

Research Article

Research on Reasoning concerning Emergency Measures for Industrial Project Scheduling Control

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Industry is an important pillar of the national economy, and industrial projects are the most complex and difficult to manage and control in the construction industry; thus, the resource scheduling control of industrial projects is one of the core issues for industrial construction projects. The performance rate of the contract time periods of previous industrial construction projects has been very low. In scheduling control based on case-based reasoning (CBR), the goal is to implement preventive measures by referring to existing scheduling control cases and control the scheduling of resources through reasoning on emergency measures to prevent scheduling control deviations. In this paper, the rough set approach is used to represent the case feature information in a case reasoning model for industrial project scheduling control, attribute reduction is used to determine the weights of the feature attributes in the rough set representation, and the similarity between cases is calculated for case retrieval. The accuracy of the rough-set-based similarity calculation is verified through matrix similarity calculations and a visual analysis of the all closeness centrality and weighted all degree centrality of the corresponding complex network; thus, similar cases of industrial project scheduling control are identified. To verify the applicability and effectiveness of the proposed methodology, a typical coal chemical general contract project case is carried out. The rough set comprehensive similarity results were 0.733, 0.621, 0.536, 0.614, 0.559, 0.950, 0.708, 0.546, 0.733, 0.664, 0.526, and 0.743, and the matrix similarity results were 0.417, 0.583, 0.417, 0.417, 0.417, 0.833, 0.417, 0.500, 0.417, 0.500, 0.333, and 0.500. The results showed that the case retrieval accuracy of traditional matrix similarity is not as high as the rough set comprehensive similarity, so X_6 is the most similar case to the target case Y . Case retrieval results indicate that the proposed methodology can provide a good similar case selection strategy with project managers, and the final required preventive measures for the target case can be found. Based on the identified similar cases, preventive measures for scheduling control are formulated to effectively prevent scheduling deviations of industrial projects.

1. Introduction

With the development of science and technology, industrial construction projects are becoming increasingly large and complex. Industrial construction projects are large in scale and involve large investments, complex process systems, dense layouts, open-air environments, automatic control, high construction technology requirements, many design companies, many suppliers, many construction companies, many collaborating companies, many work interface relations, and long construction periods, which make it difficult to control the resource scheduling problem. The performance rate of the contract time period is typically very low, and it is difficult to deliver projects within contractual

deadlines. Furthermore, for project management perspective, the construction industry is an empirical industry. Looking for similar past projects is crucial to project management; it can help project managers learn from past experiences and avoid past mistakes. The urgent problem of industrial project is scheduling control for success. Therefore, a new method of industrial project scheduling control based on reasoning concerning emergency measures is needed to ensure the contract time period performance of industrial projects.

The project scheduling problem was first proposed in the 1960s, and the research of Conway et al. [1] on the scheduling problem is usually regarded as the formal beginning of scheduling theory research. Subsequently,

Pritsker et al. [2] proposed a resource-constrained project scheduling problem in 1969. With further research, project scheduling theory has been expanded and enriched. Since the 1980s, with the development of computer technology and the rise of artificial intelligence algorithms, the focus of scheduling research has shifted from theory to applications, and scholars have begun to devote themselves to solving complex project scheduling problems. At present, great progress has been made in scheduling theory in terms of theoretical modeling, algorithm design, and experimental verification of the project scheduling problem [1, 2].

Pritsker et al. [2] first proposed the basic resource-constrained project scheduling problem (RCPSp) model. RCPSps represent an important class of combinatorial optimization problems in operations research. RCPSp research includes research on robust RCPSps, random RCPSps, fuzzy RCPSps, the critical chain method, and interfering project scheduling theory.

Aritigues et al. [3] took minimizing the absolute regret value under all scenarios as the goal when solving a robust RCPSp and adopted heuristic algorithms based on integer programming and scenario relaxation to solve for the earliest execution strategy for each activity. Wu et al. [4] proposed four cloud-theory-based simulated annealing (CSA) hyperheuristic algorithms incorporating seven low-level heuristics to solve a robust two-stage assembly flowshop problem with scenario-dependent processing times. Wu et al. [5] also proposed five heuristics, adopting combined two-scenario-based processing times to produce initial solutions and then improve each solution through pairwise interchange.

Case-based reasoning (CBR) is an important branch of artificial intelligence in which existing cases are used to solve new problems. Based on the existing cases, the degrees of similarity between different engineering cases are based on selected case feature attributes and their weight coefficients in order to identify similar cases that can be used to solve new problems. Rough set theory is a data analysis theory proposed by Polish mathematician Pawlak et al. [6] in 1982, which is considered a new mathematical tool for dealing with fuzzy and uncertain problems. A large amount of literature shows that the application of rough set in case-based reasoning is very correct. Previous researches on scheduling control mainly focused on resource optimization, which neither considered the reference significance of similar case measures to resource optimization nor applied case-based reasoning to scheduling control.

The existing literature review had made a lot of contributions for case retrieval of industrial projects, but there is no systematic and scientific method.

Since the beginning of the 21st century, case-based reasoning has undergone rapid development and has been applied in the contexts of construction safety accidents, risk management, emergency decision-making, network public opinion analysis, and so on. Yan and Li [7] applied ontology-supported case-based reasoning to emergency treatment for construction safety accidents. Tan et al. [8] proposed an emergency decision-making method based on case-based reasoning in a heterogeneous information

environment. In 2020, Xie et al. [9] proposed a case-based reasoning model for emergency network public opinion. Case-based reasoning models have been successfully applied for the emergency treatment of project management and project control. Zhai et al. [10] have taken advantage of advanced artificial intelligence techniques, in particular, the case-based reasoning approach, to estimate the reference evapotranspiration and therefore to calculate the amount of irrigation water in grape farming. For improving the current case-based reasoning approach, especially the solution revision part, this paper proposes a learning-based adaptation strategy by fully making use of the hidden information in the case base. Cao et al. [11] proposed a novel reasoning strategy based on an extensible P-Graph. In the proposed methodology, P-Graph is regarded as the basic method of superstructure optimization. In the absence of available solutions, a reasoning strategy is integrated into extensible P-Graph to obtain new feedstock scheduling solutions. Park et al. [12] proposed a case-based reasoning-(CBR-) based model for estimating the time when the first repair will be needed after the completion of construction, even in phases where maintenance-related information is scarce. CBR and fuzzy-analytic hierarchy process (AHP) were employed as research methodologies. The method will help in the preliminary estimation of the repair time of rebuilding components.

Industrial projects are the most complex and difficult to manage and control in the construction industry; accordingly, there are still deficiencies in theoretical applications with the goal of effectively using past construction experience and selecting appropriate construction cases to guide the scheduling control of proposed industrial projects. The research question is how to effectively carry out scheduling control through similar cases.

