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Coupling Analysis of Multiple Risk Factors in Oil and Gas Accidents Based on N-K Coupling Model

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Abstract: To delve into the determinants of peril and their interlacing dynamics in oil mishaps, and to prudently avert and curtail the jeopardy of oil calamities, an examination of the causative agents' risk interlinkage mechanisms in oil accidents was undertaken, traversing multiple elements across a quartet of strata: personnel, facilities, environment, and management. By combining the risk factors and impact issues in the risk coupling process of oil production and use, combined with the complex N-K coupling mode, the possibility of oil accidents occurring under various risk factors coupling was comprehensively calculated, and the risk coupling mode that affects the occurrence of oil and gas accidents was analyzed. The analysis of the results shows that the more factors involved in risk coupling in the electrical system, the higher the probability of electrical accidents. Among them, the probability of personnel single-factor accidents accounted for 3.64%, while the average value of other single-factor accidents was 1.403%. It can be seen that personnel operational errors are the key factor. To prevent and reduce oil and gas accidents, it is necessary to improve people's technical level and avoid the coupling of personnel participation in risk factors, and improve the safety construction level in oil and gas production and transportation.

1. Introduction

Oil and gas play a vital role in daily life and are the cornerstone of the survival of countries and people.They provide essential energy for homes and industries. According to the 2022 China Statistical Yearbook [1], 25.6% of the country's energy comes from oil and natural gas,However, with the wide application of oil and gas, the related safety problems are becoming increasingly prominent.Oil and gas accidents not only harm personal health, but also threaten public safety.

Therefore, it is indispensable to carry out a detailed inquiry.[2].

The production and transportation system of oil and gas is huge and complex, and the occurrence of accidents is both random and inevitable, which is the product of the interaction and combination of many factors[3-4]. Many researchers have discussed this in depth. For example, Liu Haifeng proposed to use fault tree analysis to analyze the risk factors of factory fire accidents. By constructing fault tree, fault tree analysis method intuitively displays the logical relationship between fire events and their possible causes and consequences, so as to evaluate the overall reliability and risk level of the system [5-6]. However, this method also has limitations. It usually only focuses on the fault path of a specific event, and may not fully consider all potential failure modes and event sequences, thus ignoring some potential failure paths and affecting the accuracy of risk assessment [7]. For this reason, some scholars have proposed other risk analysis models to complement and improve this approach. In his article, Wang Lijie suggested using a risk matrix model to assess the safety risks of construction sites [8-9]. By dividing the likelihood and impact into several levels and cross combining them to find common ground, the priority of various risks in construction accidents can be determined, and corresponding risk management strategies can be formulated. This risk analysis model also has certain limitations [10], and the evaluation results of the risk matrix are often influenced by the subjective judgment of the evaluator.

The previous researches on accident risk mainly focus on descriptive analysis, without in-depth quantitative risk assessment [11-12], and the conclusions obtained are also mostly based on the analysis of single-dimensional risk factors. In view of this, this paper intends to adopt the N-K coupling framework to analyze the risk, and analyze and evaluate the multiple risk factors of oil and gas accidents through the N-K coupling framework, so as to reveal the internal mechanism of oil and gas accident risk coupling. When analyzing oil and gas accidents, the N-K coupling framework takes into account both quantitative and qualitative dimensions [13], eliminates the interference of subjective factors in the assessment process, and takes human factors, mechanical device factors, environmental factors and management factors as the four indicators of risk factors [14], and then conducts in-depth research on risk coupling. On the basis of the existing research, this paper further constructed a risk index evaluation system of oil and electricity accidents based on the risk sources of organizational conditions, physical conditions and trigger conditions of accidents [15]. Combining N-K framework with probability theory, this paper constructed a oil and electricity accident risk coupling framework [16] to analyze the maximum risk coupling path. The root causes of oil and gas accidents were excavated to provide data support for oil and gas management [17].

2. Establishment of N-K Risk Coupling Model System

2.1 Risk Factors for Oil and Gas Accidents

Oil and gas accidents are divided into the following parts:

Oil production accidents: In the oil production process, there are mainly complex dynamic systems composed of multiple subsystems such as crude oil and natural gas extraction equipment, relevant operators, mechanical equipment, as well as personnel management and storage equipment training. This chapter mainly starts from the perspective of comprehensive quality supervision [18]. Through the collation, generalization and literature research of oil incidents, the main risk factors leading to leakage of heating pipelines are determined, including the following four aspects.

