Strategic Learning and Knowledge Management of Technological Innovation in Safety Evaluation Planning of Construction Projects

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Abstract
The safety evaluation of construction projects is a very important problem. In the current study, the new smart methods especially for the complexity and variability of construction safety evaluation are absent. Combined with the engineering examples, this paper analyzes the sensitive factors that affect the construction project safety and makes discretizing of influencing factors based on expert and BIM technique. Based on BIM and Bayesian network, this paper established a new construction project safety evaluation model and presented the hybrid methods of strategic learning and knowledge management of technological innovation in construction project safety evaluation. Combined with the example of underground traffic engineering of Zhengzhou city comprehensive transportation hub, the Bayesian network was used to predict its security level. The probability of the safety level of the project in grade 3 is 0.614. Compared to other evaluation methods, presented hybrid method is more intelligent in strategic learning and knowledge management of technological innovation. Through the Bayesian network sensitivity analysis, we can know that the sensitivity factor of the construction project safety in the project is the construction risk, the continuous operation time, the protective measures, the material risk, and the number of maintenance. Presented detailed computational methods and steps in this paper can be used to improve the level of construction project safety effectively and help construction managers to take more effective control measures to prevent or reduce the occurrence of security incidents.

Keywords
evaluation planning, technological innovation, strategic learning, knowledge management, safety, construction

Introduction
In recent years, construction project safety accidents remain high, so the safety situation of construction projects is very grim. In construction projects, more and more people pay attention to its safety evaluation problem. The construction project safety evaluation is a very complex problem composed of many factors. The current researches about safety evaluation problems of construction projects are mainly focused on the safety evaluation index system and some traditional evaluation methods. In view of the complexity and variability of construction safety evaluation problems, new smarter safety evaluation methods should be studied. Therefore, studying new strategic learning and knowledge management method of technological innovation in construction project safety evaluation is very significant.

The objective of this paper is to study strategic learning and knowledge management problems of technological innovation in construction project safety evaluation. The technology innovation of construction management can be used to improve the management level of construction enterprises to reduce the occurrence of safety incidents. The BIM technology can be used to analyze the major hazards that may arise during the construction process in a virtual environment, so some appropriate preventive measures can be used to improve the level of building safety effectively. The BIM technology can also be used to help construction managers to take more effective control measures to prevent or reduce the occurrence of security incidents.

Literature Review
The current research on the safety evaluation of construction projects is mainly focused on the safety evaluation index system and some traditional evaluation methods. In recent years, more and more people pay attention to the safety evaluation problem. However, the current research on the safety evaluation of construction projects is mainly focused on the safety evaluation index system and some traditional evaluation methods. In view of the complexity and variability of construction safety evaluation problems, new smarter safety evaluation methods should be studied. Therefore, studying new strategic learning and knowledge management method of technological innovation in construction project safety evaluation is very significant.

The objective of this paper is to study strategic learning and knowledge management problems of technological innovation in construction project safety evaluation. The technology innovation of construction management can be used to improve the management level of construction enterprises to reduce the occurrence of safety incidents. The BIM technology can be used to analyze the major hazards that may arise during the construction process in a virtual environment, so some appropriate preventive measures can be used to improve the level of building safety effectively. The BIM technology can also be used to help construction managers to take more effective control measures to prevent or reduce the occurrence of security incidents.
System and the evaluation method. Detailed classification summarization for related literature is as follows.

1. Some references only focused on the safety evaluation index system. For example, Ding et al. (2011) established the safety evaluation index system of different construction projects. Shah et al. (2021) presented the safety value index system about computation and evaluation of safety of geographical area using fuzzy logic.

2. Some references don’t special concern about intellectualization of safety evaluation. For example, an earned value method for construction project safety management was worked out (Lu et al., 2013). An assessment method based on BDD (Binary Decision Diagram) is presented (Yang et al., 2013). A safety entropy evaluation model for hydropower construction based on Euclidean theory was established (Zheng et al., 2014). Guo et al. (2014) used BIM to study the early warning mechanism of unsafe behavior of workers. Saito and Iwasaki (2017) conducted a scoping review of the regulations for hemodialyzer’s in the safety evaluation in Japan and the United States. Zhang and He (2017) conducted a simulation study to investigate such issues and provide some practical suggestions for using the propensity score (PS) methods in road safety evaluations.

3. Some references don’t special concern about strategic learning and knowledge management of technological innovation. For example, Zhong et al. (2015) integrated RFID and BIM technology in the construction site. Chen and Shan (2016) put forward the framework of security early warning management based on Internet of Things and BIM. Shi et al. (2016) integrated the system dynamics and BIM technology to establish an early warning simulation system model of construction project safety risk based on the flow graph method. Wu et al. (2016) combined with rough set theory and Bayesian network to establish a safety risk assessment model for subway shield construction adjacent bridge.

