents have corresponding handling methods according to the characteristics of the construction site, which will be helpful to form a rapid response emergency rescue mechanism.

3. Evaluation and identification of safety accident

This paper uses the Analytic Hierarchy Process (AHP) to study the influencing factors of the prevention and control of construction safety accidents. The Analytic Hierarchy Process (AHP) is a multi-objective decision analysis method that combines qualitative and quantitative analysis methods. The main idea of this method is to decompose complex issues into several levels and several factors, makes comparative judgment on the importance degree between two indicators, establish a judgment matrix, obtaining the weights of the importance of different schemes by calculating the maximum eigenvalue and corresponding eigenvector of the judgment matrix, which provides a basis for the selection of the best scheme.

(1) Establish a hierarchical structure

Based on the in-depth analysis of the construction company's construction safety accident prevention and control problems, this article divides the relevant factors into three levels: the target level, the criterion level and the project level, as shown in Table 1.

| Target level | Criterion level | Project level |
|--------------|----------------|---------------|
| Evaluation on the prevention and control of building construction safety accidents (A) | Equipment failure (B₁) | Construction Equipment (C₁₁) |
| | | Monitoring and measuring equipment (C₁₂) |
| | | Reliability of building materials (C₁₃) |
| | Environmental risk (B₂) | Weather condition (C₂₁) |
| | | High temperature factor (C₂₂) |
| | | Pollutant factor (C₂₃) |
| | | Employee security awareness (C₃₁) |
| | Personnel error (B₃) | Employee security knowledge and skills (C₃₂) |
| | | Employee training (C₃₃) |
(2) Establish a hierarchical structure

The questionnaire was distributed to 15 experts from the construction industry and the management of construction companies. According to the proportional scale method, they scored and evaluated in turn, then returned the results of the questionnaire, and finally sorted and analysed the data.

The first is the calculation of the weights of indicators at the criterion level. The judgment matrix of the first-level indicators is determined according to the expert scores. The meaning of the judgment matrix is the comparison of the importance of all elements related to the specific factors of the previous level in the same level, and the relative importance of the indicators is determined by the 1-9 scale method, as shown in table 2. And table 3 is the judgment matrix formed by the experts based on the target level.

| Scale | meaning                                      |
|-------|----------------------------------------------|
| 1     | Indicators i and j are equally important     |
| 2     | Indicators i and j are slightly more important |
| 5     | Indicators i and j are obviously important   |
| 7     | Indicators i and j are strongly important    |
| 9     | Indicators i and j are extremely important   |
| 2, 4, 6, 8 | Between the above two scales of importance |

Table 3. Expert judgment matrix based on the target level

| A    | B₁ | B₂ | B₃ | B₄ |
|------|----|----|----|----|
| B₁   | 1  |    |    |    |
| B₂   | 1/4| 1  | 1/3| 1/2|
| B₃   | 1/2| 3  |    | 2  |
| B₄   | 1/2|    | 1/2| 1  |

The square root method is used to determine the index weight, and the calculation formula is shown in the formula (1) and (2).

\[ W_i = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \]  \hspace{1cm} (1)

\[ W = \frac{\bar{W}_i}{\sum_{i=1}^{n} \bar{W}_i} \]  \hspace{1cm} (2)

Then to check the consistency, first calculate the maximum eigenvalue, as shown in the formula (3).
\[ \lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} \frac{(AW)_{ii}}{W_i} \]  

(3)

Next calculate the consistency index \( CI \), as shown in the formula (4).

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

(4)

And then use the random consistency index \( RI \) to check the consistency of the matrix, the value of \( RI \) is shown in Table 4.

| \( n \) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-------|---|---|---|---|---|---|---|---|---|
| B4    | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

According to the \( CI \) value and the \( RI \) value, the random consistency ratio \( CR \) is further calculated. The calculation formula is shown in (5). When \( CR < 0.1 \), the judgment matrix is consistent.

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

(5)

According to formulas (1) to (5), get the weight vector \( W = (0.434, 0.098, 0.286, 0.182)^T \), \( \lambda_{\text{max}} = 4.046 \), \( CR = 0.017 < 0.1 \), Consistency test passed.