Therefore, the application of a case-based reasoning model for emergency treatment and deviation control in project scheduling can compensate for the deficiencies of project scheduling control theory. The similarity calculation and visual analysis of the all closeness centrality and weighted all degree centrality are the way to solve this problem.

2. Reasoning Model for Emergency Measures in Industrial Project Scheduling Control

The proposed reasoning model for emergency measures in industrial project scheduling control uses rough set theory to approach the selection of feature attributes for similarity measurement. The weights of feature attributes can be determined by using only the existing information, without assuming any preparatory information or additional data. The reasoning model combines rough set theory and case-based reasoning to solve the problems of feature information representation and case similarity calculation. The proposed reasoning model for emergency measures in industrial project scheduling control is divided into four steps: feature information representation, case retrieval, case recommendation, and case base maintenance. The proposed model is shown in Figure 1.

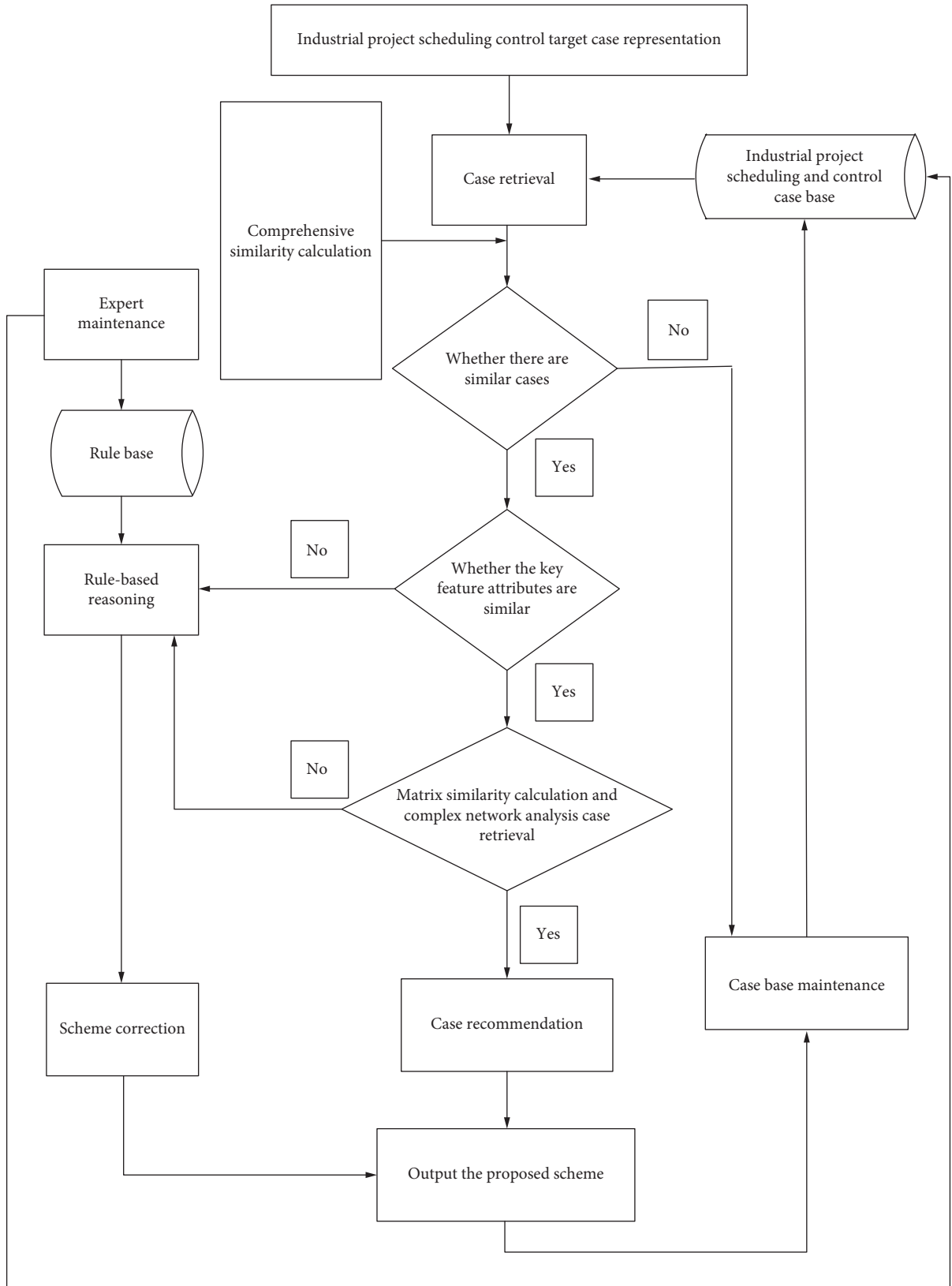


FIGURE 1: Reasoning model for emergency measures in industrial project scheduling control.

2.1. Feature Information Representation. With the incorporation of the basic concept of rough set theory, the feature information of a sample case can be expressed as an information system $S = (U, A, V, f)$. Here, $U = \{X_i, i = 1, 2, \dots, n\}$, where X_i is the i -th case in the historical case set for industrial project scheduling control; U is a nonempty finite set. $A = C \cup D$, where C is a limited set that represents the feature attribute information relevant to scheduling control, such as technical factors, procurement factors, construction factors, and management factors, whereas D is the decision attribute set, which indicates the preventive measures taken, such as resource allocation and scheme optimization; $C \cap D = \emptyset$. V is the set of attribute values. f is an information function of the form $U \times A \rightarrow V$. An industrial project scheduling control case X_j has m feature attributes, expressed as $X_j = \{C_1^j, C_2^j, \dots, C_m^j\}$, where C_m^j is the soft value of the m -th feature attribute of X_j . The set of sample cases can be expressed as $X = \{X_1, X_2, \dots, X_n\}$, where n represents the number of sample cases. The target case is represented by Y , where $Y = \{Y_1, Y_2, \dots, Y_m\}$.

2.2. Rough Set for Case Retrieval. For case retrieval, the target case is compared with the sample cases by calculating the similarities between cases to identify which sample cases are most similar to the target case, based on which the corresponding preventive measures can be output.

The comprehensive similarity between target case Y and sample case X_i is denoted by $\text{SIM}(Y, X_i)$. The calculation formula is as follows:

$$\text{SIM}(Y, X_i) = \sum_{j=1}^m w_j \text{SIM}(y_j, C_j^i), \quad (1)$$

where $\text{SIM}(y_j, C_j^i)$ is the similarity between y_j and C_j^i , which are the j -th feature attributes of target case Y and sample case X_i , respectively, and w_j is the weight of attribute j . The weights satisfy $\sum_{j=1}^m w_j = 1$. By comparing the comprehensive similarity scores, the most similar cases are selected for reference.