4. Some references don’t special concern about detailed evaluation methods and intellectualization of safety evaluation. For example, Wetzel and Thabet (2016) described the data collection and analysis methods. Valente and Milani (2016) presented the evaluation of the seismic safety index by means of the simplified sectional approach suggested by Italian Guidelines on Cultural Heritage. Patel and Jha (2016) predicted and evaluated the work behavior of employees on construction projects using the constructs of the safety climate. The mixed safety risk assessment method based on entropy-weight method and CIM model was applied to calculate the index weight, then the safety risk probability of a building among them was determined (Zhao et al., 2017). The integrated evaluation method was used to evaluate the construction of green construction (Zhang & He, 2017). Hua (2017) established a framework for the full management model of the highway cross-bridge through the BIM construction project safety management system. Kashwani and Nielsen (2017) exposed the defects and challenges in the risk assessment tool in oil and gas construction projects in the UAE (United Arab Emirates) through a questionnaire survey. Gleirscher and Carlan (2017) observed that safety arguments are prone to stay too abstract, for example, solutions refer to larger packages, argument strategies to complex reasoning steps, contexts and assumptions lack traceability. Endroyo et al. (2017) used a questionnaire, interview and focus group discussion (FGD) to identify and measure as well as validate the contribution of all project participants in Pre-Construction project Safety Planning (PCSP). The Light Weight Deflectometer (LWD) was used to measure the surface deflection, Elastic Light Weight Deflectometer (ELWD) (Poranic et al., 2017). Alexander et al. (2017) aimed to build upon these current methodologies by creating and testing the first objective precursor-analysis program for construction fatalities. A synthesis of the available literature on construction project safety in Nigeria was conducted to determine the current state of safety practice and performance (Nnaji et al., 2018). An innovation evaluation model has been developed for macro-construction sector companies and is applied in the Spanish case (Zubizarreta et al., 2017). Dansoh et al. (2017) dwalled on evidence from four construction projects in Ghana by means of interviews. Suprun et al. (2018) presented a novel five-stage integrated participatory systems modeling (IPSM) approach. McCarthy et al. (2018) illustrated the utility of a recently published conceptual model of social innovation. Killip et al. (2018) reported a cross-case comparison of four previous studies focused on low-energy renovation of housing, using a co-evolutionary framework in which five systems are mutually interdependent: ecosystems, technologies, user practices, business strategies and institutions. Park et al. (2019) investigated the safety evaluation of the SUS material, which is mainly used in boiler and heat exchanger piping. Wang and Zhou (2019) developed and tested a model linking safety innovation intention with safety innovation behavior and safety performance. Nguyen (2021) aimed in developing an optimal construction site layout planning by fulfilling three main objectives, namely minimum cost facility, minimum risk of safety facility, and minimum noise pollution.
In conclusion, there are already many researchers to study the safety evaluation index system and evaluation methods, but smarter safety evaluation methods are absent. The motivation of the study is to solve construction safety evaluation problems and establish a new construction project safety evaluation model and presented the smarter hybrid methods. Compared to other evaluation methods, presented hybrid method is more intelligent in strategic learning and knowledge management of technological innovation.

**Proposed New Hybrid Methods**

The overall methodology diagram is shown as Figure 1.

**Engineering Background**

The Zhengzhou integrated transport hub underground traffic engineering (East Plaza) project is located in Zhengzhou East Station East. The project consists of two parts, the ground landscape and underground space design. The project covers an area of 51,953.21 m², a total of three underground with the area of 113,558 m², of which the underground floor area of 37,706 m², the second floor of the building are about 37,926 m². The ground floor for commercial development, underground two and three for a large parking lot. During the construction process, due to involving more professional such as construction, structure, electro-mechanical, ventilation, air conditioning, and fire, so the BIM technology for construction management is chosen.

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| Analysis of the influencing factors of construction safety |
|----------------------------------------------------------|
| The discretization of influencing factors based on expert interview and BIM technique |
| The attribute reduction in knowledge management based on genetic algorithm |
| Building the Bayesian network strategic learning model |
| The parameter strategic learning of Bayesian network |
| Pre-risk level forecast |
| Identifying the accident critical risk factor |
| Sensitivity analysis result of risk factors in knowledge management |

*Figure 1. The overall methodology diagram.*

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The safety evaluation planning model of construction projects consists of three modules: BIM module, data processing module, and decision support module, shown as in Figure 2.

**The Framework of Construction Project Safety Evaluation Model**

The safety evaluation planning model of construction projects consists of three modules: BIM module, data processing module, and decision support module, shown as in Figure 2.