Then there is the calculation of the weight of the indicators at the project level. The judgment matrix obtained is shown in Table 5 to Table 8, and the calculation method is the same as above.

| B1 | C11 | C12 | C13 |
|----|-----|-----|-----|
| C11 | 1   | 1/3  | 1/2 |
| C12 | 3   | 1   | 3   |
| C13 | 2   | 1/3  | 1   |

The calculated feature vector is \( W = (0.157, 0.594, 0.249)^T \), \( CR = 0.046 < 0.1 \), Consistency test passed.

| B2 | C21 | C22 | C23 |
|----|-----|-----|-----|
| C21 | 1   | 2   | 1/2 |
| C22 | 1/2 | 1   | 1/3 |
| C23 | 2   | 3   | 1   |

The calculated feature vector is \( W = (0.297, 0.163, 0.540)^T \), \( CR = 0.008 < 0.1 \), Consistency test passed.

| B3 | C31 | C32 | C33 | C34 |
|----|-----|-----|-----|-----|
| C31 | 1   | 1   | 1/4 | 2   |
| C32 | 1   | 1   | 1/2 | 2   |
| C33 | 4   | 2   | 1   | 4   |
| C34 | 1/2 | 1/2 | 1/4 | 1   |

The calculated feature vector is \( W = (0.178, 0.212, 0.504, 0.106)^T \), \( CR = 0.022 < 0.1 \), Consistency test passed.
Table 8. Management risk Judgment Matrix

| B4  | C41 | C42 | C43 |
|-----|-----|-----|-----|
| C41 | 1   | 1/2 | 1/2 |
| C42 | 2   | 1   | 2   |
| C43 | 2   | 1/2 | 1   |

The calculated feature vector is $W = (0.196, 0.493, 0.311)^T$, $CR = 0.046 < 0.1$, Consistency test passed.

Finally, through the above calculation, the weight of each indicator to the target level is obtained, as shown in Table 9.

Table 9. Evaluation index weights of construction company construction safety accident prevention and control problems

| Target level | Criterion level | Absolute weight | Project level | Relative weight | Absolute weight |
|--------------|-----------------|-----------------|---------------|----------------|-----------------|
|              | Equipment failure (B1) | 0.434          | Construction Equipment (C11) | 0.157          | 0.068           |
|              |                  |                | Monitoring and measuring equipment (C12) | 0.594          | 0.258           |
|              | Evaluation on the prevention and control of building construction safety accidents (A) | 0.098          | Reliability of building materials (C13) | 0.249          | 0.108           |
|              | Environmental risk (B2) | 0.098          | Weather condition (C21) | 0.297          | 0.029           |
|              | Personnel error (B3) | 0.286          | High temperature factor (C22) | 0.163          | 0.016           |
|              |                  |                | Pollutant factor (C23) | 0.540          | 0.053           |
|              |                  |                | Employee security awareness (C31) | 0.178          | 0.051           |
|              |                  |                | Employee security knowledge and skills (C32) | 0.212          | 0.061           |
|              |                  |                | Employee training (C33) | 0.504          | 0.144           |
Employee incentive system (C34) 0.106 0.030
Organization setting (C41) 0.196 0.036
Prevention, control and Supervision System (C42) 0.493 0.090
Emergency plan (C43) 0.311 0.057

Management risk (B4) 0.182

It can be seen from Table 9 that, for the prevention and control of construction safety accidents, the most important factor is Equipment failure, followed by Personnel error and Management risk, and again, Environmental risk. The relative weight is the degree of importance of each index in the project level relative to the criterion level. Specifically, in the case of Equipment failure, the importance of each index is ranked from high to low as Monitoring and measuring equipment, Reliability of building materials, and Construction equipment. Under Personnel error, the importance of each indicator is ranked from high to low as Employee training, Employee security knowledge and skills, Employee security awareness, Employee incentive system. Under the Management risk, the importance of each index is ranked from high to low as Prevention, control and supervision system, Emergency plan, and Organization setting. Under Environmental risk, the importance of each index is ranked from high to low as Pollutant factor, Weather condition, and High temperature factor.