2.2.1. Determination of Attribute Weights. Through the concept of the rough degree in rough set theory as well as the dependence and importance of the attributes, redundant attributes are simplified, and useful feature information is extracted. Thus, rough set theory is used to assign weights to the case feature attributes.

If P is a subset of case attribute A , then the indistinguishability relation $\text{ind}(P)$ determined by P is

$$\text{ind}(P) = \{(x, y) \in U \times U \mid \forall a \in P, f(x, a) = f(y, a)\}. \quad (2)$$

For $X \in U$, the subset $\underline{P}X$ is called the lower approximation set of X , also known as the P positive domain of X , denoted by $\text{pos}_P(X)$.

$$\underline{P}X = \{x \in U \mid \text{ind}(P) \in X\}. \quad (3)$$

Therefore, the dependence of decision attribute D on the conditional attribute set (indicator) P is as follows:

$$\gamma_P(D) = \frac{|\text{pos}_P(D)|}{|U|}. \quad (4)$$

In accordance with the above, the importance degree σ_j of attribute C_j in the case group can be calculated via the following formula:

$$\sigma_j = \gamma_C(D) - \gamma_{C-C_j}(D) = \frac{\left\{ |\text{pos}_C(D)| - |\text{pos}_{C-C_j}(D)| \right\}}{|U|}. \quad (5)$$

The obtained attribute importance degree is normalized to obtain the weight w_j of attribute C_j :

$$w_j = \frac{\sigma_j}{\sum_{j=1}^m \sigma_j}. \quad (6)$$

2.2.2. Determination of Attribute Similarity. A record of industrial project scheduling control event information will contain various types of feature information; thus, it is necessary to determine a method of calculating the similarity in accordance with the way in which these feature attributes are expressed. In this model, the main feature expression types are numerical and symbolic.

- (1) Numerical features are represented by precise numerical values, such as resource allocation deviation and progress deviation. The Manhattan distance formula is used for the similarity calculation:

$$\text{SIM}(y_j, C_j^i) = 1 - \text{Dist}(y_j, C_j^i) = 1 - \frac{|y_j - C_j^i|}{\text{Max}C_j^i - \text{Min}C_j^i}. \quad (7)$$

- (2) The properties of a symbolic feature are represented by exact text. For the similarity calculation, when the attribute value of the target case is the same as that of the sample case for the considered attribute, the similarity is 1; otherwise, it is 0. The formula is as follows:

$$\text{SIM}(y_j, C_j^i) = \begin{cases} 1, & y_j = C_j^i, \\ 0, & y_j \neq C_j^i. \end{cases} \quad (8)$$

2.3. Matrix Similarity Calculation and Complex Network Visualization Analysis for Case Retrieval. For the comprehensive similarity $\text{SIM}(Y, X_i)$ between the target case Y and sample case X_i , the calculation formula is defined as follows:

$$\text{SIM}(Y, X_i) = \sum_{j=1}^m \text{SIM}(y_j, C_j^i). \quad (9)$$

The similarity between the target case Y and the sample case X_i is represented in the form of a matrix with elements

$SIM(y_j, C_j^i)$, where $SIM(y_j, C_j^i)$ represents the similarity between target case Y and sample case X_i in terms of their corresponding values y_j and C_j^i of the j -th feature attribute. The value of $SIM(y_j, C_j^i)$ can be 1 or 0, where 1 indicates that target case Y and sample case X_i are similar in terms of the corresponding feature information C_j^i and 0 indicates no similarity.

A complex network is also used to represent the similarity between target case Y and each sample case X_i , where $SIM(y_j, C_j^i) = 1$ means that the cases are connected by an edge and $SIM(y_j, C_j^i) = 0$ means that the cases are not connected; more generally, the value of $SIM(y_j, C_j^i)$ represents the weight of the complex network arc between the two cases.

The complex network centrality result is a vector that includes the centrality indices of each node and the entire network, calculated as the all closeness centrality and weighted all degree centrality of the target case Y . These centrality indices are used to identify similar cases based on visualizations of the corresponding complex networks.

$$\text{weighted all Degree centrality} = \sum_{j=1}^m SIM(Y, X_i), \quad (10)$$

$$\text{all closeness centrality} = \sum_{j=1}^m \frac{SIM(Y, X_i)}{m}.$$

2.4. Case Recommendation. After case retrieval and similarity calculation, when the similarity between a retrieved sample case and the target case is high, the preventive measures corresponding to the sample case are confirmed by experts as appropriate preventive measures for the target case; when the differences between the sample cases and the target case are very large, various aspects of the preventive measures corresponding to many sample cases may need to be combined to form a suitable scheme through repeated revision by experts. After assessment, the preventive measures for the target case are determined.

2.5. Case Base Maintenance. The process of case base maintenance includes adding and deleting cases and adjusting the structure of the case base.

Regarding the addition and deletion of cases, experts will evaluate whether a case should be reused after the final solution measures for the problem case have been output. Representative cases of each case type in the case library will be selected for continued storage, and redundant and out-of-date cases will be selectively deleted.

Regarding case base structure adjustment, in accordance with the features of the industrial project scheduling control event domain and newly updated domain information in combination with the particular situation that is the current target of reasoning, the structure of the case base is adjusted regularly to ensure its quality and retrieval efficiency.

3. Case Study

The chemical, petrochemical, thermoelectric, metallurgy, and other industrial projects all adopt the same design, procurement, and construction standards, while chemical projects are the most complex of the whole industrial projects, so a coal chemical general contract project is typical.

A coal chemical industry EPC project is taken here as an example because of the many scheduling control problems that arose during the project execution process, as follows:

- (1) In the detailed design stage, the process plant/unit frame structure had to be changed from the original concrete structure design scheme to a steel structure design scheme, which caused delays in the frame construction schedule.
- (2) In the intermediate stage of procurement, the key long-term reactor transportation process was affected by transportation difficulties delaying the arrival of equipment, leading to delays in the reactor equipment installation period.
- (3) In the later stage of construction, the allocated construction manpower was insufficient, which caused delays in the construction process.

To avoid the occurrence of dispatching control accidents, preventive measures in scheduling control are necessary in advance.

3.1. Feature Information Representation Based on the Rough Set Reasoning Model. The selection of feature attributes is based on the item attributes that affect scheduling control, such as contract period, contract amount, process technology, changes to contract scope, changes to major design scheme, delay of key equipment, change in construction scheme, allocation of direct construction labor, schedule impact of safety accidents, scope of total time deviation, and node type affected by schedule node deviation. These characteristics and attributes cover all aspects of project execution, including contract, technology, schedule, cost, quality, safety, design, and construction. The value assignment is based on the experience of previous industrial projects.