Related data description parts can be shown as following. In this system, the BIM module is used for construction simulation and collecting information about construction personnel, materials and mechanical equipment. It’s also used for updating these data during construction, performing 3 Dimensions (3D) modeling, and storing data to provide reliable data support for safety evaluation planning of construction projects. The data processing module is used to extract and process data in the BIM module, identify influence factors about construction safety. The collected data can be used for discrete evaluation attributes and carry out the variable screening and strategic learning the Bayesian network structure and parameters. The decision support module is based on the results of Bayesian network to predict the construction project safety level and identify the sensitive factors.

The specific connotation of the three modules will be further elaborated.

**BIM module.** The main operational thinking of The BIM module is to prior simulate construction schemes and site situation by integrating the full life cycle of the construction project before the beginning of the project to discover
the safety hazards. On the other hand, in the construction process, make real-time monitoring, collect data information about construction workers, construction materials, and mechanical equipment. The source of these data information is different from traditional building construction safety evaluation data, which is directly derived from the construction site, such as the working time, workload, workload of the construction personnel and the relative position between the construction site and the mechanical equipments. They are data obtained directly through construction site monitoring, making the construction safety evaluation more objective.

Traditional safety evaluation, most of which rely on experts to score and inter-site investigation, the subjectivity is large, lacks certain objectivity. Using the BIM module to collect construction site data can not only make data more objective, but also allow construction safety managers to understand the safety status of the construction site, but have operability.

Through statistics construction safety accidents, combined with BIM technology to collect data based on the construction site, the relative weights of individual nodes for construction safety can be obtained. The gotten relative weights between each node combined with BIM technology are shown in Table 1

**Figure 2.** The framework of safety evaluation planning modules of construction projects.

**Table 1.** The Gotten Relative Weight Between Each Node Combined With BIM Technology.

| Node | C1    | C2    | C3    | C4    | C5    |
|------|-------|-------|-------|-------|-------|
| Relative weight | 0.28  | 0.17  | 0.14  | 0.25  | 0.16  |
| Node | C6    | C8    | C9    | C11   | C14   |
| Relative weight | 0.18  | 0.27  | 0.28  | 0.06  | 0.21  |
| Node | C16   | C17   | C18   | C20   | C22   |
| Relative weight | 0.18  | 0.60  | 0.22  | 0.35  | 0.42  |
| Node | C23   | C24   | C25   | C27   | C29   |
| Relative weight | 0.23  | 0.34  | 0.18  | 0.23  | 0.25  |
| Node | B1    | B2    | B3    | B4    | B5    |
| Relative weight | 0.17  | 0.35  | 0.15  | 0.15  | 0.18  |

**Data processing module.** The data processing module is the most important part of the construction safety evaluation system. The data are collected in the BIM module, and the safety evaluation of the construction site will use these data. Data must be processed. The most important function of the data processing module is to perform data processing, and the universal applicable method of construction safety evaluation is obtained. First, the collected data are classified according to the construction safety evaluation index system. Then these influencing factors are discretized by analyzing the type of data. Due to many influencing factors in the construction safety evaluation index system, the calculation is complicated due to the redundancy of the data during calculation, and the too much data is not convenient for processing and analysis. This needs to analyze these influencing factors, screening out model builds with representative influencing factors, not only convenient to calculate, but also more convenient data collection and processing, also have certain representation on the safety of the construction site. Finally, considering the lack of quantitative estimation of the safety situation in the construction site, this article introduces the Bayes network, use the collected data to make the structure and parameter learning of the Bayesian network, and finally
can get the different situation probability of the construction site safety.

**Decision support module.** When the data processing module processes the data, the corresponding building construction safety evaluation model and parameters are obtained, and the decision support module is the verification and presenter of the last result. After inputting data to the decision support module, this module can evaluate the safety of the construction project to get the probability of this item at different security levels. At the same time, sensitivity analysis can be performed by establishing the Bayesian network, identifying factors that affect the security state in the project. This is also conducive to the manager of the construction project to predict the security situation of the construction project, and target the weak links of the project safety management.

**Building the Evaluation Model of Construction Project Safety Based on BIM and Bayesian Network**

**Analysis of the influencing factors of construction safety.** On applying the BIM technology to evaluate the construction safety, it’s needed for resort the impact factors so that we can collect the appropriate data through the BIM module. The construction project safety is closely related to the construction personnel, such as the continuous working hours, workload, work location, and type of work of the construction staff. In addition to the construction workers, construction hazards, construction weather conditions and the use of materials and machinery have an impact on the construction safety. Through literature combing and the expert interview method, the impact factors of construction project safety are divided into four aspects: construction conditions, personnel, materials, and mechanical equipment. The corresponding indicators for each factor are shown as Table 2.

Related data collection work can be shown as following. On the basis of analyzing the factors affecting the construction safety, based on the measured data of a BIM construction project in Zhengzhou City, China, the measure value of the relevant attribute in the construction process is recorded. Taking the construction personnel factor (B2) as an example, we established the statistical table is shown as Table 3.