4. Result analysis
According to the final determination of the weight coefficients of the various indicators for the evaluation of construction safety accident prevention and control problems (from Table 7), analysing from the criterion level, the index weight of the equipment failure level is the largest, up to 0.434, followed by the personnel error level, with a weight of 0.286, then there is management risk with a weight of 0.182, and finally environmental risk with a weight of 0.098. It can be seen from this that the most important factor for the prevention and control of construction safety is equipment failure, followed by personnel error and management risk, and finally environmental risk.

The absolute weight is the degree of importance of each index in the project level relative to the target level. Specifically, Monitoring and measuring equipment, Employee training, Reliability of building materials, Prevention, control and supervision system are the most important factors to be considered in the prevention and control of construction safety accidents. From the absolute weight of each index, it can be seen that the index with the largest weight value is Monitoring and measuring equipment. Monitoring and measuring equipment mainly includes safety protection facilities, monitoring devices for construction equipment, communication devices installed in key positions, etc. When the monitoring and measuring equipment fails, the possibility of safety accidents will increase.

Secondly, Employee training. Insufficient knowledge of safety prevention and control and low operating skills of employees, especially for employees with more dangerous types of work, are likely to cause safety accidents during the construction process. So Employee training is more important for the prevention and control of safety accidents.

Thirdly, Reliability of building materials. Problems with steel, cement, concrete and other materials used in building materials will not only increase the probability of safety accidents, but also it may affect the overall safety of the building.
The fourth-most weighted indicator is the Prevention, control and supervision system, which is indispensable for the prevention of safety accidents and the corresponding supervision mechanism. Problems can be discovered and rectified in time during inspection and supervision.

5. Conclusion
According to the above analysis, it can be seen that the unsafe factors of construction safety accidents mainly come from people, equipment, management and the environment. Some of these indicators are very important for the prevention and control of safety accidents. Combined with the construction company’s construction safety accidents in the past two years, aiming at the insufficiency of the construction company's construction safety system, the following optimization countermeasures are further proposed:

(1) Equipment for dynamic detection, monitoring and measurement, and increase capital investment in safety protection facilities. Construction companies should conduct real-time testing of relevant monitoring and measuring equipment, strengthen daily maintenance and maintenance of equipment, ensure that safety protection facilities are in place, and focus on inspections of equipment that are more prone to failure to avoid further development into safety accidents.

(2) People-oriented, regular employee training is carried out to improve employees' safety awareness and professionalism. Many construction safety accidents are caused by human errors. During the construction process, human errors or preventive negligence can also lead to accidents. Therefore, regular employee training can not only improve the professional skills of employees, but also continuously strengthen employees’ safety awareness. It can remind employees to stay vigilant and improve the level of construction safety.

(3) Ensure the reliability of building materials. Because of the particularity of the construction industry, the requirements for building materials are extremely high. Once there are problems with building materials, especially basic building materials such as steel and cement, the consequences will be disastrous. Unqualified concrete quality directly threatens the stability of the building structure, and the resulting building collapse accidents still occur. Therefore, ensuring the reliability of building materials is not only to prevent the occurrence of construction safety accidents, but also a basic industry requirement.

(4) Improve and strictly implement the prevention, control and supervision mechanism. A scientific prevention, control and supervision system can effectively prevent the occurrence of safety accidents. On the one hand, a strict prevention, control and supervision system is formulated to regulate the regular inspection and maintenance of construction facilities and the behavior of staff. On the other hand, a reasonable reward and punishment system is implemented to ensure timely Employees who report potential safety hazards will be rewarded, and employees who violated regulations will be punished.

This article focuses on the research on the prevention and control of construction safety accidents. Based on previous studies, a relatively complete index system for the prevention and control of construction safety accidents is established. Through the analytic hierarchy process, the weight of each index system is calculated. The article obtains relevant conclusions and puts forward some suggestions, which can provide reference for the follow-up construction safety construction prevention and control.

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