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Research on the Construction Method of Double Prevention Mechanism in Chinese Heating Enterprises Based on Bidirectional Dynamic Risk-Hidden Danger Transmission

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Abstract: The heating industries are extremely dispersed in China, and most heating enterprises are small in scale, poor in foundation, and chaotic in safety management. The construction method of the double prevention mechanism of heating enterprises in China was analyzed and studied based on the PDCA cycle model and the improved risk assessment method for operating conditions. The analytic hierarchy process was used to determine the weight of dangerous and harmful factors and corresponding control measures for an accident type. The concept of "failure frequency" was introduced, and the calculation method of accident probability (L) was modified so that the accurate hierarchical control and dynamic risk assessment of accident risks can be realized. At the same time, the failure of control measures is defined as "hidden danger" in this paper. Finally, the bidirectional dynamic transmission mechanism of hidden danger investigation and treatment and risk hierarchical control was established. The main problems existing in the construction of double prevention mechanism of heating enterprises in China were discussed and some countermeasures and suggestions were put forward. According to the above methods and steps, the double prevention mechanism of heating enterprises can be reasonably established. Thus, the risks can be effectively identified, the hidden dangers can be controlled, and the safety production of heating enterprises can be guaranteed.

Keywords: heating enterprises; PDCA cycle; risk hierarchical control; hidden danger investigation and treatment; bidirectional dynamic conduction

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1. Introduction

According to the Statistical Yearbook of China's Urban Construction [1], the central heating area of China reaches 12.266 billion square meters by the end of 2020. The Beijing Heat Group which is the largest heating enterprise in China has a heating area of 506 million square meters (2020), but it only accounts for 4.6% of the country's total heating area. The Zhonghuan Huanhui Group is a leading enterprise in the heating industry in China, which has a heating area of about 150 million square meters (2020), but it only accounts for 1.4% of the country's total heating area. Thus, the heating industries are extremely dispersed in China, and most heating enterprises are small in scale [2,3], poor in foundation [4,5], and chaotic in safety management [6,7]. The safety production situation of the heating industry is still severe.

In accordance with the latest requirements of the file "Opinions of the Office of the Safety Commission of The State Council on Implementing the Work Guidelines for Containing Major and Major Accidents and the Construction of Double Prevention Mechanism" (2016) [8], which is promulgated and implemented by The State Council of China and the "Work Safety Law of the People's Republic of China" (revised in 2021), enterprises need to establish double prevention mechanism of risk hierarchical control and hidden danger investigation and treatment. The research and exploration on the construction of double prevention mechanism has been carried out all over China since 2016. For example, Shandong, Henan, Zhejiang and other provinces in China have issued local standards, guidance manuals or implementation guidelines for the construction of double prevention mechanism [9–11]. However, due to the constraints of production scale, human factors, management status, economic capacity and other conditions, most of the heating enterprises in China do not have high initiative and enthusiasm, and it is difficult to realize the comprehensive construction of the double prevention mechanism. Due to the risk assessment method adopted being unreasonable and too simple, some heating enterprises do not fully understand the connotation of double prevention, and there is a serious disconnect between hidden trouble investigation and management and risk hierarchical control, and even two sets of systems have been formed, which is a serious waste of human, material, and financial resources.

In China, the construction, review, and maintenance of double prevention mechanism of heating enterprises are mostly carried out by safety management personnel. Due to the lack of safety management personnel or the lack of professional safety and technical ability, there are big loopholes in the construction of double prevention mechanism, which cannot effectively control risks and address dangers. So, the double prevention mechanism established by enterprises becomes a mere formality [12]. At the same time, with the continuous development of risk assessment methods, scholars have made a lot of combination applications to the existing risk assessment methods. For example, Dayong Lin, Ming Chen, Kang Zhang, Gülin Feryal Can, and Yang Song et al. [13–17] used fuzzy mathematics theory and Delphi method to make qualitative and quantitative assessment of risk factors; Lei Changqun [18], Yan Wei [19], and Jia Bingli [20] et al. analyzed and studied the construction method of double prevention mechanism in the heating industry. However, the current risk assessment for heating enterprises is mostly static risk assessment, and there are few studies on dynamic risk assessment methods, and even fewer on the bidirectional dynamic conduction methods and mechanisms of risk-hidden danger.

Therefore, in order to further improve the safety management system of heating enterprises in China and overcome the drawbacks of traditional risk assessment methods, a new dynamic risk assessment method was proposed based on the improved risk assessment method for operating conditions and analytic hierarchy process in this paper. The concept of "failure frequency" was introduced and the calculation method of accident probability (L) was modified. The construction process and method of double prevention mechanism for heating enterprises based on PDCA mode was discussed. At the same time, the failure of control measures was defined as "hidden danger". A bidirectional dynamic conduction mechanism of hidden danger investigation and treatment and risk hierarchical control was established. A good and effective double prevention mechanism can change the traditional safety management mode of heating enterprises, realize the gateway forward and active defense, and greatly improve the safety management level of heating enterprises. Thus, the safe production of heating enterprises can be ensured.

2. Construction of Double Prevention Mechanism for Heating Enterprises Based on PDCA

2.1. Overview of Double Prevention Mechanism

The double prevention mechanism refers to the risk hierarchical control and the hidden danger investigation and treatment, the core of which is the risk and hidden danger. Two firewalls for enterprises to prevent production accidents are the management of risk and the treatment of hidden danger. The management of risk is the systematic identification of risks at the source and hierarchical risk control, striving to control all kinds of risks within the acceptable range in order to eliminate and reduce the potential accident. The treatment of hidden danger is to carefully investigate the missing loopholes and risk control failure links in the process of risk control, and resolutely eliminate hidden danger before the occurrence of accidents with hidden danger screening and management as the means. If the risk control is in place, there will be no hidden danger of accidents; once a hidden danger is discovered, it is impossible to deal with it in time. We can effectively control every type of risk within an acceptable range, prevent every hidden danger from forming at the beginning, and nip every accident in the bud through the double prevention mechanism. At present, the overall construction process of double prevention mechanism of heating enterprises in China is shown in Figure 1.

