



## Safety Risk Assessment During the Construction Period of Onshore Wind Power Projects

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**SUMMARY:** *In order to investigate the safety risk factors that exist in the construction phase of onshore wind power projects and their specific effects and impacts on the overall construction safety management system of wind power projects, this study uses the PDCA (covering planning, execution, inspection, and action) management concept as theoretical support, and integrates the Decision Testing and Evaluation Laboratory (DEMATEL) method and Analysis Network Process (ANP) technology to comprehensively evaluate the construction safety status of onshore wind power projects. In specific operations, relevant influencing factors are screened and determined from four key areas: potential risks in personal safety, risks in equipment safety, risks that may arise in environmental safety, and risks in managing safety processes. A scientific and reasonable evaluation index system is then constructed. Through the DEMATEL method, the comprehensive impact matrix between indicators is calculated, the indicator network structure is organized through the ANP method, and a qualitative evaluation of the risks is conducted. Empirical research has shown that the research method used in this article can effectively evaluate the safety conditions during the construction process of onshore wind power projects. This method has the ability to accurately identify key indicators that have a significant impact on construction process safety, providing valuable reference for relevant regulatory departments to make decisions and implement supervision.*

**KEYWORDS:** *DEMATEL-ANP; Risk Evaluation; Wind Power Engineering*

## 1 Introduction

In recent years, new energy technologies have become a cornerstone of the new electric power systems, with significant development in new energies such as wind, solar, and hydrogen being profoundly meaningful for sustainable development [1]. The complete lifecycle of wind power projects can be divided into four stages, namely the design and planning stage in the early stage of the project, the construction stage in the middle stage, the operation and maintenance management stage in the later stage, and the final shutdown and disposal stage. The construction phase is generally considered the stage with the highest safety risks, including the risks involved in transportation, construction, and completion, mainly focused on the second stage of the wind farm's lifecycle [2]. Due to the complex construction technologies of wind power projects, as well as the constant emergence of new technologies, materials, processes, and equipment, any issue with people, materials, environment, or management in the safety management system can lead to accidents, with potential risks present in everything.

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Research on risk identification in onshore wind farms mainly includes the classification study of occupational safety risk levels; the identification of project, market, and management risks in wind power engineering using SWOT and McKinsey matrix [3]; or the ranking study of risks in wind farms in specific areas, such as cold regions [4]; Conduct a special exploration of structural equation for risk factors (including policy orientation, economic situation, technical conditions, and construction environment) in the design phase of wind power projects, and establish a scientific and comprehensive risk index evaluation system applicable to the design phase of wind power projects [5]. In the field of risk research, the main research methods used include qualitative analysis methods and quantitative analysis methods. However, there is a prominent problem at present, which is the lack of research on relevant knowledge and practical applicability. In this context, many practitioners still overly rely on qualitative risk management methods based on past experience to conduct risk assessment and response in actual risk management work [6]. Based on this background, Emad Mohamed et al. innovatively proposed a simulation model based on Monte Carlo simulation (MCS) critical path method in the process of quantitative analysis and research on wind power engineering risks. The main function of this model is to accurately quantify the specific impact of construction project risks on project costs and time schedules. In practical applications, they used the internally developed simulation engine Symphony Project. NE to conduct detailed simulations of the construction process of wind farm projects and the risk factors that may affect project costs and time [7]. Moreover, the research team has proposed a novel risk assessment modeling method for wind farm projects. This method combines fuzzy set theory with MCS enhanced multivariate modeling techniques, aiming to model and analyze the inherent dependency relationship between risk factors and cost and schedule impacts in MCS based risk assessment models, and further explore the correlation between cost risk and schedule risk [8, 9].

Risk evaluation methods for onshore wind projects often use Analytic Hierarchy Process (AHP), ANP, TOPSIS, etc. In relevant research, reference [10] used the Analytic Hierarchy Process (AHP) to assess seven types of risks that exist throughout the entire lifecycle of distributed wind farms. The research results show that the sustainable development and profitability of distributed wind power systems will be significantly affected by changes in electricity pricing policies. In addition, to effectively address challenges such as incomplete information, data fluctuations, and subjective judgments, two evaluation models were constructed with reference to reference [11]. One is an improved network analysis method (ANP) model based on interval numbers; Secondly, it is a fuzzy comprehensive evaluation model based on trapezoidal membership degree. These two models are mainly applied to the post evaluation of onshore wind farms. Reference [12] has developed a risk assessment model that fits the characteristics of the two stages of wind turbine construction and operation. The research team invited professionals in the field of occupational health and safety to conduct research with Türkiye onshore wind turbine as a specific case, scientifically weighted the risk parameters, and comprehensively weighed and prioritized various hazard factors.

It is evident that the problem with safety risk identification is the reduction of risks before all risks are identified, merely identifying where risks may occur without specifically identifying the impact of each risk on the project. Some studies combine risk identification and evaluation, typically using various methods, with the single-method approach also posing a problem. This article, in the risk identification phase, based on expert opinions and relevant information to identify potential safety risks during the construction period of current wind power projects and supplements the risks with relevant data. For various security risks that have been accurately identified, this study combines the Decision Testing and Evaluation Laboratory (DEMATEL) method with the Analytic Network Program (ANP) method to comprehensively and systematically evaluate the weights of risk indicators. Through a series of rigorous analysis

and calculations, the main safety risk indicators that dominate the construction process of wind power projects are ultimately identified.

The core objective of this study is to enhance the awareness of safety risk management among relevant personnel in onshore wind power engineering management, and to improve their practical ability to carry out safety risk management. Whether wind power can achieve sustainable development depends not only on continuous technological innovation but also on whether wind power companies have comprehensively conducted overall project safety management. Based on the analysis results of accident causes during the wind power engineering construction period [13], this article integrates the PDCA concept for construction period safety risk issues, making decision-making scientific, assessing risks, and specifically reducing the probability of engineering accidents. It aims to improve the safety risk management awareness and ability of the government, owners, designers, and construction units, achieve the purpose of controlling risks, reducing personnel and property losses, and establish a safety science management concept.

Therefore, this article mainly explores the following three issues:

1. What are the potential safety hazards hidden during the construction phase of onshore wind power projects?
2. How to use DEMATEL and ANP to construct the network relationship of various evaluation indicators?
3. Which indicators have the greatest impact on the safety level of onshore wind power engineering management?

This article employs DEMATEL and ANP to construct a comprehensive evaluation system for safety risks during the PDCA cycle of wind power engineering construction. From the new perspective of the "multi-energy complementary, new energy main" new power system, it explores a new model of safety management in wind power engineering that combines safety system engineering theory with PDCA cycle management and establishes a comprehensive evaluation system for safety risks in wind power engineering.