(1) The frequency of oil and gas accidents has increased due to human errors and inadequate technical capabilities. In particular, operators often cause accidents due to negligence, failure to strictly observe operating procedures or lack of professional skills, such as not timely detection and treatment of equipment abnormalities or taking wrong operation steps in emergency situations to

cause leaks and explosions. In addition, some enterprises have insufficient investment in staff training, so that operators do not have a comprehensive understanding of the operating principles and safety procedures of equipment, and fail to grasp the use of new technologies and equipment in a timely manner, thus increasing the risk of operational errors. Therefore, enterprises should strengthen safety training to ensure that operators are proficient in equipment operation and emergency handling measures, and regularly organize technical exchanges to help employees master the latest technology and equipment operation methods, so as to reduce oil and gas accidents caused by operational errors and technical deficiencies.

(2)Equipment factor is an important aspect that leads to increased risks in the process of oil and gas exploitation and storage, mainly manifested as equipment quality substandard, equipment and transportation pipeline aging, pipeline damage, equipment failure[19], equipment and pipeline corrosion and other problems. For example, some equipment cannot meet safety standards in actual use and is prone to failure due to poor manufacturing process or improper material selection. In addition, with the extension of use time, equipment and transportation pipes will gradually age, and material fatigue and wear will increase, increasing the risk of leakage and explosion. Pipeline damage and corrosion are particularly problematic, which not only reduces the strength and durability of the pipeline, but can also lead to oil and gas leaks, which can further cause fire or explosion. Therefore, periodic inspection and maintenance of oil and gas facilities and pipelines and rapid replacement of aging or damaged components are essential to ensure that they continue to operate in excellent condition, thereby significantly reducing the incidence of oil and gas accidents.

(3) Environmental factors refer to the accidents caused by the interference of the external environment in the production process of oil and gas resources, including natural disasters such as rainstorm, flood and earthquake. For example, heavy rains and floods may cause oil and gas facilities to be flooded or washed out, pipelines to break and leak due to debris flows and other reasons, while earthquakes may cause equipment damage, pipeline breakage, oil and gas leaks or even explosions. In addition, extreme weather conditions such as hurricanes and thunderstorms can also cause serious damage to oil and gas production facilities, affecting their normal operations. These environmental factors are uncontrollable and difficult to predict. Therefore, in the production process of oil and gas resources, these potential environmental risks must be taken into account, and effective protective measures must be taken, such as strengthening the disaster resistance of equipment, establishing emergency plans, and regularly conducting disaster simulation exercises to minimize oil and gas accidents caused by environmental factors.

(4)Management factors refer to the risks that may exist in the oil and gas system [20], mainly due to problems such as imperfect management system, unreasonable working procedures and inadequate management implementation. For example, the management system of some enterprises is not sound enough, the lack of detailed safety operation procedures and emergency plans, resulting in employees can not respond quickly and effectively when they encounter emergencies. In addition, unreasonable work procedures may lead to cumbersome operation steps or do not meet safety specifications, increasing the possibility of accidents. The management implementation is not in place, the supervision and inspection are mere forms, and the safety hazards are not discovered and rectified in time, leading to the accumulation of problems and eventually lead to accidents. In order to reduce the risk caused by management factors, enterprises should improve the management system, optimize the work procedures, and ensure that the safety management measures are strictly implemented, regular safety training and inspection, improve the overall management level, and significantly curb the incidence of oil and gas accidents.Figure 1 shows an accident caused by human errors.

Figure 1. Dalian oil pipeline explosion caused by human factors

Figure 2 shows the accident caused by equipment factors.

Figure 2. Oil leakage caused by aging of oil pipelines

Oil and gas transportation accidents: The land link in the oil and gas transportation system is a complex dynamic system composed of multiple sub-systems such as drivers, transportation machinery, road ecology, and governance. Accidents usually result from the triggering of numerous risk elements. [21-22].