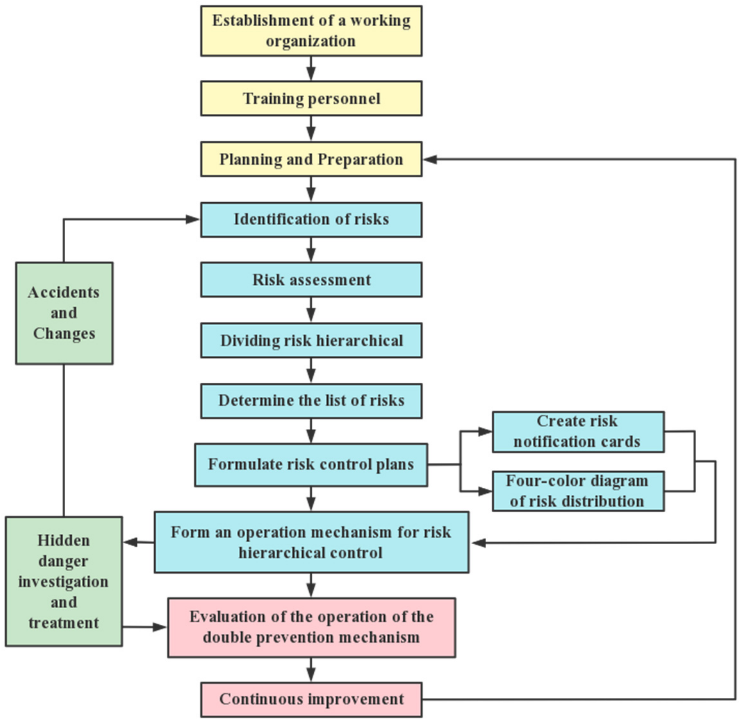


Figure 1. The overall construction process of double prevention mechanism of heating enterprises in China.

2.2. PDCA Operation Mode of Double Prevention Mechanism in Heating Enterprises

The PDCA cycle management model was put forward by Deming who was an American scholar and the model has been widely used in the safety management of various industries. The PDCA (Plan-Do-Check-Act) cycle is a recurring scientific cycle. It constantly summarizes the experience of failure in each cycle, and continuously improves it in the next cycle. By spiraling upward, the safety management level of the enterprise will improve [21]. The Schematic diagram of PDCA cycle is shown in Figure 2.

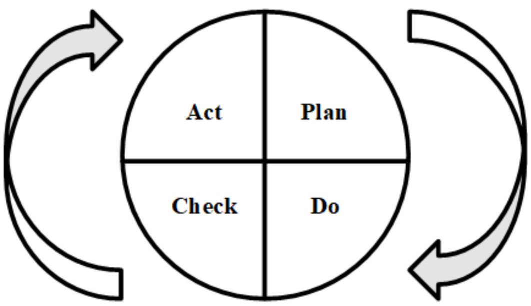


Figure 2. The schematic diagram of the PDCA cycle.

According to the system theory, the principle of correlation and the requirement of continuous improvement, combined with the current situation of safety management of heating enterprises in China and the overall construction process of the double prevention mechanism, the concrete construction work steps of the double prevention mechanism of heating enterprises can be integrated into the four links of PDCA cycle, which is Plan-Do-Check-Act. So, the PDCA operation mode of double prevention mechanism for heating enterprises can be formed, as shown in Figure 3.

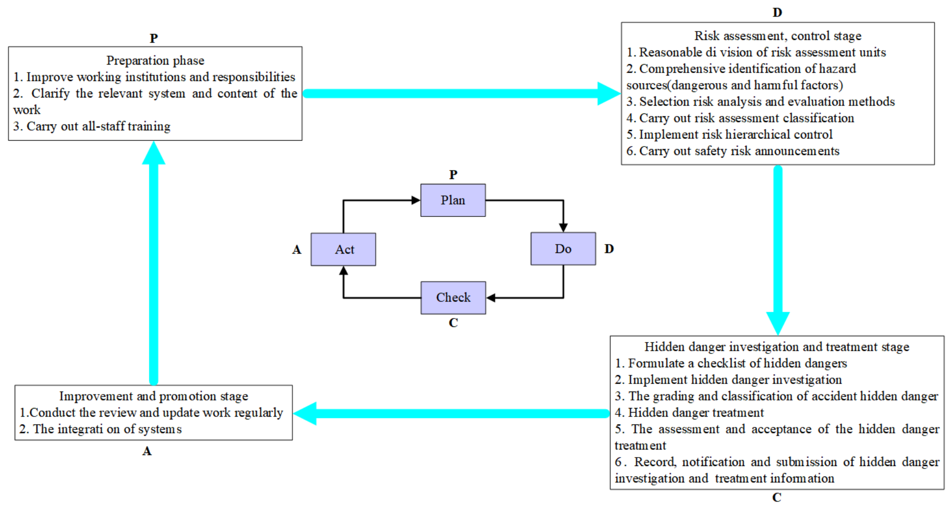


Figure 3. PDCA operation mode of double prevention mechanism in heating enterprises.

3. The Concrete Construction Implementation Steps of Double Prevention Mechanism in Heating Enterprises

3.1. Preparation Stage

In order to establish the double prevention mechanism in heating enterprises, a series of preparations must be done. The relevant working organizations, systems, and documents of double prevention mechanism should be established and improved. The work content, duty division, and safeguard measures should be clarified. The education and training activities of all staff on the double prevention mechanism should be carried out. The statistical table of risk points, the list of operational activities, the list of risk hierarchical control, and the rectification plan of major hidden danger and other documents should be prepared so that the employees can have the basic ability to identify, evaluate and control risks.

3.2. Risk Identification

(1) Division of risk assessment units (risk points)

According to the region, place, location, facilities, operation and operation activities, the risk assessment unit of heating enterprises can be divided into Large Units (LU), Sub-Units (SU), and Position Units (PU), and the Position Unit is the most basic unit of safety risk assessment. The divided risk assessment unit should contain at least one kind of energy or dangerous and harmful substances. In order to ensure that the risk assessment units at all levels are clearly organized, the units at each level can be coded according to certain numbering rules, and the units at the same level can be sorted by numbers.