The feature information is represented by attributes C_j , with the value assignments shown in Table 1.

To facilitate calculation, 12 previous cases of industrial project scheduling control associated with preventive measures are selected from the case database, expressed as $X = \{X_1, X_2, \dots, X_{12}\}$. The feature attribute values for each sample case are expressed as $X_i = \{C_1^i, C_2^i, \dots, C_{12}^i\}$, and the target case is similarly represented by $Y = \{Y_1, Y_2, \dots, Y_{12}\}$. The case features are shown in Table 2.

3.2. Case Retrieval Based on the Rough Set Reasoning Model

3.2.1. Attribute Weight Calculation. According to the rough set calculation method, the weights are calculated as follows:

TABLE 1: Feature attributes and value assignments for industrial project scheduling control.

No.	Feature attribute	Value assignment
C_1	Contract period	≤ 20 months = 1; > 20 months = 2
C_2	Contract amount	≤ 1 billion = 1; > 1 billion = 2
C_3	Process technology	Same = 1, almost the same = 2, and similar = 3
C_4	Changes to contract scope	No change = 1; change = 2
C_5	Changes to major design scheme	No change = 1; change = 2
C_6	Delay of key equipment	≤ 1 month = 1; > 1 month = 2
C_7	Change in construction scheme	No change = 1, minor change = 2, large change = 3, and significant change = 4
C_8	Allocation of direct construction labor	≤ 1000 people = 1; > 1000 people = 2
C_9	Schedule impact of safety accidents	No safety accident = 1, minor safety accident = 2, major safety accident = 3, serious safety accident = 4, and severe safety accident = 5
C_{10}	Schedule impact of quality accidents	No quality accident = 1, minor quality accident = 2, major quality accident = 3, serious quality accident = 4, and severe quality accident = 5
C_{11}	Scope of total time deviation	≤ 1 month = 1; > 1 month = 2
C_{12}	Node type affected by schedule node deviation	Project-level node = 1, department-level node = 2, and company-level node = 3

TABLE 2: Feature information for sample industrial project scheduling control cases.

Case	C_1 (actual value)	C_2 (actual value)	C_3	C_4	C_5	C_6 (actual value)	C_7	C_8 (actual value)	C_9	C_{10}	C_{11} (actual value)	C_{12}
X_1	1 (18)	1 (10)	2	1	1	1 (1)	2	1 (600)	2	4	1 (1)	1
X_2	2 (22)	2 (28)	1	2	1	2 (5)	1	2 (2100)	3	2	1 (8)	2
X_3	2 (26)	2 (26)	3	1	2	2 (6)	2	2 (2000)	4	1	2 (6)	2
X_4	2 (24)	1 (10.5)	1	2	1	2 (4)	4	1 (700)	2	2	1 (1)	2
X_5	1 (12)	1 (5)	3	1	1	1 (1)	3	1 (350)	4	4	1 (0.5)	1
X_6	1 (18)	2 (18)	2	2	1	2 (2)	3	1 (1200)	1	2	1 (1)	2
X_7	1 (16)	1 (8)	2	1	2	2 (4)	3	1 (500)	2	3	2 (4)	3
X_8	2 (24)	2 (25)	1	1	2	2 (4)	2	2 (1800)	4	1	1 (0.5)	2
X_9	1 (10)	1 (7)	2	2	1	1 (1)	3	1 (400)	2	4	1 (0.5)	3
X_{10}	2 (28)	1 (10)	3	2	1	2 (3)	2	1 (700)	1	2	1 (1)	2
X_{11}	2 (25)	2 (22)	1	1	2	1 (1)	2	2 (1500)	5	1	2 (3)	2
X_{12}	1 (12)	1 (8)	2	2	1	2 (5)	4	1 (600)	2	2	1 (1)	3
Y	1 (18)	2 (17)	2	1	1	2 (2)	3	2 (1300)	1	2	1 (1)	2

$$\frac{U}{\text{ind}(C)} = \{X_1, X_2, X_3, \dots, X_{12}\}. \quad (11)$$

After the removal of attribute C_1 ,

$$\frac{U}{\text{ind}(C - C_1)} = \{\{X_7, X_7, X_{12}\}, X_1, X_2, X_3, X_5, X_6, X_8, \dots, X_{11}\}, \quad (12)$$

$$\text{pos}_{C-C_1}(D) = \{X_1, X_2, X_3, X_5, X_6, X_8, \dots, X_{11}\}.$$

Thus, the importance degree of C_1 ' is

$$\sigma_1 = \frac{|\text{pos}_C(D)| - |\text{pos}_{C-C_1}(D)|}{|U|} = \frac{12 - 9}{12} = 0.250. \quad (13)$$

After the removal of attribute C_2 ,

$$\frac{U}{\text{ind}(C - C_2)} = \{\{X_1, X_5\}, \{X_6, X_7, X_9, X_{12}\}, X_2, X_3, X_4, X_8, X_{10}, X_{11}\}, \quad (14)$$

$$\text{pos}_{C-C_2}(D) = \{X_2, X_3, X_4, X_8, X_{10}, X_{11}\}.$$

Thus, the importance degree of C_2 ' is

$$\sigma_2 = \frac{|\text{pos}_C(D)| - |\text{pos}_{C-C_2}(D)|}{|U|} = \frac{12 - 6}{12} = 0.500. \quad (15)$$

$$\frac{U}{\text{ind}(C - C_3)} = \{\{X_1, X_5, X_7, X_9, X_{12}\}, \{X_2, X_3, X_8\}, X_4, X_6, X_{10}, X_{11}\}, \quad (16)$$

$$\text{pos}_{C-C_3}(D) = \{X_4, X_6, X_{10}, X_{11}\}.$$

Thus, the importance degree of C_3 ' is

$$\sigma_3 = \frac{|\text{pos}_C(D)| - |\text{pos}_{C-C_3}(D)|}{|U|} = \frac{12 - 4}{12} = 0.667. \quad (17)$$

Similarly, it is calculated that

$$\begin{aligned} \sigma_4 &= 0.167, \\ \sigma_5 &= 0.250, \\ \sigma_6 &= 0.167, \\ \sigma_7 &= 0.167, \\ \sigma_8 &= 0.167, \\ \sigma_9 &= 0.167, \\ \sigma_{10} &= 0.167, \\ \sigma_{11} &= 0.250, \\ \sigma_{12} &= 0.333. \end{aligned} \quad (18)$$