## 2 Literature review

The initial concept of the PDCA cycle originated from an American statistician named Walter A. However, the key figure who systematically expanded and vigorously promoted this method was William Edward Deming. He further improved and optimized the method in the 1950s. Today, the PDCA cycle has become one of the most famous and widely used management methods in the world. This cycle mainly covers four stages and is subdivided into eight steps, which provide detailed explanations of the specific operational content of each stage. The four stages are planned, executed, checked, and acted upon in sequence.

In this study, the PDCA management concept is adopted overall to complete the research. The identification and evaluation of safety risks in wind power engineering are a repetitive process consistent with the PDCA concept.

The PDCA cycle, in its initial stage, is a tool built around product quality control. Its core architecture consists of four closely related stages: planning, execution, inspection, and action. With the continuous development of practice and theory, it has gradually evolved into a method that plays an important role in the field of project management, aiming to achieve process optimization. More importantly, it successfully introduces the advanced concept of continuous process improvement into enterprise security management work [14, 15]. The core of this method focuses on promoting continuous learning processes and facilitating knowledge creation activities. The PDCA cycle often starts from the details, first examining the potential

impact of relevant measures on the system, and then gradually advancing, ultimately achieving larger scale and more targeted specific improvement measures.

In recent years, scholars both domestically and abroad have applied the PDCA cycle to aspects such as improving product quality, reducing product losses, constructing energy management systems for small and medium-sized enterprises, reducing electronic component defect rates, and improving overall equipment efficiency for automotive component manufacturers [16, 17]. Currently, scholars have applied PDCA-related concepts in offshore wind power management, such as combining periodic operation plans and enterprise information-assisted platforms with PDCA for visual management in offshore wind turbine construction. In relevant research, reference [18] innovatively constructed a new fully participatory flat closed loop (FPFCL) safety management model that meets the management needs of offshore wind power projects. This method is based on the PDCA management concept as its theoretical source and construction foundation. Some studies suggest that the PDCA model can be integrated into safety management, providing guidance for reducing the incidence of safety accidents and improving safety management efficiency [19, 20].

DEMATEL is a versatile comprehensive management method effective in solving various complex problems including industrial safety, marketing, urban transportation planning, and environmental assessment [21]. It combines multiple factors and establishes a relationship matrix based on the interrelations between these factors to better assess their mutual influences. ANP, proposed by Professor T.L. Compared to AHP, ANP considers the interactions among elements in complex dynamic systems more comprehensively. The DEMATEL-ANP fusion algorithm clarifies the interrelationships between indicators, facilitating more accurate determination of weights for safety control measure selection [22].

In recent years, scholars have applied the DEMATEL-ANP method in various fields for risk identification and assessment. For instance, Reference [23] developed a risk assessment model for photovoltaic integrated residential projects, identifying and analyzing risks and proposing a risk assessment indicator system. Additionally, Reference [24] utilized an improved Pythagorean fuzzy number DEMATEL-ANP with K-Means clustering algorithm to analyze the interaction, relationship, and relative importance among obstacles to distributed wind power development.

In summary, there is limited literature demonstrating the integration of the PDCA concept into safety management during wind power engineering construction and research on analyzing safety risks. Therefore, this study adopts the PDCA concept to integrate safety risk identification and assessment in onshore wind power engineering and employs the Delphi method and DEMATEL-ANP method to fill the research gap in safety risk analysis during onshore wind power engineering construction.

## 3 Research Methodology

### 3.1 Integration of PDCA Concept

Plan (P):

1. By relying on authoritative channels to obtain accident analysis data, and through systematic sorting and in-depth analysis, the initial risk indicators are accurately determined.
2. Risk indicators are categorized and a preliminary analysis according to expert opinions.
3. We can consider using the DEMATEL-ANP combination method to conduct in-depth analysis and determination of the weights of risk indicators.
4. A process for analyzing risk indicator weights is outlined, detailing the approach and anticipating the results.

Do (D):

5. Carry out analysis and planning work on the weight of risk indicators, which comprehensively covers the four major risk categories of personnel, equipment, environment, and management. Through this step, a complete set of safety risk indicators for wind power project construction has been successfully established.

Check (C):

6. The completeness and analysis targets of the wind power project construction safety risk indicator system are reviewed to ensure they meet the desired objectives.

Act (A):

7. The analysis results of the wind power project construction safety risk indicator system are summarized.

8. Issues that have not been analyzed are identified for future consideration.

## 3.2 Dematal-ANP Method

### 3.2.1 Dematal Method

Dematal is a multifunctional comprehensive management approach that can effectively address a variety of complex issues. Its fundamental strategy involves constructing a direct impact matrix through the logical relationships among various factors within the system, calculating the degree of influence each factor has on others as well as the degree to which it is influenced, thereby determining the causality and centrality of each factor, and graphically representing these findings. Centrality (Prominence) indicates the importance of a risk factor. The more a risk factor is susceptible to influence by other factors and the more it can affect other risk factors, the higher its centrality, warranting greater attention. When the relation is greater than 0, it signifies that the risk factor primarily impacts other risk factors; when it is less than 0, it indicates that the risk factor is mainly influenced by others.

Firstly, the operation of Dematal can be summarized in the following steps:

Step One: Carry out identification of influencing factors and evaluation of relationships: Conduct in-depth analysis and clear definitions of various elements within the system, and use diversified methods such as expert discussions and questionnaire surveys to accurately determine the relationship between each pair of elements. In the initial stage, the relationship between elements is characterized by five levels of influence. Afterwards, experts conducted pairwise comparative analysis of the elements based on their interrelationships and impact. If there are  $n$  elements in the system, the results obtained through comparison will form a matrix.

Step Two: Obtain the Direct-relation Matrix (D): The matrix element  $(i, j)$  represents the degree of influence of element  $i$  on  $j$ , and its diagonal elements are set to 0.

$$D^k = \begin{bmatrix} 0 & d_{12}^k & \cdots & d_{1n}^k \\ d_{21}^k & 0 & \cdots & d_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1}^k & d_{n2}^k & \cdots & 0 \end{bmatrix} \quad (1)$$

Step Three: Obtain the normalized direct impact matrix X:

$$X = \frac{1}{\max(\max_{1 \leq i < j \leq n} \sum_{j=1}^n d_{ij}^k, \max_{1 \leq j < i \leq n} \sum_{i=1}^n d_{ij}^k)} \times \begin{bmatrix} 0 & d_{12}^k & \cdots & d_{1n}^k \\ d_{21}^k & 0 & \cdots & d_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1}^k & d_{n2}^k & \cdots & 0 \end{bmatrix} \quad (2)$$

Step Four: Obtain the comprehensive impact matrix T:

$$\sum_{h=1}^{\infty} X^k = X \times (X + X^2 \dots + X^{h-1}) = X \times (1 - X)^{-1} \times (1 - X^h)$$

$$T = X(I - X)^{-1} \quad (3)$$

where, I is the identity matrix. Based on the empirical fact that "indirect influence decreases as the causal chain lengthens," when h approaches infinity, it should approach 0, thus the expression for T can be written as Equation(4)

$$T = \begin{bmatrix} t_{11} & \dots & t_{1j} & \dots & t_{1n} \\ \vdots & & \vdots & & \vdots \\ t_{i1} & \dots & t_{ij} & \dots & t_{in} \\ \vdots & & \vdots & & \vdots \\ t_{n1} & \dots & t_{nj} & \dots & t_{nn} \end{bmatrix} \quad (4)$$