Taking a coal-fired boiler room in China as an example, its main production process is shown in Figure 4. According to the main production area, site, position, facility, operation and operational activities, the boiler room can be divided into eight Large Units, including a coal conveying system, boiler room, slag removal system, water supply system, chimney, pipe network, limited space operation and public works. Each Large Unit can be divided into several Sub-Units and Position Units. This paper introduces the division form and numbering rules of the risk assessment unit by taking the above coal conveying system unit (LU_1) as an example, as shown in Table 1. LU_1, SU_1, SU_2, SU_3, PU_1, PU_2, PU_3, PU_4 in Table 1 are the coding symbols of risk assessment units of different levels.

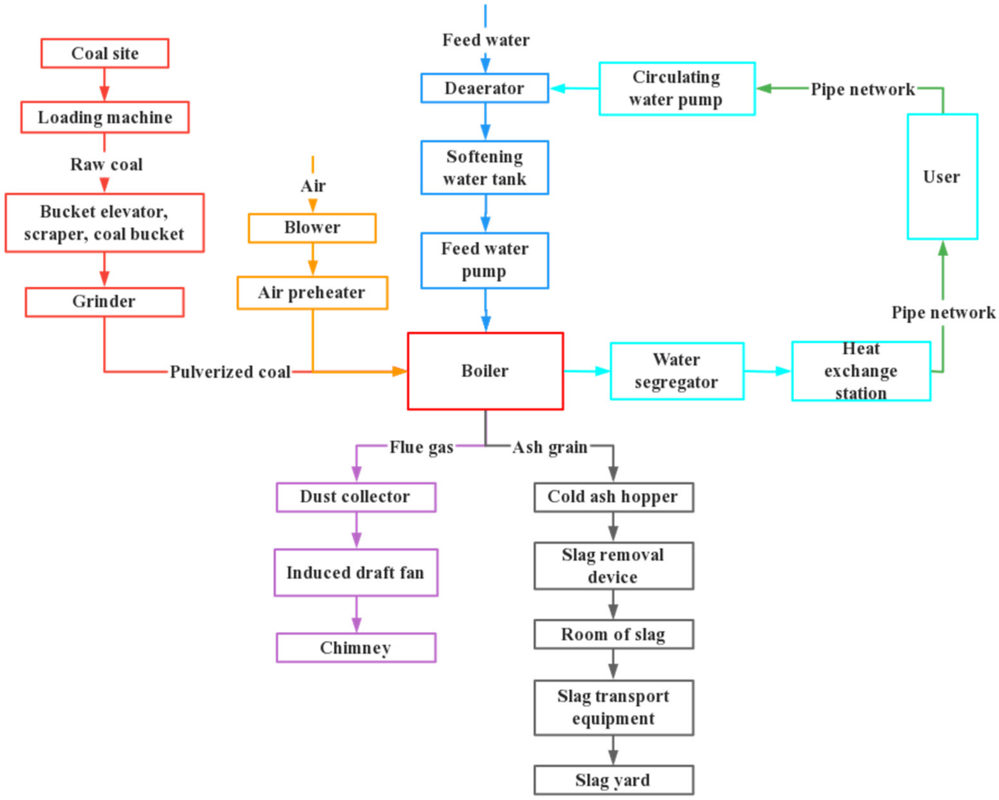


Figure 4. Overall process flow of a coal-fired heating enterprise in China.

Table 1. Division of coal conveying system units (LU_1) of a coal-fired boiler room in China.

Serial Number	Large Unit	Sub-Unit	Position Unit (Equipment and Facilities/Operational Activities)
1	Coal conveying system (LU_1)	Coal site (LU_1-SU_1)	Coal pile (LU_1-SU_1-PU_1) Windbreak and dust suppression net (LU_1-SU_1-PU_2)
		Coal conveying device (LU_1-SU_2)	The inlet through which coal enters (LU_1-SU_2-PU_1) Bucket machine (LU_1-SU_2-PU_2) Scraper (LU_1-SU_2-PU_3) Coal scuttle (LU_1-SU_2-PU_4)
		Loading machine (LU_1-SU_3)	Loading machine (LU_1-SU_3-PU_1)

(2) Identification of hazard sources (dangerous and harmful factors)

The identification of hazard sources was carried out according to the Chinese standards such as "Classification and Code for the Hazardous and Harmful Factors in Process" (GB/T 13861-2022) [22] and "Classification Standard for Casualty Accidents of Enterprise Workers" (GB 6441-1986) [23]. During the identification, it was necessary to analyze and determine the possible accident types of each unit; each accident type should be determined from the unsafe behavior of people (R), unsafe state of things (W, including environmental factors), and management factors (G) to find the source of dangers [24,25]. The identification and analysis results of hazard sources in each unit were expressed in the form of the hazard sources identification table. Taking the above sub-unit of coal conveying system of coal-fired boiler room which is called "coal yard" (LU_1-SU_1) as an example, the contents of hazard sources identification are shown in the first five columns of Table 2.

Table 2. The risk identification and assessment table of a fire accident that may occur in the coal site submit of coal conveying system (LU_1-SU_1) of coal boiler room.