**The discretization of influencing factors.** The data pre-processing and data analysis work can be shown as following. Data from BIM module are continuous data, if we want to use these data to carry out Bayesian reasoning inferring, these continuous data need to be converted into discrete data. Commonly the used discretization methods include interval discretization, genetic algorithm, etc., which is essentially a hard partition for the spatial attributes and some algorithms are more complex, not applicable to a large number of data processing. In order to make the division to have humanized performance, first of all, the construction project safety factors are initially divided, and then the results of the division are modified and perfected through the interview of construction workers and experts. The results are shown as Table 4.

In Table 4, the safety status of construction projects are divided into safety, general safety, basic safety, general danger, danger. A is the construction project safety level, B1, B2, B3, and B4 representing conditions, personnel, material, and equipment factors of construction projects, et al. Each continuous attributes has its safety status value after being dispersed interval division. The construction risk (C1), cross operations (C2) and mechanical position (C20) are simulated by BIM to obtain the construction risk coefficient, the number of operating points and the distance of the construction machinery. The maintenance rate is expressed as the number of maintenance per month of the construction machinery. Other values are based on expert interview.

**The attribute reduction in knowledge management based on genetic algorithm.** The attribute reduction in knowledge management is to remove some factors that are irrelevant or its influence is not obvious, so the calculation is quicker. At present, algorithms commonly for attribute reduction are reduced based on attribute importance, information entropy and genetic algorithm (Wu et al., 2016). The reduction of genetic algorithm has the advantages of machine learning, can handle a large amount of data. So this method is used to

### Table 2. Risk Factors of Construction Safety.

| Target layer | Factor layer | Index layer |
|--------------|--------------|-------------|
| Construction project safety level (A) | Conditions (B1) | construction risk (C1), cross operations (C2), construction climatic conditions (C3), safety signs (C4), lighting situation (C5) |
| Personnel (B2) | continuous operation time (C6), workload (C7), work location (C8), hazard of working (C9), length of service (C10), age (C11), physical conditions (C12), education level (C13), protective measures (C14) |
| Material (B3) | production date (C15), approach time (C16), material risk level (C17), material quality status (C18), material importance (C19) |
| Equipment (B4) | mechanical position (C20), operation difficult degree (C21), dangerous (C22), number of maintenance (C23) |
reduce the properties of the construction project safety index layer in this paper.

On applying genetic algorithms for calculating, it is the first need to code the construction project safety index layer. The length of the chromosome is set to 23, and the gene on each chromosome is set to 0 or 1. If the corresponding gene on the chromosome is 0, it means that the gene is not involved in modeling; otherwise, if the corresponding bit is 1, it means that the gene is involved in modeling. On applying the genetic algorithm, we need to define the fitness function, select the operation function and cross mutation operator. This paper chooses the reciprocal of the mean square error, the proportional selection operator and the single point across mutation operator to calculate. The calculation formula is as follows.

The fitness function:

$$f(X) = \frac{1}{SE} \frac{1}{n} \sum_{i=1}^{n} (\tilde{t}_i - t_i)^2 $$

Where \(\tilde{T} = \{\tilde{t}_1, \tilde{t}_2, ..., \tilde{t}_n\}\) is the predicted value of the collected data, \(T = \{t_1, t_2, ..., t_n\}\) is the true value of the data, and \(n\) is the number of samples. Proportional selection operator, the specific operation is as follows:

1. Calculate the fitness of all the individuals in the population.

$$F = \sum_{i=1}^{n} f(X_i)$$

2. Calculate the relative fitness of each individual in the population and use it as the probability that the individual is selected and transmitted to the next generation.

$$P_k = \frac{f(X_k)}{F}$$

Based on a genetic algorithm optimization algorithm to reduce the dimension to a certain extent, we selected the impact of engineering construction site safety of the main factors, and screened out some relevance are too high or less relevant to the safety factors.

Using MATLAB R2014b and BNT1.0.7 BN tool to run the program, the iterative and evolution are repeated again and again for the group. When the final result meets our iteration termination conditions, the final result of the program output is the final solution or approximate solution we want, which is the most representative factors affecting construction safety. Some processes and code are as following.

```matlab
%% Optimization calculation of genetic algorithm - input self-variable reduction
% Empty environment variable
clear all
% disclaimer global variable
global P_train T_train P_test T_test mint maxt S s1
S=23;
s1=50;
% Import Data
load data.mat
a=randperm(600);
Train=data(a(1:530),:);
Test=data(a(531:end),:);
% Training data
P_train=Train(:,3:end)';
T_train=Train(:,1)';
% P_test=Test(:,3:end)';
T_test=Test(:,2)';
```