(1) Driver factors: In the process of oil and gas transportation, the driver's behavior directly affects the incidence of accidents. These behaviors include the use of mobile phones while driving, distracted driving and other bad habits, as well as the driver's driving experience, skill level and reflexes. Safety awareness and responsibility of drivers are crucial for accident prevention, which involves whether to pay attention to safety regulations and whether to take the initiative to report potential hazards. Therefore, enterprises should strengthen the training of drivers, improve their safety awareness and responsibility, and urge them to strictly comply with traffic regulations and company safety regulations. At the same time, establish a sound supervision mechanism, timely detect and correct the driver's bad behavior, strengthen the evaluation of the driver, so as to minimize the oil and gas transportation accidents caused by the driver's behavior.

(2) Transportation vehicle factors:The risk factors of transport vehicles mainly stem from the aging of vehicle equipment, including engine failure, tire aging, brake pad breakage and so on. These problems are often caused by the wear and tear of the vehicle itself, which affects the safety performance of the vehicle. For example, engine failure may cause the vehicle to lose control or suddenly stall, tire aging increases the risk of a flat tire, and brake pad breakage may lead to brake failure, which can lead to serious traffic accidents. Therefore, regular inspection and maintenance of

the vehicle is essential, timely replacement of aging and damaged parts, to ensure that the vehicle is in good operating condition, so as to reduce the incidence of oil and gas transport accidents caused by the aging of vehicle equipment.

(3) Road environmental factors: Damage and collapse of transport roads, as well as weather causes such as heavy rain, snow and hail, are important factors in the occurrence of accidents. Broken roads can lead to loss of control or damage to vehicles, and the collapse of roads can cause serious traffic congestion and accident risk. At the same time, bad weather such as heavy rain and snow will affect the line of sight and friction on the road, increasing the difficulty of the driver to control the vehicle, easy to cause sliding and collision. Hail may damage the exterior of the vehicle and glass, and even cause the vehicle to lose control. Drivers should adjust their driving speed and attention according to weather conditions to reduce the risk of accidents caused by transport road conditions and weather.

(4) Management factors:Comprehensive training and effective management of drivers and other transport personnel is essential, including safety knowledge, operational skills and emergency response. This includes teaching them how to properly respond to various emergency situations and how to avoid accidents. At the same time, the management of transport vehicles is also essential, including regular maintenance, inspection and technical condition monitoring. Through a strict vehicle management system, potential problems can be discovered and solved in time to ensure that the vehicle is always in good running condition, thus reducing the probability of accidents. These training and management measures not only enhance the professionalism of drivers and transportation personnel, but also effectively improve the overall level of transportation safety and ensure the smooth progress of oil and gas transportation.

Figure 3 shows the accident caused by driver factors.

Figure 3. Oil tanker rollover caused by driver playing with mobile phone

Table 1 shows the risk table for oil and gas resource transportation.

Table 1. Risk factors for oil and gas resource transportation accidents

Primary risk factors	Secondary risk factors
Driver	Drowsy driving R1 Driving experience R2 Distracted driving R3
Transport vehicles	Flat tires R4 Brake failure R5 Vehicle lights R6

Road environment	Rainstorm R7 Blizzard R8 Fog R9 Sharp bends R10
Management	Negligence in the investigation of hidden dangers R11 Negligent maintenance of the vehicle R12

Table 2. Risk factors for oil and gas production and storage accidents

Primary risk factors	Secondary risk factors
Operators	The design is not reasonable R13 Operational errors R14 The construction quality is not up to standard R15
Mining and storage equipment	Aging equipment R16 Lack of safety equipment R17
Surroundings	Earthquake R18 Flood R19
Production management personnel	Equipment inspection is not in place R20

Tables 1 and 2 break down the transport and production accident risk factors for oil and gas resources into primary and secondary risk factors to better understand and manage these risks. In the transportation of oil and gas resources, the primary risk factors include two main aspects: drivers and transport vehicles. The risks for drivers mainly include fatigue driving, driving experience and distracted driving, while the risks for transport vehicles include tire damage, brake failure and so on. For the production and storage of oil and gas resources, the primary risk factors include operators, mining and storage equipment, the surrounding environment and production management personnel. These risk factors include operational errors, aging equipment, and natural disasters such as earthquakes. Each primary risk factor is further subdivided into secondary risk factors, making the possible causes of each risk clearer. This segmentation facilitates coupling analysis of various risk factors to more effectively prevent and respond to accidents that may occur during the transportation and production of oil and gas resources.