Then, the weight of each attribute can be calculated as follows:

$$w_j = \frac{\sigma_j}{\sum_{j=1}^{12} \sigma_j}. \quad (19)$$

Thus, the following values are obtained:

$$\begin{aligned} w_1 &= 0.075, \\ w_2 &= 0.150, \\ w_3 &= 0.225, \\ w_4 &= 0.050, \\ w_5 &= 0.075, \\ w_6 &= 0.050, \\ w_7 &= 0.050, \\ w_8 &= 0.050, \\ w_9 &= 0.050, \\ w_{10} &= 0.050, \\ w_{11} &= 0.075, \\ w_{12} &= 0.100. \end{aligned} \quad (20)$$

After the removal of attribute C_3 ,

3.2.2. Attribute Similarity Calculation. Following the similarity calculation method presented in the previous section, the similarity of the feature attributes between the target case and each sample case is calculated, where $C_3, C_4, C_5, C_7, C_9, C_{10}$, and C_{12} are symbolic attributes and C_1, C_2, C_6, C_8 , and C_{11} are numerical attributes. The calculation results are shown in Table 3.

For example, the similarity between sample case X_1 and target case Y in terms of the contract period, C_1 , and the similarity between sample case X_2 and target case Y in terms of C_1 are calculated as follows:

$$\begin{aligned} \text{sim}(y_1, C_1^1) &= 1 - \frac{|y_1 - C_1^1|}{\text{Max}C_1^1 - \text{Min}C_1^1} = 1 - \frac{|1 - 1|}{28 - 10} = 1, \\ \text{sim}(y_1, C_1^2) &= 1 - \frac{|y_1 - C_1^2|}{\text{Max}C_1^2 - \text{Min}C_1^2} = 1 - \frac{|2 - 1|}{28 - 10} = 0.944. \end{aligned} \quad (21)$$

3.2.3. Case Similarity Calculation. Using formula (1), the comprehensive similarity between the target case and each sample case is calculated. The calculation results are shown in Table 4.

In accordance with the comprehensive similarity $\text{SIM}(Y, X_i)$ and the basic information of the cases, the most similar case is finally determined to be X_6 .

3.3. Case Retrieval Based on the Matrix Similarity Calculation and Complex Network Visualization Analysis. In the matrix similarity calculation, the comparative analysis matrix is used to record the information on various feature comparisons in a simple form. This matrix can then be used to find the correlation between the target case and a sample case once the information on each feature C_j for the target case Y and each sample case X_i has been determined and compared in a standard form.

For example, the similarity between target case Y and sample case X_i can be determined based on the feature information C_j for each node type (C_1 - C_{12} : contract period, contract amount, process technology, changes to contract

TABLE 3: Attribute-based case similarity.

Case	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
X_1	1.000	0.957	1	1	1	0.800	0	0.999	0	0	1.000	0
X_2	0.944	1.000	0	0	1	1.000	0	1.000	0	1	1.000	1
X_3	0.944	1.000	0	1	0	1.000	0	1.000	0	0	0.867	1
X_4	0.944	0.957	0	0	1	1.000	0	0.999	0	1	1.000	1
X_5	1.000	0.957	0	1	1	0.800	1	0.999	0	0	1.000	0
X_6	1.000	1.000	1	0	1	1.000	1	0.999	1	1	1.000	1
X_7	1.000	0.957	1	1	0	1.000	1	0.999	0	0	0.867	0
X_8	0.944	1.000	0	1	0	1.000	0	1.000	0	0	1.000	1
X_9	1.000	0.957	1	0	1	0.800	1	0.999	0	0	1.000	0
X_{10}	0.944	0.957	0	0	1	1.000	0	0.999	1	1	1.000	1
X_{11}	0.944	1.000	0	1	0	0.800	0	1.000	0	0	0.867	1
X_{12}	1.000	0.957	1	0	1	1.000	0	0.999	0	1	1.000	0

TABLE 4: Comprehensive case similarity.

Case	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
SIM (Y, X_i)	0.733	0.621	0.536	0.614	0.559	0.950	0.708	0.546	0.733	0.664	0.526	0.743

scope, changes to major design scheme, delay of key equipment, change in construction scheme, allocation of direct construction labor, schedule impact of safety accidents, schedule impact of quality accidents, scope of total time deviation, and node type affected by schedule node deviation).

The matrix similarity calculation allows similar cases to be grouped together, important parameter information (contract period, contract amount, process technology, etc.) to be extracted, and the case correlations to be described based on a complex network correlation diagram. The selected parameter information or feature information is not necessarily the general comparison standard but rather represents the relatively important parameter information or feature information for the target case as extracted and summarized from the general comparison standard. Then, the similarity matrix is constructed according to the parameter information, and the similarity matrix between cases is obtained. Finally, the correlation diagram between the target case and the sample cases is drawn based on the similarity matrix between cases and used to obtain the correlation degrees between cases (see Tables 5 and 6 for details).

According to the similarity matrix between cases, the similarity analysis diagram is drawn and analyzed by means of complex network theory. The all closeness centrality and weighted all degree centrality are calculated; see Figures 2 and 3, respectively, for details.

In Figures 2 and 3, the green node represents the target case, and the grey nodes represent sample cases.

In Figure 2, it is clearly seen that the all closeness centrality between the target case Y and sample case X_6 is 1. The weight of the edge between target case Y and sample case X_6 is 10, higher than that of the edge between the target case Y and any other sample case X_i , indicating that X_6 is closest to the target case.

Similarly, in Figure 3, it is clearly seen that the weighted all degree centrality values of the target case Y and

the sample case X_6 are 71 and 69, respectively. Sample case X_6 has a node weight of 69, larger than that of any of the other sample cases X_i . Therefore, the most similar case to the target case Y can be identified as case X_6 .

Such a case similarity evaluation can assist in determining the correlation degree between target case Y and sample case X_i . The similarity SIM(Y, X_i) between target case Y and sample case X_i is expressed as a percentage. When there is absolutely no similarity between the cases, this situation is expressed by a value of 0%; when the feature information is identical, indicating a perfect correlation between the cases, the similarity is 100%. In general, the similarity between the two cases will be between 0% and 100%. A value between 1% and 40% is considered to mean that the cases show no similarity, values of 41–60% represent cases with low similarity, values of 61–80% represent cases with high similarity, and values of 81% to 100% represent cases with very high similarity.

For example, in the above example, the similarity percentages based on the twelve feature information indicators between the target case Y and the sample cases X_i are as shown in Table 7 (reported to two decimal places).