Serial Number	Accident Category	The Weight of Dangerous and Harmful Factors Category (Q_i)	The Weight of Dangerous and Harmful Factors (q_i)	Proposed Control Measures and Weights		Existing Measures	F_{ci}	L_i	Accident Risk Assessment $D = LEC$					Hazard Level	Risk Level	Supplement Measures
				Suggested Control Measures	q_{ci}				Actual Calculated Value of L	L_{max}	E	C	D			
1	Fire	R (0.3)	Workers use open flames or smoke in coal site (0.3000)	It is strictly prohibited for workers to use open flame or smoke in the coal site	0.3000	It is strictly prohibited for workers to use open flame or smoke in the coal site	1/3	1.0000	5.7470	6	6	15	540	Level 1	Major risk	
		W (0.5)	Coal is stored in the open air for a long time (0.2111)	The coal storage bin is built in the factory to avoid coal stacking in the open air for a long time	0.1372		1	1.3720								The coal storage bin is built in the factory to avoid coal stacking in the open air for a long time
				Regularly spread out the coal pile	0.0739	Regularly spread out the coal pile	0	0.0000								
			No reasonable measures of timely observation and cooling are taken (0.1775)	Reasonable and timely observation and cooling measures should be taken	0.1775		1	1.7750								Reasonable and timely observation and cooling measures should be taken
			Fire equipment is not properly equipped or fails (0.1114)	Equipped with the corresponding type of fire equipment and regular inspection	0.1114		1	1.1140								Equipped with the corresponding type of fire equipment and regular inspection
		G (0.2)	No job risk notification is made (0.0542)	Develop a coal site operation risk notification card	0.0542	Develop a coal site operation risk notification card	0	0.0000								
			The safety management system or operating procedures of coal site are not perfect (0.0793)	Improve the coal site safety management system or operating procedures	0.0793	Improve the coal site safety management system or operating procedures	1/3	0.2643								
			Failure to carry out safety education and training for coal site workers as required (0.0665)	Strengthen the safety education and training of coal site workers	0.0665	Strengthen the safety education and training of coal site workers	1/3	0.2217								

Note: In order to correspond with the description below, corresponding colors can be added in Table 2 according to the actual risk assessment results.

3.3. Risk Assessment

3.3.1. The Improved Dynamic Risk Assessment Method

(1) The improved risk assessment method for operating conditions

Safety personnel should choose different risk analysis and evaluation methods to determine the hazard sources with different characteristics. At present, the widely used risk assessment methods in the market include the risk assessment method for operating conditions, the risk matrix method, and the preliminary hazard analysis, etc. In the traditional risk assessment method for operating conditions, the calculation was generally carried out in accordance with Formula (1). Based on the field operating conditions (or analogous operating conditions), an expert group of personnel who were familiar with the operating conditions was formed to score L, E, and C, respectively, according to the prescribed standards, and the average value of each group was taken as the calculated score of L, E, and C. The calculated risk score D was used to judge the risk level of the operating conditions. In this method, the value of the probability of accident (L) was mostly determined by the evaluator according to the situation of the evaluation object and the value standard, which could not reflect the control degree of dangerous and harmful factors, and there was a large deviation.

$$D = LEC \tag{1}$$

where, D is the risk score; L is the possibility of an accident; E is the frequency of human exposure to this dangerous environment; C is the loss consequence of an accident occurs. The values of L, E, and C are given in Table 3.

Table 3. The value standard of each parameter in the risk assessment method for operating conditions.

Probability of Accident (L)	Value of Fraction	Frequency of Human Exposure to Hazardous Environments (E)	Value of Fraction	Consequences of the Accident (C)	Value of Fraction
Totally expected	10	Continuous exposure	10	More than ten people died	100
Quite likely	6	Exposure during daily working hours	6	Several people were killed	40
Maybe, but not often	3	Once a week or occasional exposure	3	One person died	15
Completely unexpected, rarely possible	1	Monthly exposure	2	Severe disability	7
You can imagine, very unlikely	0.5	Several exposures per year	1	Have a disability	3
Highly unlikely	0.2	Very rare exposure	0.5	Minor injuries required medical care	1
It's practically impossible	0.1				

The research team improved the traditional risk assessment method for operating conditions [26–28], proposed to adjust the value of accident possibility (L) to the sum of the quantified values assigned to the actual control degree of all dangerous and harmful factors by the accident category. The actual calculated value of the possibility value (L_i) of the failure of a control measure for a dangerous or harmful factor can be calculated by Formula (3), and the actual calculated value (L) of the possibility of an accident can be finally determined according to Formula (2) [29,30]. The values and calculation methods of E, C, and D are the same as Equation (1).

The improved risk assessment method for operating conditions introduces the concept of "failure frequency" [31,32], which is the failure probability of an existing control measure within a certain assessment period and can be calculated by Formula (4). This method can reflect the actual control degree of dangerous and harmful factors, and make a more accurate judgment of L value. At the same time, it can be closely combined with the subsequent hidden danger investigation, so as to realize the bidirectional dynamic transmission of risk and hidden danger.

$$L = \sum_{j=1}^{C} L_i \tag{2}$$

$$L_i = L_{\max} q_{ci} F_{ci} \tag{3}$$

$$F_{ci} = n/N \tag{4}$$

In Equations (2)–(4), L is the actual calculated value of the possibility of an accident. Considering that the risk in actual work is often large, the value of L is selected as the value close to and greater than L_i in the score table. L_i is the actual calculated value of the possibility value of the failure of a control measure; $L_{\max}$ is the maximum value of L,which is 10; j is the serial number of a control measure; C is the total number of recommended control measures for an accident type; q_{ci} is the weight of the suggested control measures, which can be calculated by analytic hierarchy process software, as is shown in the third criterion layer in Figure 2; F_{ci} is the failure frequency; N is the total number of inspections for a recommended control measure in an evaluation period; n indicates the failure times of a recommended control measure in an evaluation period.

(2) Determine the weight of each level element of an accident type by using the analytic hierarchy process (AHP)

① Construct a hierarchical model of an accident type

Aiming at the fire accidents that may occur in the above coal site submit of coal conveying system (LU_1-SU_1) of coal boiler room [33], combined with the contents of its hazard source identification table (the first 5 columns in Table 2), the yaahp meta-decision software (analytic hierarchy process software) developed by Shanxi Yuan Decision Software Technology Co., LTD. in Taiyuan city of China was used to establish the hierarchical structure model of the fire accident type, as shown in Figure 5. The fire accident is the target layer, the category of dangerous and harmful factors (R, W, G) are the first criterion layer, various dangerous and harmful factors are the second criterion layer, and the control measures proposed for each dangerous and harmful factor are the third criterion layer.