### Table 3. The Statistics of Construction Personnel Factors.

| Number | C6 | C7  | C8 | C9  | C10 | C11 | C12  | C13  | C14   |
|--------|----|-----|----|-----|-----|-----|------|------|------|
| 1      | 3.6| 74% | 5.3| Reinforced workers | 7   | 43  | Middle | Junior high school | 4   |
| 2      | 2.3| 32% | 1.7| Wood worker        | 3   | 32  | Middle | High school      | 1   |
| 3      | 3.1| 49% | 0.8| Shelve worker      | 1   | 26  | Good   | Specialist        | 3   |
| .      | .  | .   | .  | .               | .   | .   | .     | .                | .   |
| 600    | 6  | 116%| 13.6| Wood worker      | 3   | 30  | Middle | High school      | 4   |

Note. The workload (C7) is expressed as a percentage of the work done in the standard 8 hours. The working position (C8) represents the distance between the worker and the hazardous working area. The physical condition (C12) is obtained by real-time equipment monitoring such as hang ring.
% Display experimental conditions
total_B=length(find(data(:,2)==1));
total_M=length(find(data(:,2)==2));
count_B=length(find(T_train==1));
count_M=length(find(T_train==2));
number_B=length(find(T_test==1));
number_M=length(find(T_test==2));

Attribute reduction results in the construction project safety index layer are shown as Table 5.

### Table 4. Dispersed Interval Division of Continuous Attributes Based on Expert Interview and BIM Technique.

| Index | Continuous attributes | Status |
|-------|-----------------------|--------|
| A     | Construction safety level | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| B1    | Conditions            | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| B2    | Personnel             | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| B3    | Material              | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| B4    | Equipment             | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| C1    | Construction risk     | <2     | (2, 4)   | (4, 6)   | (6, 8)   | >8   |
| C2    | Cross operations      | 0      | (0, 1)   | (1, 3)   | (3, 5)   | >5   |
| C3    | Construction climatic conditions | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| C4    | Safety signs          | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| C5    | Lighting situation   | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| C6    | Continuous operation time | <2   | (2, 3)   | (3, 4)   | (4, 4.5) | >4.5 |
| C7    | Workload             | <20%   | (20%, 40%) | (40%, 80%) | (80%, 100%) | >100% |
| C8    | Work location        | >50                      | (25, 50) | (10, 25) | (3, 10) | <3   |
| C9    | Hazard of work       | 1      | 2        | 3        | 4        | 5    |
| C10   | Length of service (year) | >5   | (4, 5)   | (3, 4)   | (1, 3)   | <1   |
| C11   | Age                  | (30, 35) | (25, 30) | (15, 40) | (22, 25) | (1, 45, 50) | (<20) | (>50) |
| C12   | Physical conditions  | 1      | 2        | 3        | 4        | 5    |
| C13   | Education level      | Undergraduate and above | Specialist | High school | Junior high school | Primary school and below |
| C14   | Protective measures  | 5      | 4        | 3        | 2        | 1    |
| C15   | Production date (year) | <1 | (1, 2) | (2, 3) | (3, 4) | >4   |
| C16   | Approach time (week) | <1 | (1, 2) | (2, 3) | (3, 4) | >8   |
| C17   | Material risk level  | <2 | (2, 4) | (4, 6) | (6, 8) | >8   |
| C18   | Material quality status | (90, 100) | (80, 90) | (65, 80) | (50, 65) | <50 |
| C19   | Material importance  | Unimportant | Important | Generally important | More important | Most important |
| C20   | Mechanical position  | >50 | (25, 50) | (10, 25) | (3, 10) | <3   |
| C21   | Operation difficult degree | Easy to operate | Operable | Difficult to operate |
| C22   | Dangerous            | 1      | 2        | 3        | 4        | 5    |
| C23   | Number of maintenance | >4 | (4, 3) | (3, 1) | (1, 0.5) | <0.5 |

The Evaluation Model of Construction Project Safety Based on Bayesian Network

Building the Bayesian network strategy model with knowledge learning. Bayesian network strategy learning modeling is divided into two parts: structural learning and parametric learning. Based on the attribute reduction index of construction project safety index, the relationship among influencing factors of construction project safety is clarified. On this basis, the Bayesian network structure model of construction project safety with knowledge learning is built. The results are shown as Figure 3.