2.2 Coupling Mechanism of Oil and Gas Accident Risk

Coupling is a quantitative concept that reflects the interrelation and function of various parts in the system. Risk coupling involves the interdependence and influence of various risk factors in complex systems. Oil and gas accident risk coupling is caused by many factors such as operation error, equipment aging, environmental impact and management defects, and is usually not caused by a single factor [23-25].

Improper operation leads to errors, equipment aging leads to failures, unsafe environment weakens working conditions, and management defects lead to management failures [26]. These risk factors affect each other. Defects in the management system lead to operational errors, and interference from the external environment causes equipment failures. Reaching the risk threshold of a certain factor does not necessarily directly lead to an accident. It is often the coupling of interdependence and influence of factors that transforms the risk into an irreversible accident [27-28]. The coupling mechanism between specific oil and gas accident risk factors is shown in Figure 4.

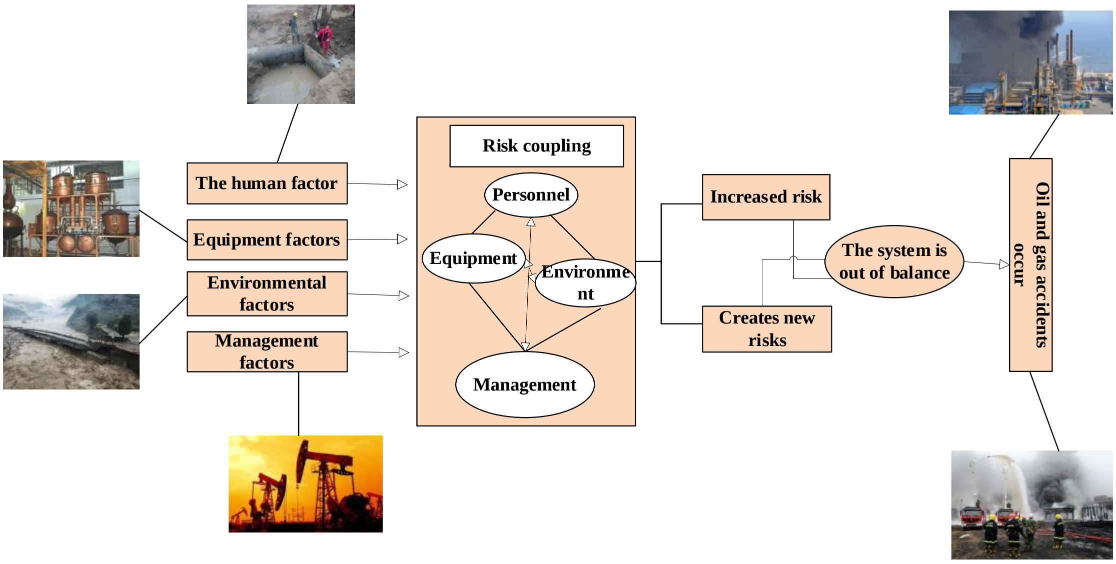

Figure 4. Coupling mechanism diagram

3. Construction of N-K Coupling Model for Oil and Gas Accidents

As early as the 1920s, biologists proposed the N-K coupling model by focusing on the self-organizing properties and dynamic behavior of biological systems, in order to describe the interactions and regulatory relationships between genes in biological systems. This is a universal model for solving the interaction of internal elements in complex dynamic systems [29-30]. The N-K model, displayed in Formula 1, computes coupling values.

$$T_N^M(a,b,c,d)=\sum_{h=0}^{H}\sum_{i=0}^{I}\sum_{j=0}^{J}\sum_{k=0}^{K}\bullet\log_2\frac{P_{h,\ i,\ j,\ k}}{P_h\bullet P_i\bullet P_j\bullet P_k} \quad (1)$$

a is represented as human factors in factor coupling; b is represented as equipment factors in factor coupling; c represents environmental factors; d represents management factors.

$P_{h,\ i,\ j,\ k}$ - It's the odds of each factor

T_N^M - the risk coupling value of the M-th combination.

3.1 Types of Risk Coupling in Oil and Gas Accidents

Risk coupling analysis of oil and gas accidents reveals how different factors promote the occurrence of accidents, which are divided into four categories: Single-factor coupling [31-32] focuses on a single risk point such as human error or equipment failure, while two-factor coupling involves the interaction of risk factors with different attributes such as people and equipment, environment and management. The three-factor coupling further takes into account the superimposed effects of operational error, equipment aging and adverse environmental conditions, increasing the risk of accidents.The integration of the four elements reflects the interaction between personnel, machinery, ecology and governance, highlighting the complex risks caused by the interweaving of multiple elements, which is extremely crucial for the development of comprehensive safety strategies and preventive measures.