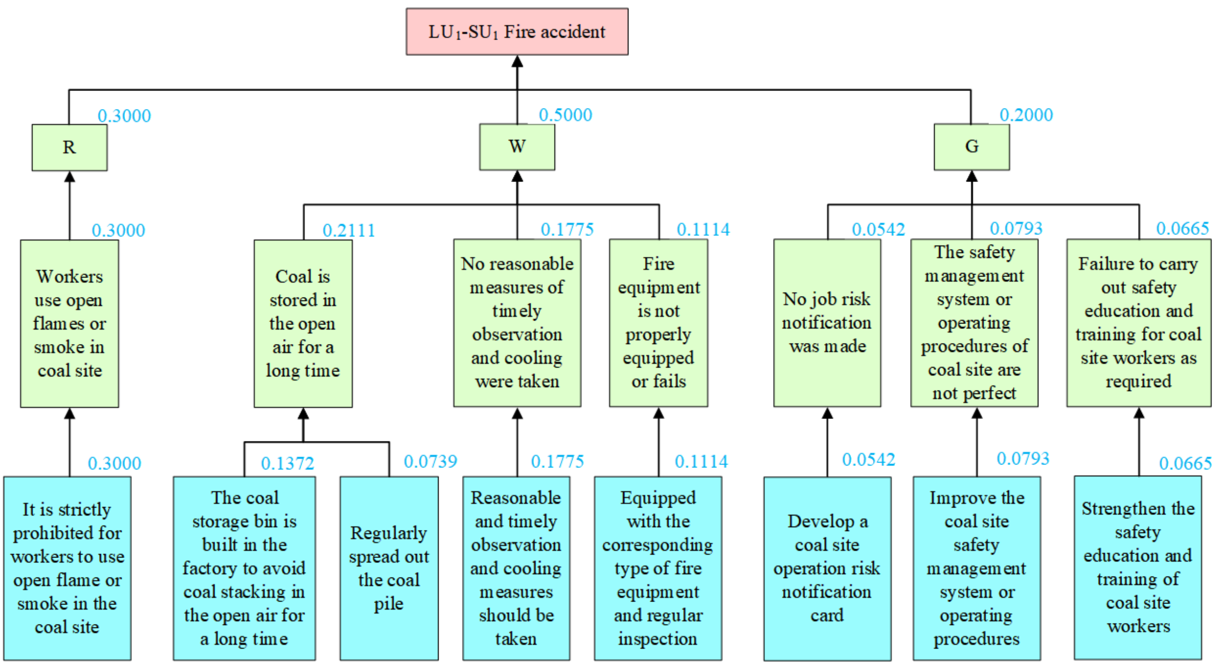


Figure 5. The hierarchical structure model and the weights of elements at all levels of a fire accident that may occur in the coal site submit of coal conveying system (LU1-SU1) of coal boiler room.

② Construct the judgment matrix of elements at all levels of an accident type

On the basis of the established hierarchical model of a certain accident type, the group decision module of yaahp meta-decision software was used to generate the AHP survey sub-software or online survey questionnaire, and some experts in related fields were invited to conduct extensive research. Each expert judged and gave the judgment matrix of elements at all levels according to the constructed hierarchical structure model of an accident type. Then, the judgment matrix data constructed by each expert was collected and imported into the yaahp meta-decision software. Finally, the value of the judgment matrix of elements at all levels of an accident type was determined by the arithmetic average method. The arithmetic average calculation method is shown in Equation (5):

$$p_{ij} = \sum_{m=1}^{M} p_{ijm} \tag{5}$$

In Formula (5), p_{ij} is the comparison result between the ith factor and the jth factor in the judgment matrix formed by elements of a certain level of an accident type; p_{ijm} is the comparison result between the ith factor and the jth factor in the judgment matrix formed by elements of a certain accident type and a certain level judged by the mth expert; m is the expert serial number; M is the total number of experts.

When determining the judgment matrix of elements at all levels of an accident type, the judgment matrix should be determined layer by layer [34]. For the above fire accident, if the judgment matrix of the first criterion layer was represented by A, and A was finally determined according to Formula (5):

$$\mathrm{A} = \begin{pmatrix} 1 & 0.6000 & 1.5000 \\ 1.6667 & 1 & 2.5000 \\ 0.6667 & 0.4000 & 1 \end{pmatrix}$$

Similarly, the correlation judgment matrix of the second criterion layer and the third criterion layer can be constructed as follows:

$$\mathrm{B}_2 = \begin{pmatrix} 1 & 1.8949 & 1.1896 \\ 0.5277 & 1 & 0.6278 \\ 0.8406 & 1.5929 & 1 \end{pmatrix}$$

$$\mathrm{B}_3 = \begin{pmatrix} 1 & 1.4617 & 1.1914 \\ 0.6841 & 1 & 0.8151 \\ 0.8394 & 1.2269 & 1 \end{pmatrix}$$

$$\mathrm{C}_{22} = \begin{pmatrix} 1 & 1.8571 \\ 0.5385 & 1 \end{pmatrix}$$

In the above fire accidents, there was a one-to-one relationship between some elements of the second criterion layer and some elements of the third criterion layer, so there was no need to construct a judgment matrix.

③ Determine the weight of elements at all levels of an accident type

For a certain accident type, after constructing the judgment matrix of elements at all levels, the maximum eigenvalue and eigenvector of each judgment matrix can be solved by the sum method, the root method, and the power method. Then, the consistency index, the random consistency ratio, and other parameters were calculated, and the consistency test of each judgment matrix was carried out to ensure its rationality. Finally, the weights of elements at all levels of an accident type were determined. In this paper, yaahp meta-decision software was used to solve the constructed judgment matrix in real time and carry out a consistency test by using the power method. Taking the above fire accident as an example, the weights of elements at each level of the accident calculated by the software

are shown in Figure 5, where the weights of suggested control measures for this type of accident are the weights of elements at the third level in Figure 5.

3.3.2. Result of Risk Assessment

According to the improved dynamic risk assessment method, the risk assessment and analysis of an accident type in a risk assessment unit of a heating enterprise can be carried out on the basis of the results of hazard source identification, and its risk fraction value and risk grade can be obtained. Taking the above fire accident as an example, the risk identification and evaluation table of the accident is shown in Table 2.