Step Five: Draw the influence relation diagram. Assuming that symbols R and C are used to represent the total sum values in the row direction and column direction, respectively:

$$R = [R_i]_{n \times 1} = \left( \sum_{j=1}^n t_{ij} \right)_{n \times 1} \quad (5)$$

$$C = [C_j]_{n \times 1} = \left( \sum_{i=1}^n t_{ij} \right)_{n \times 1} \quad (6)$$

Assume that  $R_i$  represents the total sum of the i-th row in the comprehensive impact matrix T, then it indicates the total degree of direct or indirect relational influence of that element on other elements;  $C_j$  represents the total sum of the j-th column in the comprehensive impact matrix T, indicating the total degree of direct or indirect relational influence of other elements on that element.

$$F = R + C \quad (7)$$

When  $i = j$ , that is,  $F_i = R_i + C_i$  represents the total degree to which the i-th element influences and is influenced, that is, the centrality of element i within the group of issues.

$$E = R - C \quad (8)$$

If  $E_i = R_i - C_i$  is a positive value, the i-th element influences other elements, belonging to the influencer category. If  $E_i = R_i - C_i$  is a negative value, the i-th element is influenced by other elements, belonging to the influenced category.

From the above, it can be seen that the visual relation diagram is determined by the values of (F, E), and according to the meanings represented by F and E, visual information can be obtained as a basis for scientific decision-making.

### 3.2.2 Dematal-ANP Method

Steps of the Dematal-ANP Method

Step One: Determination of Network Structure Model

Since indicators with smaller degrees of association also have smaller feedback levels, they do not significantly affect the calculation of relative weights. Therefore, we can remove connections with smaller degrees of association by setting a threshold value (Threshold). Based

on the operational steps of DEMATEL mentioned earlier, and using the comprehensive impact relation matrix T, elements below the threshold are excluded to draw the system network architecture. Introducing a threshold  $\lambda(\lambda \in [0,1])$ . The method for determining the threshold is based on statistical distribution, that is, the threshold:

$$\lambda = \bar{x} + \sigma \tag{9}$$

where  $\bar{x}$  is the average value of the elements in matrix T, and  $\sigma$  is the standard deviation.

Based on the data from the relation matrix to determine the network structure and objectives for project safety risk assessment, an ANP structural model is established. The goal is identified as project safety risk, determining the risk factors included in each risk category and the interrelationships between assessment indicators. Within the yaanp software, a network hierarchy diagram is constructed and drawn, where “1” indicates an influence relationship, and “0” indicates no influence relationship.

**Step Two: Determination of the Weight of Risk Influencing Factors**

(1) Questionnaire Design and Survey. To ensure the objectivity and feasibility of the results, experts in the field of risk assessment for wind power engineering construction projects are invited to score the assessment indicators. The relative weights of the indicators in the ANP model are determined by the results of pairwise comparisons of each level of elements. Pairwise comparisons represent their relative importance to each indicator. The measurement scale is Saaty's 1~9 scale. Table 1 shows the Saaty Comparison Scale.

*Table 1: Saaty's Comparison Scale*

Importance Level	Definition	Explanation
1	Equally Important	These two elements play an equal role and contribute equally to achieving the goal.
3	Slightly More Important	In the process of consideration, experience and judgment show a certain degree of bias, focusing more on one factor rather than the other.
5	Moderately More Important	In practice and subjective considerations, the tendency is more pronounced towards one factor rather than another.
7	Much More Important	In practical situations and subjective analysis, its tendency is significantly focused on one factor, while relatively ignoring another factor.
9	Absolutely More Important	In the process of practical operation and subjective evaluation, experience and judgment show a significant one-sided trend, unreservedly leaning towards one factor, while the support for another factor is minimal.
2, 4, 6, 8	Intermediate Values	Values between the other levels of importance to provide more nuanced assessments.

(2) Constructing the ANP's original supermatrix (unweighted supermatrix).

Assuming the overall goal of the control layer is P, with control criteria respectively being:  $B_1, B_2, \dots, B_n$ , comprising n sets of elements, and the network layer consists of element sets  $C_1, C_2, \dots, C_n$ , with the i-th element set containing  $m_i$  elements:  $d_1, d_2, \dots, d_{m_i}$ .

If the j-th element set has an influence on the i-th element set, then the normalized priority vector of all elements in the i-th element set,  $d_1, d_2, \dots, d_{m_i}$ , towards some element in the j-th

element set is denoted as  $d_{jt}$ , Hence, the influence matrix of all elements in the  $i$ -th element set on the  $j$ -th element set is  $W_{im}^{jt}$ :

$$W_{ij} = \begin{bmatrix} W_{i1}^{j1} & W_{i1}^{j2} & \cdots & W_{i1}^{jn} \\ W_{i2}^{j1} & W_{i2}^{j2} & \cdots & W_{i2}^{jn} \\ \vdots & \vdots & \cdots & \vdots \\ W_{in}^{j1} & W_{in}^{j2} & \cdots & W_{in}^{jn} \end{bmatrix} \quad (10)$$

The column vectors in this matrix represent the degree of influence of all elements in  $C_i$  on each element in  $C_j$ . If there is no influence from  $C_i$  to  $C_j$ , then  $W_{ij}=0$ .

The initial supermatrix composed of all element sets is  $W_0$ :

$$W_0 = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix} \quad (11)$$

The supermatrix is a block matrix, where each block represents the interrelationships between two sets of elements within the entire system. Each sub-block  $W_{ij}$  signifies the influence of elements in set  $i$  on elements in set  $j$ . When there is no influence between element sets, the sub-block  $W_{ij}$  is 0. By comparing the importance of each element set under the criteria layer, matrix  $A$  is obtained.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (12)$$

$$\overline{W}_{ij} = a_{ij}W_{ij} \quad (13)$$

where,  $i=1, 2, 3, \dots, n, j=1, 2, 3, \dots, n$ .

Letting  $\overline{W} = \overline{W}_{ij}$ , the weighted supermatrix is then

$$\overline{W} = \begin{bmatrix} a_{11}W_{11} & a_{12}W_{12} & \cdots & a_{1n}W_{1n} \\ a_{21}W_{21} & a_{22}W_{22} & \cdots & a_{2n}W_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1}W_{n1} & a_{n2}W_{n2} & \cdots & a_{nn}W_{nn} \end{bmatrix} \quad (14)$$

(3) Consistency Test. By using the formula  $AW_{ij}=\lambda_{\max}W_{ij}$ , the eigenvector and the largest eigenvalue can be calculated, and after obtaining  $W_{ij}$ , a consistency check is performed.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (15)$$

Here, CR (Consistency Ratio) represents the consistency ratio; CI (Consistency Index) represents the consistency index, which reflects the degree to which the judgment matrix deviates from complete consistency; RI (Random Index) is a reference indicator for determining the random consistency of a matrix. The reference values for RI are detailed in Table 2.