The similarity percentages of sample cases $X_1, X_2, X_3, X_4, X_5, X_7, X_8, X_9, X_{10}, X_{11},$ and X_{12} are between 41% and 60%, which means that these are cases with low similarity to the target case. The similarity percentage of X_6 is 83.33%, between 81% and 100%, which means that it shows a very high similarity to the target case. Therefore, we choose X_6 as the most similar case to the target case Y .

3.4. The Applicability, Effectiveness, and Reliability for Case Retrieval Based on the Rough Set Reasoning Model. The above rough set case retrieval successfully calculated the similar case with the target case, indicating that rough set case retrieval is applicable to the reasoning concerning emergency measures for industrial project scheduling control.

TABLE 5: Similarity matrix.

Case comparison	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	C ₁₁	C ₁₂
(X ₁ , X ₂)	0	0	0	0	1	0	0	0	0	0	1	0
(X ₁ , X ₃)	0	0	0	1	0	0	1	0	0	0	0	0
(X ₁ , X ₄)	0	1	0	0	1	0	0	1	1	0	1	0
(X ₁ , X ₅)	1	1	0	1	1	1	0	1	0	1	1	1
(X ₁ , X ₆)	1	0	1	0	1	0	0	1	0	0	1	0
(X ₁ , X ₇)	1	1	1	1	0	0	0	1	1	0	0	0
(X ₁ , X ₈)	0	0	0	1	0	0	1	0	0	0	1	0
(X ₁ , X ₉)	1	1	1	0	1	1	0	1	1	1	1	0
(X ₁ , X ₁₀)	0	1	0	0	1	0	1	1	0	0	1	0
(X ₁ , X ₁₁)	0	0	0	1	0	1	1	0	0	0	0	0
(X ₁ , X ₁₂)	1	1	1	0	1	0	0	1	1	0	1	0
(X ₁ , Y)	1	0	1	1	1	0	0	0	0	0	1	0
(X ₂ , X ₃)	1	1	0	0	0	1	0	1	0	0	0	1
(X ₂ , X ₄)	1	0	1	1	1	1	0	0	0	1	1	1
(X ₂ , X ₅)	0	0	0	0	1	0	0	0	0	0	1	0
(X ₂ , X ₆)	0	1	0	1	1	1	0	0	0	1	1	1
(X ₂ , X ₇)	0	0	0	0	0	1	0	0	0	0	0	0
(X ₂ , X ₈)	1	1	1	0	0	1	0	1	0	0	1	1
(X ₂ , X ₉)	0	0	0	1	1	0	0	0	0	0	1	0
(X ₂ , X ₁₀)	1	0	0	1	1	1	0	0	0	1	1	1
(X ₂ , X ₁₁)	1	1	1	0	0	0	0	1	0	0	0	1
(X ₂ , X ₁₂)	0	0	0	1	1	1	0	0	0	1	1	0
(X ₂ , Y)	0	1	0	0	1	1	0	1	0	1	1	1
(X ₃ , X ₄)	1	0	0	0	0	1	0	0	0	0	0	1
(X ₃ , X ₅)	0	0	1	1	0	0	0	0	1	0	0	0
(X ₃ , X ₆)	0	1	0	0	0	1	0	0	0	0	0	1
(X ₃ , X ₇)	0	0	0	1	1	1	0	0	0	0	1	0
(X ₃ , X ₈)	1	1	0	1	1	1	1	1	1	1	0	1
(X ₃ , X ₉)	0	0	0	0	0	0	0	0	0	0	0	0
(X ₃ , X ₁₀)	1	0	1	0	0	1	1	0	0	0	0	1
(X ₃ , X ₁₁)	1	1	0	1	1	0	1	1	0	1	1	1
(X ₃ , X ₁₂)	0	0	0	0	0	1	0	0	0	0	0	0
(X ₃ , Y)	0	1	0	1	0	1	0	1	0	0	0	1
(X ₄ , X ₅)	0	1	0	0	1	0	0	1	0	0	1	0
(X ₄ , X ₆)	0	0	0	1	1	1	0	1	0	1	1	1
(X ₄ , X ₇)	0	1	0	0	0	1	0	1	1	0	0	0
(X ₄ , X ₈)	1	0	1	0	0	1	0	0	0	0	1	1
(X ₄ , X ₉)	0	1	0	1	1	0	0	1	1	0	1	0
(X ₄ , X ₁₀)	1	1	0	1	1	1	0	1	0	1	1	1
(X ₄ , X ₁₁)	1	0	1	0	0	0	0	0	0	0	0	1
(X ₄ , X ₁₂)	0	1	0	1	1	1	1	1	1	1	1	0
(X ₄ , Y)	0	0	0	0	1	1	0	0	0	1	1	1
(X ₅ , X ₆)	1	0	0	0	1	0	1	1	0	0	1	0
(X ₅ , X ₇)	1	1	0	1	0	0	1	1	0	0	0	0
(X ₅ , X ₈)	0	0	0	1	0	0	0	0	1	0	1	0
(X ₅ , X ₉)	1	1	0	0	1	1	1	1	0	1	1	0
(X ₅ , X ₁₀)	0	1	1	0	1	0	0	1	0	0	1	0
(X ₅ , X ₁₁)	0	0	0	1	0	1	0	0	0	0	0	0
(X ₅ , X ₁₂)	1	1	0	0	1	0	0	1	0	0	1	0
(X ₅ , Y)	1	0	0	1	1	0	1	0	0	0	1	0
(X ₆ , X ₇)	1	0	1	0	0	1	1	1	0	0	0	0
(X ₆ , X ₈)	0	1	0	0	0	1	0	0	0	0	1	1
(X ₆ , X ₉)	1	0	1	1	1	0	1	1	0	0	1	0
(X ₆ , X ₁₀)	0	0	0	1	1	1	0	1	1	1	1	1
(X ₆ , X ₁₁)	0	1	0	0	0	0	0	0	0	0	0	1
(X ₆ , X ₁₂)	1	0	1	1	1	1	0	1	0	1	1	0
(X ₆ , Y)	1	1	1	0	1	1	1	0	1	1	1	1
(X ₇ , X ₈)	0	0	0	1	1	1	0	0	0	0	0	0
(X ₇ , X ₉)	1	1	1	0	0	0	1	1	1	0	0	1
(X ₇ , X ₁₀)	0	1	0	0	0	1	0	1	0	0	0	0

TABLE 5: Continued.