The parameter strategic learning of Bayesian network for available knowledge. Based on the Bayesian network reasoning algorithm, the Bayesian network parameter learning for available knowledge is divided into the following steps:

1. Statistics discretized data in the BIM module and identify the number of indices at different levels, so as to calculate the probability of the root node at different levels. The results are shown in Table 6.
2. Determine the relative weights between nodes. In order to determine the construction probability between the leaf nodes, it’s necessary to know the relative weights between the nodes. Using the expert scoring method, we can get the relative weight between the nodes of the construction safety, and verify or correct the results. The relative weights between the nodes are shown as Table 7.
Get the conditional probability distribution of the sub-nodes in different states. Through the above analysis, we have obtained the initial probability of the root node and the relative weight between the nodes. By the Bayesian network forward reasoning, we can know that the probability of the sub-nodes in different states on the basis of the known root node state. Since the distance in the same child node and the different parent nodes is different, it is necessary to introduce the concept of distance. Consider the absolute value of the "weighted distance between the parent node state and the sub-node state" (referred to as the weighted distance) to allocate the probability that the child nodes are in different states. The absolute value \( D_j \) of the weighted distance can be calculated by the following equation.

\[
D_j = \sum_{i=1}^{n} D_{ij} \cdot w_{ij}, D_j \in [0, 2] 
\]

Where \( D_j \) is the distance between the state of the ith root node and the state in which the child node. If the root node “continuous operation time (C6)” is in the “1” state, the state where the sub-nodes “person (B2)” is considering “1,” then \( D_j \) is equal to 0. \( n \) is the number of root nodes, and \( j \) is the state of the sub-nodes, \( j = (1, 2, 3, 4, 5) \).

The following parts describe how to calculate the weighted distance with the child “Person (B2).” Assuming that the parent node “continuous operation time (C6),” “working position (C8),” “job hazard (C9),” “age (C11),” and “protective measures (C14)” are in “3, 2, 3, 3, 4,” then we can know that \( C6 = 3, C8 = 2, C9 = 3, C11 = 3, C14 = 4 \). At this point, consider the “person (B2)” in a different state of the weighted distance. Assuming that the first consideration is the case of \( B2 = 1 \), that is, \( j = 1 \), then we can know that \( D_2 = 1, D_3 = 1, D_4 = 1, D_5 = 2 \).

According to Table 7, the weight between them are \( W_{C8} = 0.27, W_{C9} = 0.28, W_{C11} = 0.06, W_{C14} = 2.1 \), and the weighted distance is \( D_1 = 1.94 \). Similarly, according to the formula (3) we can also know that \( D_2 = 0.94, D_3 = 0.06, D_4 = 1.06, D_5 = 2.06 \).

The problem of probability assignment for different values of \( D_j \) is calculated using the formula, shown as

\[
P_j = \frac{e^{-RD_j}}{\sum_{j=0}^{c} e^{-RD_j}}, P_j \in [0, 1] 
\]
Table 6. Probability Table of Root Nodes.

| Node | Status | 1 | 2 | 3 | 4 | 5 |
|------|--------|---|---|---|---|---|
| C1   | 0.021  | 0.30 | 0.26 | 0.12 | 0.11 |
| C2   | 0.017  | 0.25 | 0.36 | 0.14 | 0.08 |
| C3   | 0.024  | 0.32 | 0.21 | 0.19 | 0.04 |
| C4   | 0.150  | 0.22 | 0.38 | 0.13 | 0.12 |
| C5   | 0.122  | 0.26 | 0.29 | 0.32 | 0.01 |
| C6   | 0.122  | 0.18 | 0.32 | 0.25 | 0.13 |
| C8   | 0.130  | 0.25 | 0.29 | 0.24 | 0.09 |
| C9   | 0.150  | 0.23 | 0.29 | 0.25 | 0.08 |
| C10  | 0.200  | 0.18 | 0.29 | 0.25 | 0.08 |
| C11  | 0.200  | 0.23 | 0.31 | 0.19 | 0.10 |
| C12  | 0.200  | 0.18 | 0.29 | 0.25 | 0.08 |
| C13  | 0.200  | 0.23 | 0.31 | 0.19 | 0.10 |
| C14  | 0.200  | 0.18 | 0.29 | 0.25 | 0.08 |
| C15  | 0.200  | 0.23 | 0.31 | 0.19 | 0.10 |
| C16  | 0.200  | 0.18 | 0.29 | 0.25 | 0.08 |
| C17  | 0.200  | 0.23 | 0.31 | 0.19 | 0.10 |
| C18  | 0.200  | 0.18 | 0.29 | 0.25 | 0.08 |
| C19  | 0.200  | 0.23 | 0.31 | 0.19 | 0.10 |
| C20  | 0.200  | 0.18 | 0.29 | 0.25 | 0.08 |
| C21  | 0.200  | 0.23 | 0.31 | 0.19 | 0.10 |
| C22  | 0.200  | 0.18 | 0.29 | 0.25 | 0.08 |
| C23  | 0.200  | 0.23 | 0.31 | 0.19 | 0.10 |

Where the $R$ value need be determined, if a high $R$ index value is assigned, it means that the sub-node is in a state far from its root node. The probability of the corresponding node in this state is a low probability. By introducing this $R$ value into equation (4), we can calculate the conditional probability distribution of the nodes in different states, shown as Table 8.