3.4. Risk Hierarchical Control

In the improved risk assessment method for operating conditions, the classification method of risk levels is the same as the traditional classification method, which is also divided into five levels according to the size of risk score (D). The risk level of a certain type of accident can be eventually divided into four levels, major risk, greater risk, general risk and low risk, which are marked by four colors, red, orange, yellow and blue. After risk levels are determined, control levels of different risks need to be determined in order to more accurately control risks.

According to the principle that the greater the risk, the higher the level of control, and the principle that the risk controlled by the superior must be also controlled by the subordinate so that the person responsible for risk control of different risk levels can be defined, key controls for operations that are difficult to operate, have high risk levels or may lead to serious consequences should be carried out. The levels of risk control can be increased or combined. Heating enterprises should reasonably determine the levels of risk control at all levels according to the basic principles of risk hierarchical control and the institutional settings of their own units.

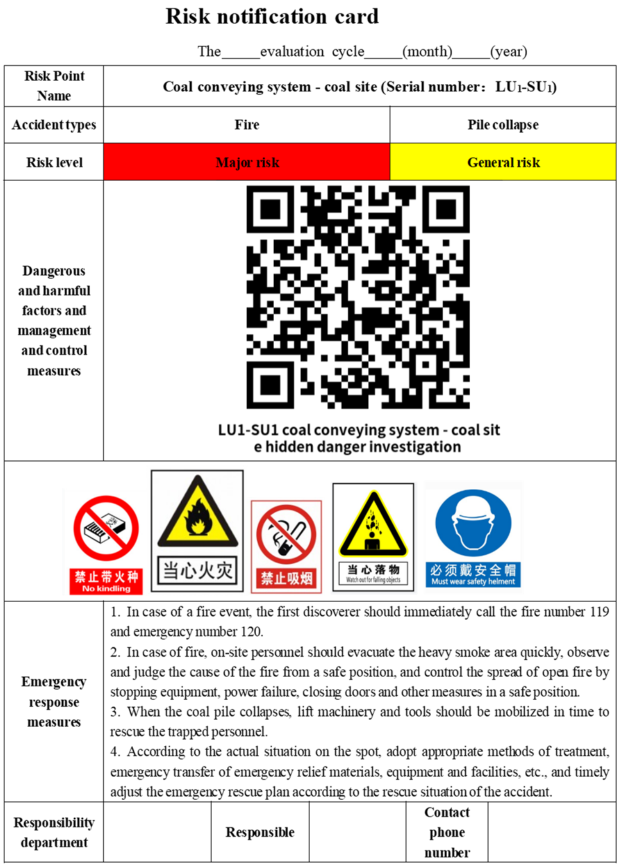
The corresponding relationship between accident risk level, risk level, management and control level, and sign color proposed in this paper is shown in Table 4. The corresponding relationship between the level of general accident hidden danger and the level of risk is also shown in Table 4, again reflecting the bidirectional dynamic transmission of hidden danger screening and management and risk hierarchical control. Taking the above fire accident as an example, it is concluded that the risk level of the accident is "major", which is indicated in red. The detailed contents are shown in Table 2.

Table 4. Comparison table of risk level, management and control level, and accident hidden danger level.

Corresponding Improved LEC Method Hazard Level	Level 1	Level 2	Level 3	Level 4 and Level 5
Risk level	Major risk	Greater risk	General risk	Low risk
General accident hidden danger level	Level 1 hidden danger	Level 2 hidden danger	Level 3 hidden danger	Level 4 hidden danger
management and control level	The company	The departmental	District team	Team
Corresponding color	Red	Orange	Yellow	Blue

3.5. Risk Notification

Based on the results of risk identification and assessment, heating enterprises should urge the implementation of various control measures and responsibilities, strengthen the control of change risks, and carry out safety-risk notification, such as making risk notification cards for key positions, setting up risk bulletin boards, drawing four-color charts of risk distribution, etc. Taking the above coal-fired boiler room as an example, the risk notification card of the coal site submit of coal conveying system (LU_1-SU_1) is shown in Figure 6, and the four-color diagram of risk distribution in the entire production area of the boiler room is shown in Figure 7.



Risk notification card

The____evaluation cycle____(month)____(year)

Risk Point Name	Coal conveying system - coal site (Serial number: LU_1-SU_1)				
Accident types	Fire			Pile collapse	
Risk level	Major risk			General risk	
Dangerous and harmful factors and management and control measures	LU1-SU1 coal conveying system - coal site hidden danger investigation				
	禁止带火种 No kindling; 当心火灾; 禁止吸烟; 当心落物 Watch out for falling objects; 必须戴安全帽 Must wear safety helment				
Emergency response measures	1. In case of a fire event, the first discoverer should immediately call the fire number 119 and emergency number 120. 2. In case of fire, on-site personnel should evacuate the heavy smoke area quickly, observe and judge the cause of the fire from a safe position, and control the spread of open fire by stopping equipment, power failure, closing doors and other measures in a safe position. 3. When the coal pile collapses, lift machinery and tools should be mobilized in time to rescue the trapped personnel. 4. According to the actual situation on the spot, adopt appropriate methods of treatment, emergency transfer of emergency relief materials, equipment and facilities, etc., and timely adjust the emergency rescue plan according to the rescue situation of the accident.				
Responsibility department		Responsible		Contact phone number	

Figure 6. The risk notification card of the coal site submit of coal conveying system (LU_1-SU_1).