Case comparison	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	C ₁₁	C ₁₂
(X ₇ , X ₁₁)	0	0	0	1	1	0	0	0	0	0	1	0
(X ₇ , X ₁₂)	1	1	1	0	0	1	0	1	1	0	0	1
(X ₇ , Y)	1	0	1	1	0	1	1	0	0	0	0	0
(X ₈ , X ₉)	0	0	0	0	0	0	0	0	0	0	1	0
(X ₈ , X ₁₀)	1	0	0	0	0	1	1	0	0	0	1	1
(X ₈ , X ₁₁)	1	1	1	1	1	0	1	1	0	1	0	1
(X ₈ , X ₁₂)	0	0	0	0	0	1	0	0	0	0	1	0
(X ₈ , Y)	0	1	0	1	0	1	0	1	0	0	1	1
(X ₉ , X ₁₀)	0	1	0	1	1	0	0	1	0	0	1	0
(X ₉ , X ₁₁)	0	0	0	0	0	1	0	0	0	0	0	0
(X ₉ , X ₁₂)	1	1	1	1	1	0	0	1	1	0	1	1
(X ₉ , Y)	1	0	1	0	1	0	1	0	0	0	1	0
(X ₁₀ , X ₁₁)	1	0	0	0	0	0	1	0	0	0	0	1
(X ₁₀ , X ₁₂)	0	1	0	1	1	1	0	1	0	1	1	0
(X ₁₀ , Y)	0	0	0	0	1	1	0	0	1	1	1	1
(X ₁₁ , X ₁₂)	0	0	0	0	0	0	0	0	0	0	0	0
(X ₁₁ , Y)	0	1	0	1	0	0	0	1	0	0	0	1
(X ₁₂ , Y)	1	0	1	0	1	1	0	0	0	1	1	0

TABLE 6: Similarity matrix between cases.

Similarity	Case number													Label
	1	2	3	4	5	6	7	8	9	10	11	12	13	
1	0	2	2	5	9	5	6	3	9	5	3	7	5	X ₁
2	2	0	5	8	2	7	1	7	3	7	5	5	7	X ₂
3	2	5	0	3	3	3	4	10	0	5	9	1	5	X ₃
4	5	8	3	0	4	7	4	5	6	9	3	9	5	X ₄
5	9	2	3	4	0	5	5	3	8	5	2	5	5	X ₅
6	5	7	3	7	5	0	5	4	7	8	2	8	10	X ₆
7	6	1	4	4	5	5	0	3	7	3	3	7	5	X ₇
8	3	7	10	5	3	4	3	0	1	5	9	2	6	X ₈
9	9	3	0	6	8	7	7	1	0	5	1	9	5	X ₉
10	5	7	5	9	5	8	3	5	5	0	3	7	6	X ₁₀
11	3	5	9	3	2	2	3	9	1	3	0	0	4	X ₁₁
12	7	5	1	9	5	8	7	2	9	7	0	0	6	X ₁₂
13	5	7	5	5	5	10	5	6	5	6	4	6	0	Y

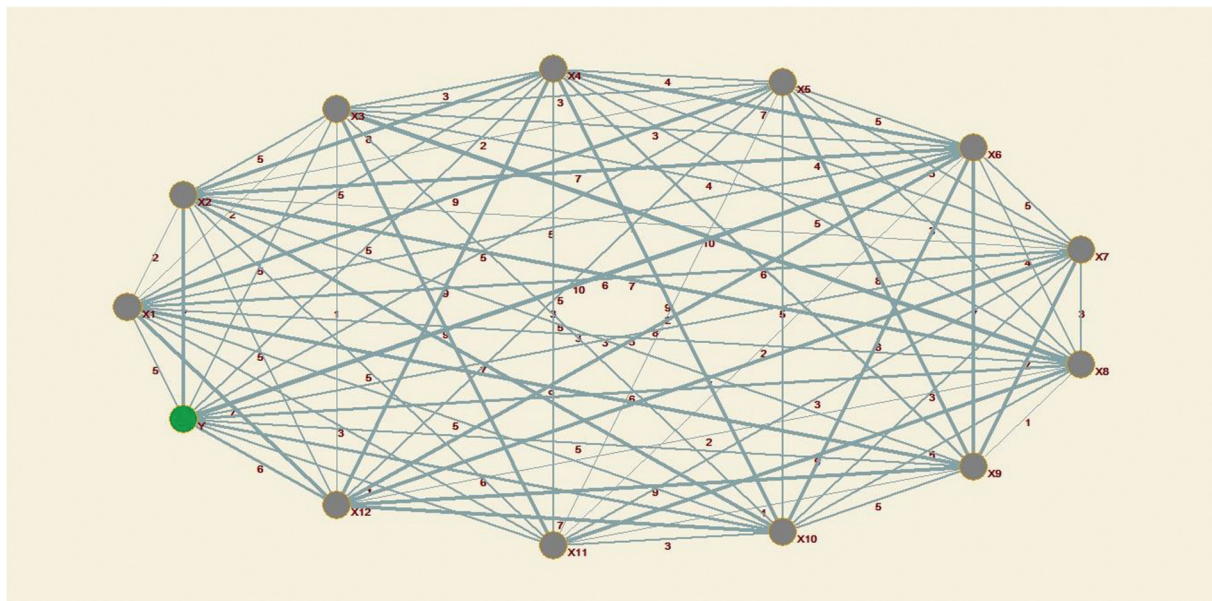


FIGURE 2: Case similarity analysis based on complex network, represented by the all closeness centrality.

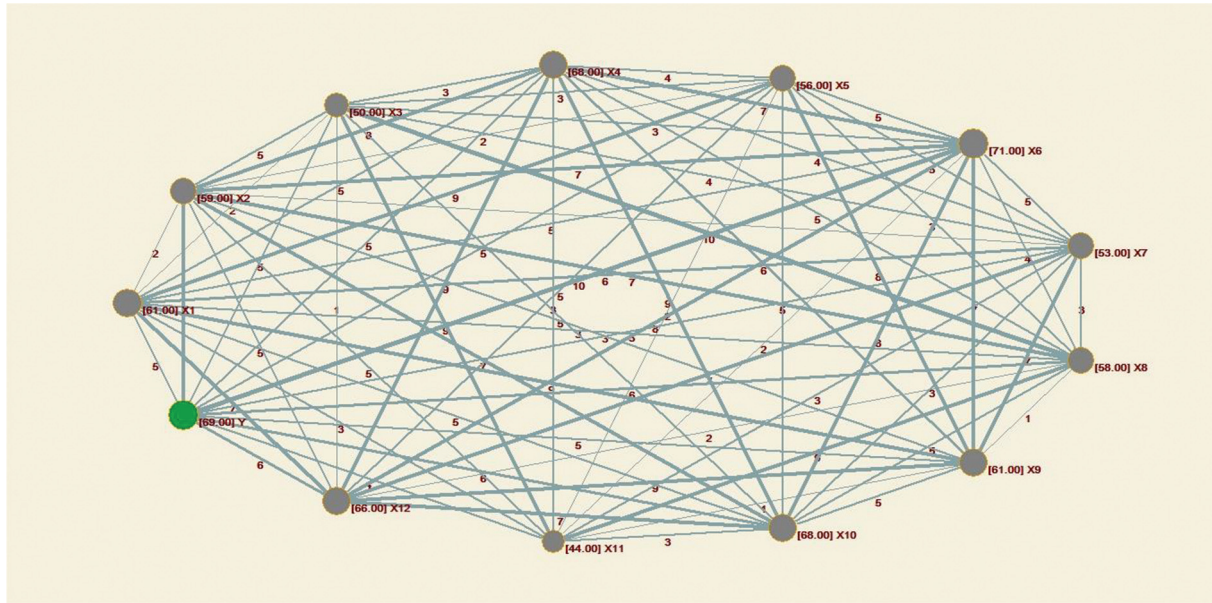


FIGURE 3: Case similarity analysis based on complex network, represented by the weighted all degree centrality.