The Decision Support Module Based on Bayesian Network Strategic Learning Model

Pre-risk level forecast with knowledge learning. Bayesian networks can be used to conduct forward reasoning and predict their safety before an accident occurs, so that the construction management staff can develop the appropriate construction programs and adopt some preventive measures. The parent nodes of the “construction project safety level (A)” are “construction conditions (B1),” “personnel (B2),” “materials (B3),” and “equipment (B4).” The state of can be represented by $b_i$, then the possible value for $b_i$ is 1, 2, 3, 4, 5. So the probability that a node A is in the state can be expressed as follows.

\[
P(A = a | B_1 = b_1, B_2 = b_2, B_3 = b_3, B_4 = b_4, B_5 = b_5)
\]

According to the formula (5) and the sub-node conditional probability distribution table we can get the conditional probability of the sub-node “construction project safety level (A),” where $B_i$ is in different states.

Identifying the accident critical risk factor. In order to find out the sensitive factors that have an important influence on the construction project safety accidents from many uncertain evaluation indexes, it’s necessary to analyze the sensitivity of each index. Sensitive factors and non-sensitive factors in the safety evaluation planning results of construction projects are very different, through the sensitivity analysis, we can identify the key factors that affect the construction project safety and understand the central focus of the construction process. The sensitivity of the root node $C_k$ can be expressed as follows if the node $T$ is in $t$ state.

\[
I(C_k) = \frac{1}{p_t} \sum_{c_i} [P(T = t | C_k = c_i) - P(T = t)]
\]

Where $C_k$ is the root node, $c_i$ is the state of the root node $C_k$, $p_t$ is the number of $C_k$ states. $I(C_k)$ is the sensitivity of the root node $C_k$ when the node $T$ is in $t$ state.

Results and Discussion

Forecast the pre-risk level

Using BIM technology to simulate the construction plan, monitor the construction project and extract the relevant data. The construction scheme and its site conditions were evaluated and we can know that the values of construction risk cross operation, construction climatic condition, safety marking and lighting are 4, 3, 81, 72, and 83. Corresponding node status are $C_1 = 3$, $C_2 = 2$, $C_3 = 3$, $C_4 = 3$, $C_5 = 2$. The status of the construction workers can be monitored and we can know that the value of working hours, working position, hazard of workers, the age of the construction workers and the average of the protective measures are 4.2, 10, 3, 45, and 3. The corresponding node states are $C_6 = 4$, $C_8 = 3$, $C_9 = 3$, $C_11 = 4$, $C_{14} = 3$. The BIM technology is used to monitor the construction site material when it comes into play and we can know that the value of material entry time (weeks), material risk and quality are 2.5, 3, 85. The corresponding node states are $C_16 = 2$, $C_17 = 2$, $C_{18} = 2$. The state information of the construction machinery is modeled by BIM technology to evaluate its operating position and status. The values of mechanical position, risk and maintenance factor are 16, 3, 1. The corresponding node states are $C_20 = 3$, $C_22 = 3$, $C_23 = 4$. Use formula (5) to calculate the construction project safety level. The result is shown as Table 9.

According to the results of the reasoning we can know that the safety level of the construction project is 3 in a basic safe state. The overall age of construction workers is too large and the construction machinery maintenance rates need to be improved.
Use the formula (7) to calculate the sensitivity of each root node; we can know that C1, C6, C14, C17, and C23 are the key factors that should be considered in construction safety. The construction risk (C1) is closely related to the construction scheme and the construction site environment. Combined with the example of underground traffic engineering of Zhengzhou city comprehensive transportation hub, this paper analyzes the sensitive factors that affect the construction project safety and can provide the decision-making basis for the construction manager. The Bayesian network was used to predict its safety level. The probability of the safety level of the project in grade 3 is 0.614. Through the Bayesian network sensitivity analysis, we can know that the sensitivity factor of the construction project safety in the project is the construction risk, the continuous operation time, the protective measures, the material risk and the number of maintenance. Before constructing, the risk of construction should be reduced by BIM modeling and be carried out design optimization. In the construction process, the construction manager should try to avoid the workers fatigue work and ensure that the protective protection measures should be formulated. For the on-site construction machinery, we should develop a special applying procedures and regular maintenance checks in order to reduce the construction project safety risk.