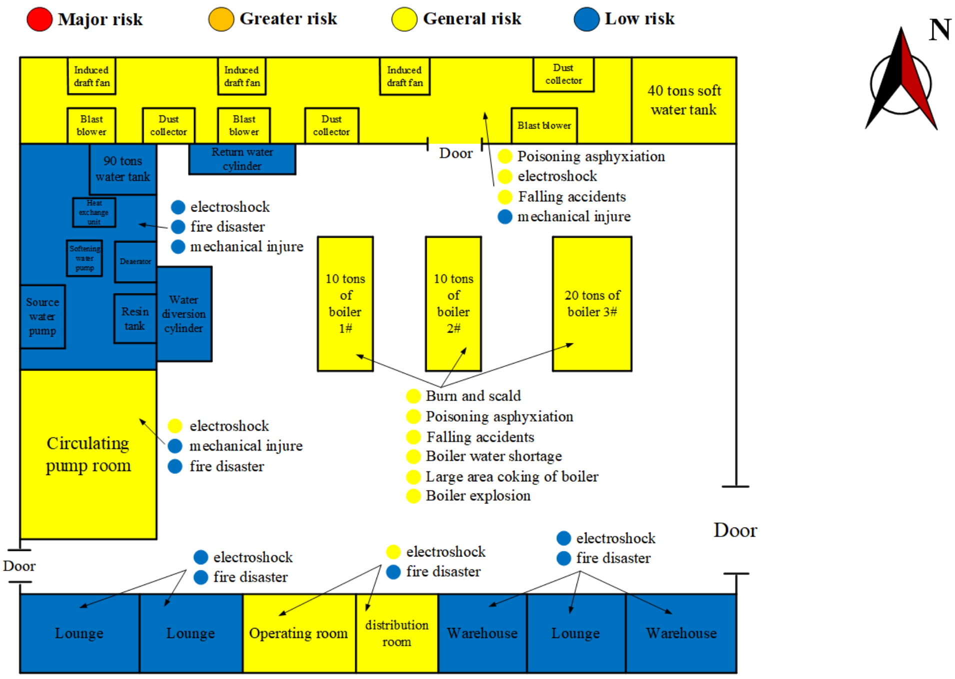


Figure 7. Four-color diagram of risk distribution of a coal-fired boiler room in China.

3.6. Hidden Danger Investigation and Treatment

In China, the hidden danger refers to the violation of production safety laws, regulations, rules, standards, procedures and the provisions of the production safety management system by the production and business units, or the occurrence of dangerous conditions of objects, unsafe behaviors of people, and management defects that may lead to accidents in production and business activities due to other factors. The research team also defined the failure of control measures as a "hidden danger" in this paper.

The hidden danger investigation and treatment is an important part of the double prevention mechanism construction of heating enterprises. Heating enterprises should establish a perfect hidden danger investigation and treatment system, clarify and refine the work requirements of hidden trouble investigation, classification, management, acceptance, summary and analysis, break down and implement the responsibilities one-by-one, and promote all employees to participate in hidden danger investigation and treatment.

3.6.1. Hidden Danger Investigation

Heating enterprises should prepare a targeted and practical hidden danger investigation list in advance, which can be divided into a production site and basic management investigation list. The hidden danger investigation list should at least contain the contents (or scope) of investigation, investigation types, investigation standards or requirements, etc. The hidden danger investigation contents mainly include the risk points and sources determined in the above hazard identification and assessment activities. According to the actual situation of heating enterprises, the type of investigation can be divided into comprehensive hidden danger investigation, professional hidden danger investigation, daily hidden danger investigation, post hidden danger investigation, etc. The investigation standards or requirements are the requirements of current national laws and regulations or industry standards. Taking the coal boiler room as an example, the hidden danger investigation table of the coal site submit of coal conveying system (LU1-SU1) is shown in Table 5.

Table 5. The hidden danger investigation table of the coal site submit of coal conveying system (LU_1-SU_1).

Investigation Type				**□Comprehensive Hidden Danger Investigation □DAILY Hidden Danger Investigation**	**□Professional Hidden Danger Investigation □Post Hidden Danger Investigation**		
Investigation Personnel				**Investigation Department/Team**	**Investigation Date**		**___(day)___(month)___(year)**
Serial Number	**Accident Category**	**Dangerous and Harmful Factors Category**	**Dangerous and Harmful Factors**	**Control Measures**	**Whether It Is Effective**		**Existing Problems**
					√	×	
1	Fire	R	Workers use open flames or smoke in coal site	It is strictly prohibited for workers to use open flame or smoke in the coal site			
		W	Coal is stored in the open air for a long time	The coal storage bin is built in the factory to avoid coal stacking in the open air for a long time			
				Regularly spread out the coal pile			
			No reasonable measures of timely observation and cooling are taken	Reasonable and timely observation and cooling measures should be taken			
			Fire equipment is not properly equipped or fails	Equipped with the corresponding type of fire equipment and regular inspection			
		G	No job-risk notification is made	Develop a coal site operation risk notification card			
			The safety management system or operating procedures of coal site are not perfect	Improve the coal site safety management system or operating procedures			
			Failure to carry out safety education and training for coal site workers as required	Strengthen the safety education and training of coal site workers			

Within a certain risk assessment cycle, all the hidden danger investigation tables of a certain risk assessment unit are collected and statistically analyzed to obtain n and N in Formula (4), and close attention should be paid to whether the control measures are effective. If the control measures fail, the risk assessment and grading should be carried out immediately. In this way, hidden danger investigation and risk assessment are dynamically linked to realize bidirectional dynamic conduction of risk-hidden danger, which is conducive to the accurate prevention and control of risk-hidden danger.

3.6.2. Hidden Danger Classification

According to the "Interim Provisions on the Investigation and Treatment of Hidden Accidents in Production Safety" in China, the hidden danger is divided into general accident hidden danger and major accident hidden danger. The research team subdivided the general accident hidden danger into level 1, level 2, level 3 and level 4, also using four colors of red, orange, yellow and blue. The level 1 hidden danger, level 2 hidden danger, level 3 hidden danger and level 4 hidden danger of general accident hidden danger, respectively, correspond to major risk, greater risk, general risk and low risk. The corresponding relationship is shown in Table 4, which further reflects the internal dynamic conduction relationship of risk-hidden danger. If any hazard source contained in the risk assessment unit meets the criteria for determining a major accident hidden danger of each industry formulated by the state, all hazard sources contained in the risk assessment unit shall be classified as major accident hidden danger, regardless of the risk level of the risk assessment unit, and all major accident hidden dangers shall be marked in red. The judgment standard of major accident hidden danger of heating enterprises refers to the notice of "Judgment Standard of Major production Safety Accident Hidden Danger of Industry and Trade (2017 edition)" [35] stipulated by China, which will not be repeated here.