TABLE 7: Case similarity evaluation.

(X_1, Y) (%)	(X_2, Y) (%)	(X_3, Y) (%)	(X_4, Y) (%)	(X_5, Y) (%)	(X_6, Y) (%)	(X_7, Y) (%)	(X_8, Y) (%)	(X_9, Y) (%)	(X_{10}, Y) (%)	(X_{11}, Y) (%)	(X_{12}, Y) (%)
41.67	58.33	41.67	41.67	41.67	83.33	41.67	50.00	41.67	50.00	33.33	50.00

TABLE 8: Comparative study of rough set case retrieval and matrix case retrieval.

Cases	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Rough set comprehensive similarity $SIM(Y, X_i)$	0.733	0.621	0.536	0.614	0.559	0.950	0.708	0.546	0.733	0.664	0.526	0.743
Matrix similarity $SIM(Y, X_i)$	0.417	0.583	0.417	0.417	0.417	0.833	0.417	0.500	0.417	0.500	0.333	0.500

After comparing the similarity between rough set case retrieval and matrix case retrieval, it can be seen that, for 12 similar cases, matrix case retrieval calculated 5 kinds of similarity, the highest similarity is 0.833, while rough set case retrieval calculated 11 kinds of similarity, the highest similarity is 0.950. The calculation results are shown in Table 8. The results showed that the case retrieval accuracy of traditional matrix similarity is not as high as the rough set comprehensive similarity, so the effectiveness and reliability of rough set case retrieval are superior to the traditional case retrieval method.

3.5. Formulation of Preventive Measures for the Target Case. According to the results of the above case similarity calculation, the preventive schemes associated with sample case X_6 are also the proposed scheduling control schemes for target case Y . The recommended schemes are listed in Table 9.

By comparing the basic engineering situations between sample case X_6 and target case Y , we can see that the basic situation is roughly similar for both cases. Therefore, the proposed solutions for X_6 can be directly output as the

accident prevention measures for target case Y after some slight modifications, as shown in Table 10.

In the preliminary planning stage of such a coal chemical industry EPC project, the project management personnel should review the design, procurement, and construction scheme; then, follow-up on the case execution record should be completed during project development in accordance with the evaluation results of the project team and department experts; and finally, the new case should be stored in the case database to prepare for matching with similar cases in the future for the recommendation of solutions. Hence, similar projects can adopt the same scheme to prevent the occurrence of scheduling control deviations.

4. Discussion

This study contributes to the literature by exploratively examining the similar projects of scheduling control. There has been limited research into the scheduling control. How to find similar cases of scheduling control through intelligent computing is a direction of scheduling control, and how to establish an effective scheduling similar case base is another direction of scheduling control.

TABLE 9: Proposed scheduling control schemes and measures.

Scheme	Measure
Strengthening the principle of the design scheme	Adoption of a steel structure design scheme for the process frame
Strengthening the procurement planning for key long-term equipment	Specification of the time of arrival in the technical agreement portion of the procurement contract
Strengthening the planning of the construction scheme	Increasing the direct construction labor resources (specifically, increasing the numbers of pipefitters and welders)

TABLE 10: Preventive measures.

Scheme	Measure
Strengthening the principle of the design scheme	In the early detailed design stage, the design basis of the basic design should be confirmed, and the process frame should be designed with a steel structure.
Strengthening the procurement planning for key long-term equipment	In the procurement planning stage, the reactor should be designated as key long-term equipment, and a detailed reactor procurement plan should be developed. Corresponding nodes such as contract signing and arrival time should be specified in the technical agreement portion of the reactor procurement contract.
Strengthening the planning of the construction scheme	In the pipeline installation stage, the pipeline installation scheme should be planned in advance, and it should be ensured that the allocation of the direct labor force for construction is consistent with the construction effort. Accordingly, a manpower plan should be prepared for the key work to be performed by pipefitters and welders.

5. Conclusions

Through case study, the preventive schemes associated with sample case X_c are also the proposed scheduling control schemes for target case Y , and the proposed solutions for X_c can be directly output as the accident prevention measures for target case Y for the target case scheduling control.

Deviations in project scheduling control will cause delays in project duration and increases in cost. It is necessary and significant for the planning and execution of new projects to prevent scheduling control deviations by referring to the scheduling control cases of previous projects. In this paper, rough set theory is introduced into the CBR method; the case feature information is represented in the form of an information table, and the weights of the feature attributes are effectively determined in accordance with historical data. The CBR model can be used to solve the problem of project scheduling control case similarity calculation while effectively avoiding dependence on subjective experience, improving the validity and credibility of the case retrieval results, and providing a new direction and basis for the formulation of preventive measures for early warning and feedback tracking feedback in industrial project scheduling control. The application of the rough-set-based similarity calculation and the complex network to scheduling control is demonstrated by a case study.

This paper has obtained the following conclusions:

- (1) Rough set theory is incorporated into CBR. The feature attribute weights are determined by using attribute reduction to calculate the similarity between cases, and analyses based on matrix similarity calculation and the visualization of complex network density degree centrality and degree weights are added to review the rough set calculation in order to ensure accurate case similarity calculation and case retrieval.

- (2) The proposed reasoning model for emergency measures can be applied in the scheduling control of industrial projects, which is an excellent way to provide effective case support and decision data for the improvement of early warning and feedback tracking theory in project scheduling control.
- (3) A knowledge base for reasoning concerning emergency measures for industrial project scheduling control has a certain application value for the subsequent execution of industrial projects and future scheduling control cases. In view of the importance of early warning and feedback tracking in industrial project scheduling control, further research is warranted.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Table S1: feature information for sample industrial project scheduling control cases. Table S2: matrix similarity for sample industrial project scheduling control cases. (*Supplementary Materials*)

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