*Table 2: Random Index RI Reference Table*

Matrix Order	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

**(4) Obtaining the Limit Matrix**

Because elements influence each other, the weighted supermatrix is processed for stability, denoted as  $W^\infty$ , and then its limit is sought.

$$W^\infty = \lim_{k \rightarrow \infty} \frac{1}{N} \sum_{k=1}^N (\bar{W})^k \quad (16)$$

In the limit matrix  $W^\infty$ , the sum of the values in each column equals 1, and each row converges to the same value, which is the weight of the first column element of that row.

(5) Obtain the final hybrid weight by averaging the weights derived from the ANP method with those obtained from DEMATEL, completing the selection of significantly influential indicators in the safety risk assessment of wind power engineering construction projects.

## **4 Results and Discussion**

### **4.1 Risk identification**

By distributing questionnaires to obtain expert opinions, the positivity coefficients of the experts were all 100%, indicating a high level of attention and enthusiasm from the experts towards this survey. By analyzing the data presented in Table 3, it can be found that the average values of each item in the secondary indicator layer exceed 3.5 points, and the coefficients of variation are all below 0.25, indicating that all indicators meet the established requirements. Keep 4 primary indicators and 36 secondary indicators as the final indicators. Organize the primary and secondary indicators into the final indicator system and code them, as shown in the Table 4 below.

Table 3: Results of the Third Round of Expert Consultation for Second-Level Indicators

Second-Level Indicator	Standard Deviation	Mean	Coefficient of Variation
Vehicle Operation Error C1	0.6992	3.6	0.1942
Lack of Personal Protection C2	0.3162	4.9	0.0645
Misjudgment of Distance C3	0.6749	3.7	0.1824
Lack of Safety Work Skills C4	0.3162	4.9	0.0645
Lack of Personnel Qualifications C5	0.7888	3.8	0.2076
Risk-taking Entry C6	0.4216	4.8	0.0878
Accidental Contact with a Live Part C7	0.3162	4.9	0.0645
Unauthorized Work C8	0.8233	4.3	0.1915
Non-compliant Equipment Operation C9	0.3162	4.9	0.0645
Low Sensitivity to Equipment Changes C10	0.9189	3.8	0.2418
Bringing Fire into Wind Farms C11	0.3162	4.9	0.0645
Storing Flammable Items C12	0.7379	3.9	0.1892
Mistakenly Climbing Outdoor Electrical Equipment C13	0.3162	4.9	0.0645
Not Performing Fire Isolation C14	0.6749	3.7	0.1824
Wind Turbine Blades, Towers, Gearbox Equipment Transport Failure C15	0.3162	4.9	0.0645
Lifting Equipment Failure C16	0.6992	3.6	0.1942
Equipment with Hazardous Voltage C17	0.3162	4.9	0.0645
Too Close to a Live Part C18	0.8233	3.7	0.2225
Non-compliance with Safety Protective Equipment Installation C19	0.4216	4.8	0.0878
Wind Turbine and Accessory Equipment Failure C20	0.8756	3.9	0.2245
Lack of Automatic Fire Alarms or Extinguishing Systems C21	0.3162	4.9	0.0645
Lack of Inspected and Approved Safety Tools and Protective Equipment C22	0.6992	3.6	0.1942
Areas with Excessive Mud and Unreinforced Slopes C23	0.3162	4.9	0.0645
Landslides, Mudflows Obstruction C24	0.6667	4	0.1667
Strong Wind, Heavy Rain, Freezing Weather C25	0.3162	4.9	0.0645
Limited Working Platform/Space C26	0.7379	4.1	0.18
Sudden Environmental Changes at the Workplace C27	0.3162	4.9	0.0645
Excessive Toxic or Harmful Gas Content in Ditches (Pools, Wells) C28	0.6667	4	0.1667
Lack of Safety Management Supervision C29	0.8756	3.9	0.2245
Deficiency in Safety and Organizational System Implementation C30	0.4216	4.8	0.0878
Lack of Safety Training, Education, and Guidance C31	0.7379	4.1	0.18
Insufficient Accident Hazard Investigation C32	0.3162	4.9	0.0645
Inadequate Safety Risk Level Control System C33	0.3162	4.9	0.0645
Inadequate Routine Safety Inspections C34	0.8433	3.6	0.2342
Inadequate Safety Briefings C35	0.6992	3.6	0.1942
Shortage of Personnel C36	0.8233	4.3	0.1915

Table 4: Final Indicator System Objective Layer

	Primary Indicator	Secondary Indicator
Safety Risks During Wind Power Engineering Construction Phase A	Human Safety Risks (B1)	Vehicle Operation Error C1
		Lack of Personal Protection C2
		Misjudgment of Distance C3
		Lack of Safety Work Skills C4
		Lack of Personnel Qualifications C5
		Risk-taking Entry C6
		Accidental Contact with a Live Part C7
		Unauthorized Work C8
		Non-compliant Equipment Operation C9
		Low Sensitivity to Equipment Changes C10
		Bringing Fire into Wind Farms C11
		Storing Flammable Items C12
		Mistakenly Climbing Outdoor Electrical Equipment C13
		Not Performing Fire Isolation C14
	Equipment Safety Risks (B2)	Wind Turbine Blades, Towers, Gearbox Equipment Transport Failure C15
		Lifting Equipment Failure C16
		Equipment with Hazardous Voltage C17
		Too Close to a Live Part C18
		Non-compliance with Safety Protective Equipment Installation C19
		Wind Turbine and Accessory Equipment Failure C20
		Lack of Automatic Fire Alarms or Extinguishing Systems C21
	Environmental Safety Risks (B3)	Lack of Inspected and Approved Safety Tools and Protective Equipment C22
		Areas with Excessive Mud and Unreinforced Slopes C23
		Landslides, Mudflows Obstruction C24
		Strong Wind, Heavy Rain, Freezing Weather C25
		Limited Working Platform/Space C26
	Safety Management Risks (B4)	Sudden Environmental Changes at the Workplace C27
		Excessive Toxic or Harmful Gas Content in Ditches (Pools, Wells) C28
		Lack of Safety Management Supervision C29
		Deficiency in Safety and Organizational System Implementation C30
		Lack of Safety Training, Education, and Guidance C31
		Insufficient Accident Hazard Investigation C32
		Inadequate Safety Risk Level Control System C33
		Inadequate Routine Safety Inspections C34
		Inadequate Safety Briefings C35
	Shortage of Personnel C36	

## 4.2 Analysis of the Safety Risk Indicator Weights for Wind Power Engineering Construction Period Based on DEMATEL-ANP

### 4.2.1 DEMATEL Method Weight Analysis Results

Step 1: Identifying influencing factors and assessing their relationships through preliminary determination of the relationships between influencing factors via questionnaire distribution.