3.2 Empirical analysis

200 oil and gas accidents in different areas were collected, and the risk factors of these 200 accidents were summarized into four factors, and binary codes 0 and 1 were used to represent whether the four risk factors affected the occurrence of oil and gas accidents.0 means no coupling; 1 Coupling exists. If it is a single-factor coupling of personnel factors, it is represented as P_{1000}. Table 3 presents the number and probability of accidents.

Table 3. Risk coupling table for oil and gas accidents

Coupling Category	Type of accident	P
Single-factor	P1000 P0100 P0010 P0001	0.0364 0.0169 0.0098 0.0154
Two-factor	P1100 P1010 P1001 P0110 P0011 P0101	0.0456 0.0433 0.0536 0.0214 0.0321 0.0345
Three-factor	P1110 P1011 P1101 P0111	0.0654 0.0754 0.0987 0.0564
Four-factor	P1111	0.0987

Table 3 delineates the probabilistic spectra of oil and gas incidents within a spectrum of risk interlinkages. The underpinning data hinge on binary ciphers to signify the engagement of disparate risk elements in such interlinkages. The "Type of Interlinkage" column delineates quartet interlinkage modalities: univariate, bivariate, trivariate, and multivariate interlinkages. Beneath each interlinkage modality, the distinct genre of incidents is enumerated, denoted by a tetrad of numerals succeeded by the letter P, with "1" signifying the participation of the pertinent element in the interlinkage and "0" signifying its absence from the interlinkage.

"P1000" under "Single-factor" means that only the first factor (the people factor) is involved in coupling, while the other factors (equipment, environment, and management) are not. The corresponding accident probability is 0.0364, which means that in all the collected oil and gas accident samples, only the accident probability caused by human factors coupling is about 3.64%.

For "Two-factor", indicating the accident probability in the case of two-factor coupling. Similarly, "three-factor" and "four-factor" indicate that there are Three and Four factors coupled at the same time, and the corresponding accident probabilities are 0.0654 to 0.0987 and 0.0987, respectively.

The data in Table 3 reveal an important trend: As the number of coupling factors increases, so does the probability of oil and gas accidents. In practice, the data in Table 3 can be used to identify which coupling of risk factors has the greatest impact on oil and gas accidents, thereby helping decision makers and managers to develop more effective prevention and risk mitigation strategies. In this way, resources can be more targeted, safety management processes can be optimized, and the risk of accidents can be reduced.

The single-factor coupling values of other factors are shown in Table 4.

Table 4. Single factor accident probability

Coupling mode	P0...	P1...	P.0..	P.1..	P..0.	P..1.	P...0	P...1
Probability	0.00785	0.00974	0.00687	0.00865	0.00798	0.00887	0.00745	0.00865
Type of factors	Personnel		Equipment		Environment		Management	

Table 4 lists each of the eight possibilities. Each possibility corresponds to a coupling of different types of risk factors, including people, equipment, environment, and management. By comparing the probability of different coupling modes, we can roughly understand the impact of various types of risk factor coupling on the probability of oil and gas accidents.Table 5 illustrates the probability computation of dual-factor coupling.

Table 5.Two-factor accident probability

Coupling mode	P0011	P0101	P1010	P1100	P0101	P1100	P0110	P1010
Probability	0.0166	0.0250	0.0323	0.0359	0.00823	0.0259	0.0336	0.0323
Coupling mode	P0101	P1100	P0101	P1001	P1010	P.10.	P.01.	P.11.
Probability	0.0153	0.0366	0.0262	0.0417	0.0117	0.0232	0.0382	0.0111
Coupling mode	P.0.0	P.1.0	P.0.1	P.1.1	P..00	P..10	P..01	P..11
Probability	0.0213	0.0306	0.0276	0.0204	0.0133	0.0386	0.0206	0.0273