Table 7. The Relative Weight Table for Each Node After Attribute Reduction.

| Node  | C1  | C2  | C3  | C4  | C5  | C6  | C8  | C9  | C11 | C14 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Relative weight | 0.28 | 0.17 | 0.14 | 0.25 | 0.15 | 0.18 | 0.27 | 0.28 | 0.06 | 0.21 |

Table 8. The Conditional Probability Calculation Table for Sub-Node (Part).

| C6 | C8 | C9 | C11 | C14 | P(B2 = I|C6, C8, C9, C11, C14), I = 1, 2, 3, 4, 5 |
|----|----|----|-----|-----|--------------------------------------------|
| I  | 1  | 1  | 1   | 1   | 0.960                                      |
| I  | 1  | 1  | 1   | 2   | 0.715                                      |
| I  | 1  | 1  | 1   | 3   | 0.626                                      |

Table 9. Probability calculation table of construction project safety level.

| Target layer | The state of variable | Probability of safety level | The level |
|--------------|-----------------------|-----------------------------|-----------|
| Construction project safety level | C1 = 3, C2 = 2, C3 = 3, C4 = 3, C6 = 4, C8 = 3, C9 = 3, C11 = 4, C14 = 3, C16 = 2, C17 = 2, C18 = 2, C20 = 3, C22 = 3, C23 = 4 | A = 1 | A = 2 | A = 3 | A = 4 | A = 5 | Calculate the level |
|              |                       | 0.08 | 0.143 | 0.614 | 0.127 | 0.036 | 3           |

**Sensitivity Analysis Results of Risk Factors in Knowledge Management**

Use the formula (7) to calculate the sensitivity of each root node; we can know that C1, C6, C14, C17, and C23 are the key factors that should be considered in construction safety. The construction risk (C1) is closely related to the construction scheme and the construction site environment.

Combined with the example of underground traffic engineering of Zhengzhou city comprehensive transportation hub, this paper analyzes the sensitive factors that affect the construction project safety and can provide the decision-making basis for the construction manager. The Bayesian network was used to predict its safety level. The probability of the safety level of the project in grade 3 is 0.614. Through the Bayesian network sensitivity analysis, we can know that the sensitivity factor of the construction project safety in the project is the construction risk, the continuous operation time, the protective measures, the material risk and the number of maintenance. Before constructing, the risk of construction should be reduced by BIM modeling and be carried out design optimization. In the construction process, the construction manager should try to avoid the workers fatigue work and ensure that the protective protection measures should be formulated. For the on-site construction machinery, we should develop a special applying procedures and regular maintenance checks in order to reduce the construction project safety risk.

The contributions of the paper include:

1. This paper studied strategic learning and knowledge management problems of technological innovation in construction project safety evaluation, and established a new safety evaluation model about the construction project. It consists of three modules: BIM module, data processing module, and decision support module.

The BIM module is used for construction simulation and collecting information about construction personnel, materials and mechanical equipments. The data processing module is used to extract and process data in the BIM module, identify the influence factors about construction safety. The decision support module is based on the results of Bayesian network to predict the construction project safety level and identify the sensitive factors.

2. This paper presented the hybrid methods of strategic learning and knowledge management of technological innovation in construction project safety evaluation. Compared to other evaluation methods, presented hybrid method is more intelligent in strategic learning and knowledge management of technological innovation.

In the hybrid method, a genetic algorithm is used to filter out the key factors. 23 influencing factors were identified from
the four aspects of construction conditions, personnel, materials, and mechanical equipment. Status of these continuous influencing factors was classified as more dangerous, dangerous, basic, safe, safe, and safer by expert interview. Through the optimization algorithm of genetic algorithm, 16 key factors of construction project safety were excavated from 23 influencing factors and the Bayesian network strategic learning model was established.

(3) Combined with the engineering examples, this paper analyzes the sensitive factors that affect the construction project safety and can provide the decision-making basis for the construction manager. Through sensitivity analysis of Bayesian network, we can know that the sensitivity factor of the construction project safety in the project is the construction risk, the continuous operation time, the protective measures, the material risk and the number of maintenance.

Presented detailed computational methods and steps in this paper can be used to improve the level of construction project safety effectively and help construction managers to take more effective control measures to prevent or reduce the occurrence of security incidents.

Conclusions

There are already many researchers to study the safety evaluation index system and evaluation methods, these references are mainly focused on the safety evaluation index system and some traditional evaluation methods, with no special concern about the complexity and variability of construction safety evaluation problems. Other issues included a lack of flexibility for adapting to new changes and intellectualization in strategic learning and knowledge management of technological innovation.

Based on the hybrid method, this paper established a new safety evaluation planning model of construction projects and presented the hybrid methods of strategic learning and knowledge management of technological innovation safety evaluation planning of construction projects. The flowcharts and veracity of presented methods are mainly limited by the accuracy of the field data, these field data and information may contain substantial inaccuracies due to the imperfection of data acquisition ways in the construction site. As a result, the study has certain limitations, is only suitable for some cases that the field data and information are correct. For this reason, the future direction of research is to study better data acquisition ways and detection means for construction projects.

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