In order to explore the inherent correlation between safety risk indicators during the construction phase of wind power projects, this study specially invited 10 authoritative experts from the field of wind power construction management and professional research institutions to participate in a questionnaire survey.

All 10 experts have years of experience in construction safety management or research in wind power engineering, holding titles, including 4 technicians, 2 professors, 2 associate professors, and 4 senior engineers, ensuring high credibility. A total of 10 questionnaires were distributed and all were retrieved.

Step 2: Obtaining the Direct-relation Matrix (D)

Experts compared the elements pairwise based on their relationship and degree of influence, with 36 elements resulting in a 36\*36 matrix, the Direct-relation Matrix D, forming 10 order-36 matrices based on the initial judgments of 10 experts. The elements  $d_{ij}$  in the matrix represent the degree of influence of element  $i$  on  $j$ , setting the diagonal elements to 0.

Step 3: Normalizing the Direct-relation Matrix X.

According to formulas (1) and (2), the standardized direct relationship matrix X can be calculated, and its specific content is detailed in Appendix 1.

Step 4: Obtaining the Comprehensive Influence Matrix T.

The comprehensive influence matrix T is derived according to formula (3)(4), as shown in Appendix 2.

Step 5: Drawing the Influence Relation Diagram. The results of the DEMATEL analysis are obtained based on the formulas for centrality and causality.

Table 5 shows the DEMATEL analysis results. Figure 1 shows the centrality and causal distribution of each indicator. Figure 2 shows the network structure model of risk indicators.

Table 5: DEMATEL Analysis Results

Results	Influenced Degree	Influencing Degree	Centrality	Causality	Weight
C1	0.3461	0.1972	0.5433	-0.1489	0.018542915
C2	0.4239	0.1747	0.5986	-0.2492	0.020430313
C3	0.3611	0.1234	0.4845	-0.2377	0.016536062
C4	0.2395	0.4949	0.7344	0.2554	0.025065189
C5	0.1894	0.3705	0.5599	0.1811	0.019109476
C6	0.5032	0.0815	0.5847	-0.4217	0.019955904
C7	0.6273	0.1724	0.7997	-0.4549	0.027293888
C8	0.4309	0.1684	0.5993	-0.2625	0.020454204
C9	0.6498	0.1375	0.7873	-0.5123	0.026870674
C10	0.0923	0.3173	0.4096	0.225	0.013979713
C11	0.5306	0.0678	0.5984	-0.4628	0.020423487
C12	0.5008	0.0864	0.5872	-0.4144	0.020041229
C13	0.7926	0.1988	0.9914	-0.5938	0.033836639
C14	0.551	0.1986	0.7496	-0.3524	0.025583967
C15	0.8901	0	0.8901	-0.8901	0.030379254
C16	0.617	0.0136	0.6306	-0.6034	0.021522478
C17	0.3117	0.1155	0.4272	-0.1962	0.014580404
C18	0.5915	0.2648	0.8563	-0.3267	0.029225655
C19	0.5272	0.4094	0.9366	-0.1178	0.031966307
C20	0.3857	0	0.3857	-0.3857	0.013164002
C21	0.3982	0.0812	0.4794	-0.317	0.016361998
C22	0.6228	0.2677	0.8905	-0.3551	0.030392906
C23	0.275	0.4666	0.7416	0.1916	0.025310926
C24	0.2251	0.294	0.5191	0.0689	0.017716965
C25	0.0558	0.4902	0.546	0.4344	0.018635067
C26	0.1989	0.1915	0.3904	-0.0074	0.013324414
C27	0.4355	0.3011	0.7366	-0.1344	0.025140275
C28	0.3674	0.2242	0.5916	-0.1432	0.020191402
C29	0.2547	1.2812	1.5359	1.0265	0.052420511
C30	0.1933	1.4898	1.6831	1.2965	0.05744447
C31	0.2337	1.3395	1.5732	1.1058	0.053693566
C32	0.5448	1.2025	1.7473	0.6577	0.059635626
C33	0.514	1.1057	1.6197	0.5917	0.055280618
C34	0.3392	0.7529	1.0921	0.4137	0.037273546
C35	0.3239	0.7058	1.0297	0.3819	0.035143824
C36	0.1058	0.8632	0.969	0.7574	0.033072124