Table 5 shows the probability of oil and gas accidents affected by dual factor coupling under different conditions. Each coupling pattern corresponds to the way in which the two risk factors are related, for example, P0011 indicates that both people and equipment occur simultaneously, while P.10. Indicates that personnel factors occur but equipment factors do not occur. It can be observed from the table that the probability of accidents is usually higher in the case of two-factor coupling than in the case of single-factor coupling. This is because there may be mutual influence and superposition effect between the two risk factors, which increases the possibility of accidents. For example, when the two factors of personnel and equipment occur at the same time (P0011), the probability of accidents is relatively high due to the dual risks of possible operation errors and equipment failures. Therefore, the impact of two-factor coupling is usually more significant than that of single factor coupling, which indicates that in the prevention and management of oil and gas accidents, more attention should be paid to the interrelationship between different risk factors to comprehensively consider and effectively respond to various possible risk situations. The probabilities of coupling of the other three factors are shown in Table 6 below.

Table 6. Multi-factor accident probability

Coupling mode	P000.	P100.	P010.	P001.	P110.	P101.	P011.	P111.
Probability	0.0354	0.0451	0.0314	0.0145	0.0365	0.0421	0.0424	0.0614
Coupling mode	P10.0	P01.0	P00.1	P11.0	P10.1	P01.1	P11.1	P00.0
Probability	0.0636	0.0454	0.0778	0.0549	0.0646	0.0312	0.0769	0.0515
Coupling mode	P.000	P.100	P.010	P.001	P.110	P.101	P.011	P.111
Probability	0.0569	0.0658	0.0314	0.0645	0.0654	0.0514	0.0456	0.0456

It can be seen that the accident probability of multi-factor coupling is greater, and the average value of calculated factor coupling is shown in Table 7.

Table 7. Mean value of risk coupling

Coupling type	Single-factor coupling risk	Two-factor coupling risk	Multi-factor coupling risk
	P1	P11	P111
Numeric value	0.008258	0.025564	0.050054

According to Table 7, the probability of risk coupling increases as the risk factors increase. Tables 5 an 6 and Formulas 1-6 are used to calculate the coupling value T ranking of various risk factors in different ways, as shown in Table 8, arranged according to the coupling value from small to large.

Table 8. Coupling values of risk factors for oil and gas accidents

Coupling factors	Abbreviation	T
Human-Equipment-Environment-Management	T(a,b,c,d)	0.0876
Human-Equipment	T(a,b)	0.0412
Equipment-Environment-Management	T(b,c,d)	0.0356
Human	T(a)	0.0321

From Table 8, it can be seen that the coupling factors with the highest risk are all influenced by human factors.

In order to study the practicability of this model in other fields, a cross-industry risk coupling comparative experiment is designed. The purpose of this experiment is to identify the unique risk coupling characteristics of different industries through comparative analysis, and to provide scientific basis for cross-industry risk management strategies. In addition to the oil and gas industry mainly studied in this paper, chemical industry and construction industry are also selected for comparison in the experiment to ensure that the experimental results are representative. The data used in the experiment included historical accident records, risk reports, and relevant industry safety standards for each industry to build a data set.The study classifies key hazards in different sectors, gauges their interconnectedness, and evaluates their effect on accident likelihoods. Factors, labeled from 1 to 5, encompass equipment breakdowns, operational mishaps, environmental influences, managerial deficiencies, and deliberate interference, as depicted in Table 9:

Table 9 Results of cross-industry experiments

Industry	Risk factor	Coupling strength with factor 1	Coupling strength with factor 2	Coupling strength with factor 3	Coupling strength with factor 4	Coupling strength with factor 5	Accident probability (%)
Oil gas	Factor 1	1	0.06	0.05	0.04	0.03	1.5
	Factor 2	0.06	1	0.05	0.04	0.03	1.2
	Factor 3	0.05	0.05	1	0.04	0.03	1.0
	Factor 4	0.04	0.04	0.04	1	0.05	0.8
	Factor 5	0.03	0.03	0.03	0.05	1	0.5
Chemical engineering	Factor 1	1	0.04	0.06	0.05	0.03	1.4
	Factor 2	0.05	1	0.04	0.03	0.02	1.1
	Factor 3	0.05	0.03	1	0.06	0.04	0.9
	Factor 4	0.04	0.02	0.02	1	0.07	0.6
	Factor 5	0.07	0.04	0.05	0.03	1	1.2
Architecture	Factor 1	1	0.05	0.04	0.03	0.02	1.3
	Factor 2	0.04	1	0.03	0.02	0.01	1.0
	Factor 3	0.05	0.03	1	0.03	0.02	1.1
	Factor 4	0.03	0.02	0.02	1	0.06	0.8
	Factor 5	0.02	0.01	0.01	0.06	1	0.7