3.6.3. Hidden Danger Treatment

The hidden danger treatment should adhere to the principles of hierarchical management, classified implementation, and management while investigating. The heating enterprises should implement monitoring and management for identified hidden danger according to the division of duties. When the hidden troubles are small, the management personnel should manage and solve them on the spot; when the hidden troubles are large and cannot be rectified immediately, rectification plans should be issued for them. The hidden danger treatment should be dealt with in a scientific way, with funds in place, in a timely manner, with responsibilities to people and within a specified time limit. Before dealing with hidden danger, preventive measures should be studied and formulated, and monitoring responsibilities should be implemented to prevent hidden danger from developing into accidents. The management of major accidents should achieve the "five implementation" requirements, including responsibility, measures, funds, time limit and plan.

The hidden danger investigation and treatment also includes the evaluation and acceptance of hidden danger treatment, information recording, notification and submission, so as to realize the closed-loop management of hidden danger investigation, registration, evaluation, grading, treatment, acceptance, report, number cancellation and other continuous improvement. The overall process of hidden danger investigation and treatment is shown in Figure 8.

3.7. Management Review and Continuous Improvement

In the construction and operation of the double prevention mechanism, heating enterprises in China need to re-evaluate and grade as long as they discover that the risk level or hidden danger level changes due to the failure of management and control measures or poor implementation [36]. At the same time, because the internal and external conditions of heating enterprises are constantly changing, in order to make the application of the double prevention mechanism follow the actual changes, dynamic risk assessment should be carried out to achieve the purpose of continuous improvement [37,38].

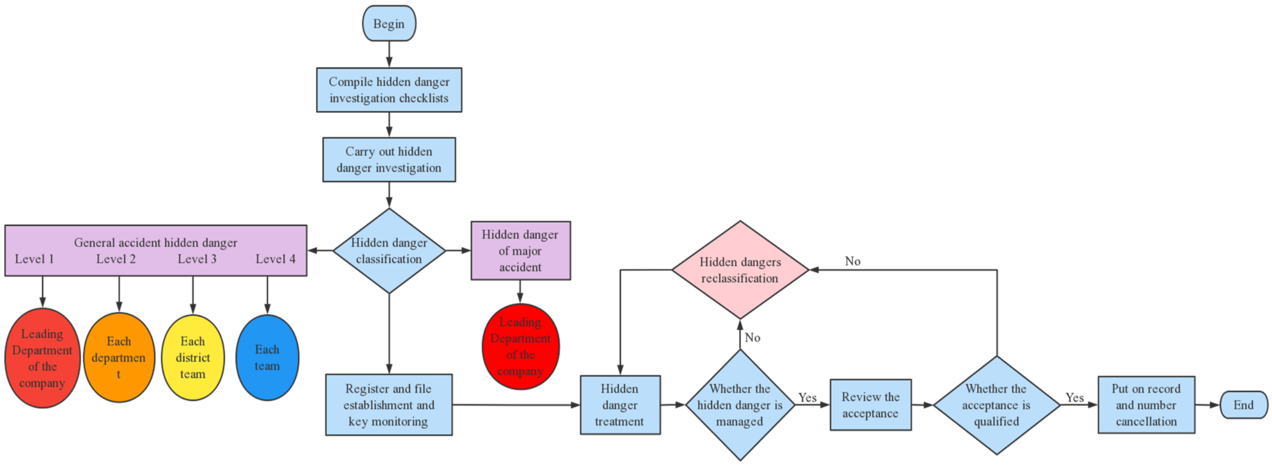


Figure 8. Flow chart of hidden danger investigation and treatment.

4. Discussions

(1) The heating enterprises need to establish a comprehensive and perfect double prevention mechanism that can operate effectively. It requires that the leaders of heating enterprises must learn and master the relevant contents of the construction of enterprise double prevention mechanism, improve the relevant documents and systems, carry out the education and training of all staff, increase the investment in safety, and pay attention to the research and development of the double prevention mechanism information system, etc.

(2) Chinese government supervision departments at all levels should establish and improve the documents, systems, standards and norms for the construction of the double prevention mechanism according to the actual situation in their jurisdiction, so that the enterprises can have rules to follow. The government supervision departments should broaden the way of learning the double prevention mechanism and provide technical support for enterprises. Meanwhile, the hierarchical risk control and supervision responsibilities should be fully implemented, and differentiated dynamic management of risks should be realized.

(3) The division method of risk assessment units proposed in this paper needs to be determined in combination with the actual production process or production system of heat supply enterprises. Users can reset unit numbers of each level according to certain rules. At the same time, users can further dig into the functions of the analytic hierarchy process software, so as to obtain a reasonable and standardized judgment matrix through expert group decision making. Thus, the actual calculated value of the accident possibility (L) calculated by the software is more accurate.

(4) The construction method of double prevention mechanism proposed in this paper requires the close cooperation and participation of on-site technical personnel and safety management personnel familiar with heating enterprises so as to ensure the effectiveness of risk identification and evaluation unit results, control measures, and hidden danger investigation and treatment results. At the same time, the staff should truthfully and accurately record the daily hidden danger investigation and treatment, form a strict and standardized record ledger, and combine the hidden danger investigation and treatment with risk hierarchical control. Therefore, the bidirectional dynamic conduction of risk-hidden danger can be truly realized.

5. Conclusions

(1) Combined with the current situation of safety management and double prevention mechanism construction in heating enterprises in China, based on the PDCA operation mode the overall process and specific steps of the double prevention mechanism construction in heating enterprises were elaborated in detail. By improving the tradi-

tional risk assessment method for operating conditions and combining with analytic hierarchy process, a new dynamic risk assessment method was proposed to realize dynamic risk assessment and accurate hierarchical control of accident risk.

(2) The concept of "failure frequency" was put forward, and the definition of "hidden danger" was added. By organically combining the risk hierarchical control and hidden danger investigation and treatment of heating enterprises, the bidirectional dynamic conduction of risk-hidden danger was truly realized, which could avoid the disconnect between hidden danger investigation and risk assessment, and ensure the construction effect of double prevention mechanism in heating enterprises.

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