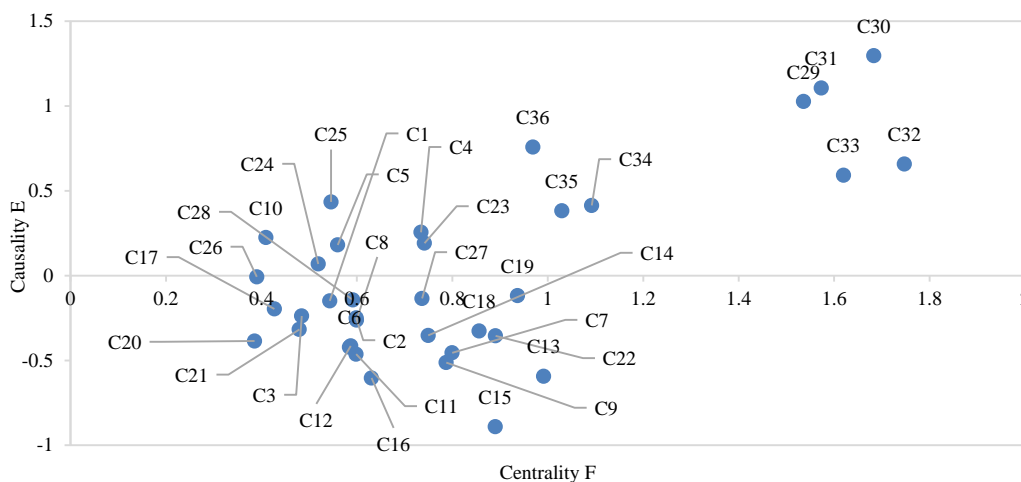


Figure 1: Distribution Chart of Centrality and Causality for Each Indicator

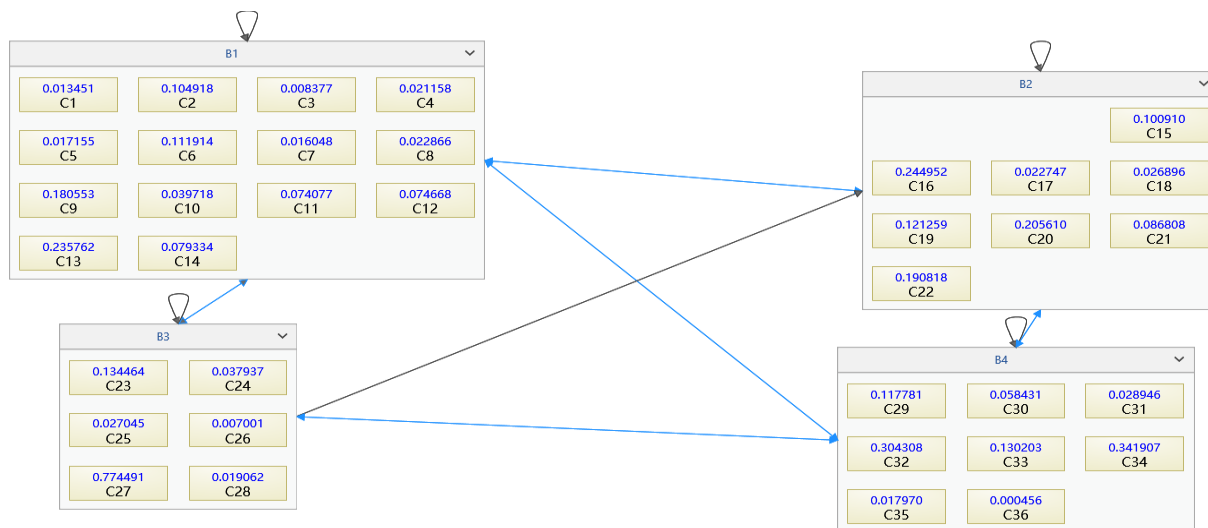


Figure 2: Risk Indicator Network Structure Model

#### 4.2.2 DEMATEL Method Results and Discussion

The top ten indicators with the highest centrality are as follows: C32 (Insufficient Accident Hazard Investigation), C30 (Deficiency in Safety and Organizational System Implementation), C33 (Inadequate Safety Risk Level Control System), C31 (Lack of Safety Training, Education, and Guidance), C29 (Lack of Safety Management Supervision), C34 (Inadequate Routine Inspection), C35 (Inadequate Safety Briefings), C13 (Mistakenly Climbing Outdoor Electrical Equipment), C36 (Shortage of Personnel), and C19 (Non-compliance with Safety Protective Equipment Installation) are key influencing factors within the risk system.

Among these, indicators C4, C5, C10, C23, C24, C25, C29 to C36 with a causality greater than 0 are considered cause indicators that can influence other elements.

##### (1) Human Safety Risks:

Within the framework of construction safety risk assessment for wind power engineering projects, comprehensive analysis has revealed that deficiencies in safety work skills (marked as C4), inadequate personnel qualifications (marked as C5), and weak perception of equipment

status changes (marked as C10) are identified as key causal indicators for safety risks. These factors profoundly reveal their significant negative impact on engineering construction safety from the perspective of personnel safety. Among them, the lack of safety work skills exhibits the highest centrality feature, which reflects that in the complex and ever-changing implementation environment of wind power engineering, the lack of workers' safety operation skills has become a core factor restricting safety management due to multiple factors such as equipment condition, management level, and environmental conditions, and urgently needs to be improved through targeted measures. According to the table, accidental contact with a live part (C7) and non-compliant equipment operation (C9) are effect indicators, with centrality above the safety work skills indicator, indicating they are also intertwined within the dense network of risk interactions.

#### (2) Equipment Safety Risks:

Failures in the transport of wind turbine blades, towers, gearbox equipment, lifting equipment malfunction, equipment with hazardous voltage, proximity to live parts, non-compliance in the installation of safety protective equipment, wind turbine and accessory equipment failure, lack of automatic fire alarms or extinguishing systems, and the absence of safety tools and protective equipment that have been inspected and approved. Among these, the top three in centrality are non-compliance with safety protective equipment installation (C19), lack of inspected and approved safety tools and protective equipment (C22), and failures in the transport of wind turbine blades, towers, gearbox equipment (C15), indicating these areas are highly influenced by other dimensions.

#### (3) Environmental Safety Risks:

In environmental safety risks, the areas with excessive mud and unreinforced slopes (C23), landslides, mudflows obstruction (C24), and severe weather conditions (C25) have causality greater than 0, making them cause indicators. The areas with excessive mud and unreinforced slopes and sudden changes in workplace environment (C27) have higher centrality, indicating they are significantly influenced by other risks.

#### (4) Management Safety Risks:

In management safety risks, all 8 indicators are cause indicators, with the top three being insufficient accident hazard investigation (C32), deficiency in safety and organizational system implementation (C30), and inadequate safety risk level control system (C33). The lack of accident hazard investigation is at the core of the safety risk system, where system imperfections and lack of enforcement are key triggers for risk incidents. In addition, there are deficiencies in the safety risk level control mechanism, inadequate implementation of safety training, education, and guidance, weak safety management supervision links, insufficient frequency and depth of daily safety inspections, and inadequate preparation and dissemination of safety information briefings, all of which are key factors affecting the effectiveness of wind power project safety management.

### 4.2.3 Determination of Safety Risk Indicator Weights after Integrating ANP Method

#### DEMATEL-ANP Method Steps

##### Step 1: Construction of Network Structure Model

Based on the calculation steps in section 3.3.2, a threshold  $\lambda$  ( $\lambda \in [0,1]$ ) is introduced to compute the relationship matrix of the comprehensive influence matrix T. The threshold is determined by the formula:  $\lambda = \bar{x} + \sigma$ , where  $\bar{x}$  is the average of all factors in matrix T, and  $\sigma$  is its standard deviation. Elements below the threshold are excluded, the yaanp software is used for computation.

A network structure model of the interrelationships among the second-level indicators is constructed as shown in Figure 2. Due to the large volume of calculations, the yaanp software is

used for computation.

### Step 2: Determination of Risk Influencing Factor Weights

(1) To ensure the accuracy of the survey results, another 10 experts are invited to assess the project based on their theoretical knowledge and the specific situation of current onshore wind power engineering construction. The assessment is scored according to Saaty's comparison scale as shown in Table 3. A network structure model of the interrelationships among the second-level

indicators is constructed as shown below. Due to the large volume of calculations, the yaanp software is used for computation.

#### (2) Constructing the ANP Original Supermatrix (Unweighted Supermatrix).

Based on formulas (10)~(16) from section 3.2.2, the ANP original supermatrix, the weighted supermatrix, and the limit matrix are constructed as shown in Appendices 3, 4, and 5, respectively.

#### (3) Consistency Test

According to the consistency test formula, calculations were carried out using yaanp software, and the consistency test results of the control layer judgment matrix are presented in Tables 6 to 10. Specifically, Table 6 presents the relevant results of the control layer judgment matrix constructed based on B1; Table 7 shows the verification results of the control layer decision matrix formed around B2; Table 8 presents the control layer decision matrix verification data based on B3; Table 9 reflects the verification information of the control layer discrimination matrix generated according to B4; Table 10 presents the verification content of the node decision matrix established based on standard C4.

*Table 6: Judgment Matrix for Control Layer Based on B1*

	B1	B2	B3	B4	Wi
B1	1	5	8	1/4	0.280655
B2	1/5	1	1	1/7	0.061336
B3	1/8	1	1	1/7	0.056367
B4	4	7	7	1	0.601642

Here, the Consistency Ratio (CR) = 0.088157 < 0.1, meeting the consistency requirement.

*Table 7: Judgment Matrix for Control Layer Based on B2*

	B1	B2	B4	Wi
B1	1	2	1/6	0.151247
B2	1/2	1	1/7	0.090507
B4	6	7	1	0.758246

Here, the Consistency Ratio (CR) = 0.031122 < 0.1, meeting the consistency requirement.

*Table 8: Judgment Matrix for Control Layer Based on B3*

	B1	B2	B3	B4	Wi
B1	1	7	7	1/2	0.362437
B2	1/7	1	2	1/7	0.073223
B3	1/7	1/2	1	1/7	0.051777
B4	2	7	7	1	0.512563

Here, the Consistency Ratio (CR) = 0.045438 < 0.1, meeting the consistency requirement.

*Table 9: Judgment Matrix for Control Layer Based on B4*

	B1	B2	B3	B4	Wi
B1	1	9	8	3	0.587821
B2	1/9	1	1	1/7	0.052647
B3	1/8	1	1	1/7	0.054635
B4	1/3	7	7	1	0.304897

*Table 10: Node Judgment Matrix Based on Standard C4*

	C1	C2	C7	C9	C13	Wi
C1	1	1/4	9	1	9	0.230790
C2	4	1	9	2	7	0.459609
C7	1/9	1/9	1	1/7	1	0.034359
C9	1	1/2	7	1	9	0.239558
C13	1/9	1/7	1	1/9	1	0.035685

Here, the Consistency Ratio (CR) = 0.039588 < 0.1, meeting the consistency requirement. Due to space constraints, the consistency test results for node judgment matrices are exemplified by node C4. Taking C4 as the standard, the importance comparison of C1, C2, C7, C9, and C13 to C4 is assessed using yaalp software, resulting in a consistency ratio of 0.059667 and  $\lambda_{\max}$ :5.267306. The consistency <0.1 meets the requirements, indicating the weights are within an acceptable range.

The consistency test results show that the consistency ratio of each control layer element and node judgment matrices are all below 0.1, indicating the influence results are within an acceptable range. Based on the limit super matrix results, the weight results for safety evaluation indicators in wind power engineering construction based on the ANP method are obtained in Table 11.

Table 11: Safety Evaluation Indicator Weights for Wind Power Engineering Construction Based on the ANP Method

Risk Indicator	Weight
Vehicle Operation Error C1	0.006172
Lack of Personal Protection C2	0.048145
Misjudgment of Distance C3	0.003844
Lack of Safety Work Skills C4	0.009709
Lack of Personnel Qualifications C5	0.007872
Risk-taking Entry C6	0.051355
Accidental Contact with a Live Part C7	0.007364
Unauthorized Work C8	0.010493
Non-compliant Equipment Operation C9	0.082853
Low Sensitivity to Equipment Changes C10	0.018226
Bringing Fire into Wind Farms C11	0.033993
Storing Flammable Items C12	0.034264
Mistakenly Climbing Outdoor Electrical Equipment C13	0.108187
Not Performing Fire Isolation C14	0.036405
Wind Turbine Blades, Towers, Gearbox Equipment Transport Failure C15	0.025815
Lifting Equipment Failure C16	0.062663
Equipment with Hazardous Voltage C17	0.005819
Too Close to a Live Part C18	0.006881
Non-compliance with Safety Protective Equipment Installation C19	0.031020
Wind Turbine and Accessory Equipment Failure C20	0.052599
Lack of Automatic Fire Alarms or Extinguishing Systems C21	0.022207
Lack of Inspected and Approved Safety Tools and Protective Equipment C22	0.048815
Areas with Excessive Mud and Unreinforced Slopes C23	0.005091
Landslides, Mudflows Obstruction C24	0.001436
Strong Wind, Heavy Rain, Freezing Weather C25	0.001024
Limited Working Platform/Space C26	0.000265
Sudden Environmental Changes at the Workplace C27	0.029324
Excessive Toxic or Harmful Gas Content in Ditches (Pools, Wells) C28	0.000722
Lack of Safety Management Supervision C29	0.029143
Deficiency in Safety and Organizational System Implementation C30	0.014458
Lack of Safety Training, Education, and Guidance C31	0.007162
Insufficient Accident Hazard Investigation C32	0.075296
Inadequate Safety Risk Level Control System C33	0.032217
Inadequate Routine Safety Inspections C34	0.084600
Inadequate Safety Briefings C35	0.004446
Shortage of Personnel C36	0.000113

The final hybrid weights are obtained by averaging the weights derived from the ANP method with those obtained from the DEMATEL method, completing the selection of significantly influential indicators in the safety risk evaluation of wind power engineering construction projects. Table 12 shows the comprehensive weight values.

Table 12: Comprehensive Weights

Secondary Factor	Comprehensive Secondary Weight	Tertiary Factor	ANP Weight	DEMATEL Weight	Comprehensive Weight		
B1	0.384	C1	0.006	0.019	0.012		
		C2	0.048	0.020	0.034		
		C3	0.004	0.017	0.010		
		C4	0.010	0.025	0.017		
		C5	0.008	0.019	0.013		
		C6	0.051	0.020	0.036		
		C7	0.007	0.027	0.017		
		C8	0.010	0.020	0.015		
		C9	0.083	0.027	0.055		
		C10	0.018	0.014	0.016		
		C11	0.034	0.020	0.027		
		C12	0.034	0.020	0.027		
		C13	0.108	0.034	0.071		
		C14	0.036	0.026	0.031		
B2	0.222	C15	0.026	0.030	0.028		
		C16	0.063	0.022	0.042		
		C17	0.006	0.015	0.010		
		C18	0.007	0.029	0.018		
		C19	0.031	0.032	0.031		
		C20	0.053	0.013	0.033		
		C21	0.022	0.016	0.019		
		C22	0.049	0.030	0.040		
		B3	0.079	C23	0.005	0.025	0.015
				C24	0.001	0.018	0.010
C25	0.001			0.019	0.010		
C26	0.000			0.013	0.007		
C27	0.029			0.025	0.027		
C28	0.001			0.020	0.010		
B4	0.316			C29	0.029	0.052	0.041
				C30	0.014	0.057	0.036
		C31	0.007	0.054	0.030		
		C32	0.075	0.060	0.067		
		C33	0.032	0.055	0.044		
		C34	0.085	0.037	0.061		
		C35	0.004	0.035	0.020		
		C36	0.000	0.033	0.017		

#### 4.2.4 Comprehensive Evaluation Results and Discussion

To facilitate the classification and management of risk factors using the comprehensive weights of risk indicators, this study divides the comprehensive weights into three levels: high, medium, low, and very low. The grading indicators are in Table 13.

Table 13: Risk Level to Project Safety Impact Table

Quantitative Standard	Level
$C \leq 0.01$	Very Low Risk (Minimal impact on safety objectives)
$0.010 < C \leq 0.020$	Low Risk (Small impact on safety objectives)
$0.020 < C \leq 0.035$	Medium Risk (Moderate impact on safety objectives)

Based on the degree of impact of each indicator on the project, a classification work is carried out for the 36 observation indicators involved in the safety risk index system evaluation of wind power engineering construction stage, which are divided into three categories: high-risk level, medium risk level, and low-risk level.

This classification assists in prioritizing safety management efforts, focusing on high-risk indicators to mitigate potential impacts on the safety objectives of wind power engineering construction projects.

According to the analysis results, within human safety risks, behaviors such as risk-taking entry, non-compliant equipment operation, and mistakenly climbing outdoor electrical equipment are categorized as high risks. In terms of equipment safety risks, failures of lifting equipment and the lack of inspected and approved safety tools and protective equipment are considered high risks. For environmental safety risks, there are no high-risk factors, but sudden environmental changes at the workplace are identified as medium risks. In the field of safety risk management, the lack of safety management supervision, the weak performance of safety and organizational systems in the execution process, the insufficient depth of accident hazard investigation, the lack of completeness in the safety risk level control system, and the failure to fully implement daily inspection work are all defined as high-risk factors. These factors have had a very serious negative impact on achieving the safety goals of wind power construction projects.

In human safety risks, factors such as lack of personal protection, bringing fire into wind farms, storing flammable items, and not performing fire isolation are medium risks, which could also significantly lead to accidents during the construction of wind power projects, affecting the achievement of safety objectives.

In equipment safety risks, non-compliance with the installation of safety protective equipment and malfunction of wind turbine and accessory equipment are medium risks, which could cause accidents related to equipment issues during the construction phase.

For environmental safety risks, sudden environmental changes at the workplace are considered medium risks, referring to the transition from normal to abnormal weather and geological conditions, such as sudden strong winds or rainstorms causing landslides and mudflows. It's essential to enhance sensitivity to sudden environmental changes and strengthen weather risk forecasting measures.

The lack of safety training, education, and guidance in safety risk management work has been identified as a moderate risk factor. In view of this, it is equally important to carry out scientific and appropriate safety training, education, and guidance for frontline workers on the basis of strengthening safety management supervision, improving the effectiveness of safety and organizational system execution, deepening the investigation of accident hazards, improving the safety risk level control system, and implementing daily safety inspections. Accordingly, it is necessary to respond to and monitor the risks based on the assessment results mentioned above. Table 14 shows the grading results of risk indicators.

*Table 14: Risk Indicator Grading Results*

Risk Indicator	Composite	Risk Level
Vehicle Operation Error C1	0.012	Low Risk
Lack of Personal Protection C2	0.034	Medium Risk
Misjudgment of Distance C3	0.010	Very Low Risk
Lack of Safety Work Skills C4	0.017	Low Risk
Lack of Personnel Qualifications C5	0.013	Low Risk
Risk-taking Entry C6	0.036	High Risk
Accidental Contact with a Live Part C7	0.017	Low Risk
Unauthorized Work C8	0.015	Low Risk
Non-compliant Equipment Operation C9	0.055	High Risk
Low Sensitivity to Equipment Changes C10	0.016	Low Risk
Bringing Fire into Wind Farms C11	0.027	Medium Risk
Storing Flammable Items C12	0.027	Medium Risk
Mistakenly Climbing Outdoor Electrical Equipment C13	0.071	High Risk
Not Performing Fire Isolation C14	0.031	Medium Risk
Wind Turbine Blades, Towers, Gearbox Equipment Transport Failure C15	0.028	Medium Risk
Lifting Equipment Failure C16	0.042	High Risk
Equipment with Hazardous Voltage C17	0.010	Very Low Risk
Too Close to a Live Part C18	0.018	Low Risk
Non-compliance with Safety Protective Equipment Installation C19	0.031	Medium Risk
Wind Turbine and Accessory Equipment Failure C20	0.033	Medium Risk
Lack of Automatic Fire Alarms or Extinguishing Systems C21	0.019	Low Risk
Lack of Inspected and Approved Safety Tools and Protective Equipment C22	0.040	High Risk
Areas with Excessive Mud and Unreinforced Slopes C23	0.015	Low Risk
Landslides, Mudflows Obstruction C24	0.010	Very Low Risk
Strong Wind, Heavy Rain, Freezing Weather C25	0.010	Very Low Risk
Limited Working Platform/Space C26	0.007	Very Low Risk
Sudden Environmental Changes at the Workplace C27	0.027	Medium Risk
Excessive Toxic or Harmful Gas Content in Ditches (Pools, Wells) C28	0.010	Very Low Risk
Lack of Safety Management Supervision C29	0.041	High Risk
Deficiency in Safety and Organizational System Implementation C30	0.036	High Risk
Lack of Safety Training, Education, and Guidance C31	0.030	Medium Risk
Insufficient Accident Hazard Investigation C32	0.067	High Risk
Inadequate Safety Risk Level Control System C33	0.044	High Risk
Inadequate Routine Safety Inspections C34	0.061	High Risk
Inadequate Safety Briefings C35	0.020	Low Risk
Shortage of Personnel C36	0.017	Low Risk

## 5 Conclusion

To effectively enhance the cognitive level and practical ability of onshore wind power

engineering projects in safety risk management, this study deeply integrates the PDCA concept and fully absorbs expert professional insights to accurately identify potential risks. Build a comprehensive and detailed evaluation index system from four key directions: personal safety assurance, equipment safety and stability, environmental safety protection, and management safety standards. In terms of specific research methods, this study uses the DEMATEL method to accurately calculate the comprehensive impact matrix between various indicators, in order to clarify the interaction relationship between indicators; At the same time, the ANP method is used to scientifically organize the network structure of indicators, ensuring that the logical connections and hierarchical structure between indicators are reasonable and orderly. Moreover, based on the risk weights during the construction phase of onshore wind power projects, a systematic classification and targeted construction of four types of safety risks, namely personal, equipment, environment, and management, is carried out to provide solid and powerful support for the safety risk management of the project.

This study uses the DEMATEL-ANP combination method to conduct risk assessment during the construction phase of onshore wind power projects, and comprehensively and effectively analyzes various risk factors. The risk assessment system for onshore wind power engineering management constructed can provide highly practical guidance for ensuring construction safety, preventing various accidents during construction and management processes. At the same time, the research results also provide valuable reference for subsequent research on optimizing the safety management system of onshore wind power projects.

Due to the lack of relevant accident data during the construction phase of onshore wind power projects, this study inevitably has certain limitations. Future work will focus on assessing dynamic risks during the construction period, considering the impact of human influences, environmental changes, and management status on the overall risk level. Further research could be conducted using dynamic Bayesian analysis to achieve more targeted maintenance plans and management decisions, comprehensively evaluating the safety level of wind power engineering construction and refining risk management.

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