In Table 9, the oil and gas sector, equipment malfunction's coupling strength with operational errors is 0.06, while with environmental influences, managerial lapses, and deliberate sabotage, it stands at 0.05, 0.04, and 0.03 respectively, leading to a 1.5% accident probability. Operational errors have a 1.2% accident probability, closely linked to managerial shortcomings. In the chemical industry, equipment malfunction's coupling strength surpasses that of operational errors and environmental influences (0.04 and 0.06 respectively), resulting in a 1.4% accident probability. Despite lower coupling strength, managerial deficiencies highlight their significance with a 0.6% accident probability, when coupled with environmental influences and deliberate sabotage.The coupling strength of operation error and environmental impact is 0.04, the probability of accident is 1.1%, and the operation control should be strengthened. In the construction industry, the coupling strength of equipment failure with operational error and environmental impact is higher (0.05 and 0.04, respectively), resulting in a probability of accident of 1.3%, indicating that operational error and environmental impact may increase the frequency of equipment failure. The coupling strength of management loss and human damage is 0.06, the probability of accident is 0.8%, and management control should be strengthened. The probability of misoperation is 1.0%.

By analyzing the data in Table 9, we can fully reflect the effect of this model on risk assessment in three different industries. The model of this paper has good practicability in the analysis of different industries, which proves that the model of this paper is accurate in the exploration of risk factors.

3.3 Results

The study showed that the human factor accounted for the highest proportion of single-factor accidents, highlighting the urgency of upgrading operator skills and safety awareness. In addition, establishing risk warning systems and strengthening equipment and environmental management are key measures to reduce accident rates, and these findings provide valuable data support and prevention strategies for safety risk management in the oil and gas industry.

3.4 Article Contribution

The specific contributions of this paper are as follows:

Through the N-K coupling model, this paper makes a comprehensive quantitative and qualitative analysis of the human, equipment, environment and management factors in oil and gas accidents, reveals the interaction and interlinkage between these factors, and explains how they synergetically lead to the occurrence of accidents. Furthermore, the model is used to calculate the probability of accidents under different interleaving situations, which provides data support for the quantitative grasp of accident risk. In addition, the coupling values of each risk element are calculated and sorted through the model, and the factors that have the greatest impact on the occurrence of oil and gas accidents are identified, thus providing key quantitative indicators for risk management.Strategies to prevent and reduce accidents: Based on the results of risk coupling analysis, strategies to prevent and reduce oil and gas accidents are proposed, including improving the technical level and safety awareness of operators, improving equipment and environmental management, and establishing risk early warning systems.

Safety Management Recommendations: This paper proposes safety management recommendations based on risk coupling analysis to improve the safety of the oil and gas industry by reducing human interference, strengthening equipment and environmental management, and establishing effective risk early warning systems.

Empirical data analysis: Through the empirical analysis of the oil and gas industry accident data of a province, the application effectiveness of the N-K coupling model in the actual oil and gas accident risk assessment is verified.

4. Conclusions

The model in this paper can significantly reveal the coupling relationship and action mechanism of multiple risk factors in oil and gas accidents. The results highlight the significant impact of human factors in oil and gas accidents, which requires the oil and gas industry to strengthen the training and education of operators to improve their safety awareness and operational skills. At the same time, the study proposed the importance of establishing a risk early warning system, which can identify and respond to potential safety risks in time, so as to effectively prevent the occurrence of accidents. In addition, the empirical analysis of the accident data of the oil and gas industry in a province was suggested to strengthen the equipment and environmental management, which verified the effectiveness of the model in the accident risk assessment, and provided data support and prevention strategies for safety risk management.

Future research can be explored in depth from multiple perspectives, for example, to further develop and optimize the risk early warning system to improve its prediction accuracy and response speed. Researchers can explore the development of a comprehensive risk management training system aimed at improving safety awareness and risk response capabilities of oil and gas workers. In addition, interdisciplinary research methods can provide a more comprehensive perspective for the analysis of risk factors of oil and gas accidents, and combining theories and methods in engineering, psychology, management and other fields can better understand the complexity of risk coupling. At the same time, by collecting and analyzing more empirical data, the N-K coupling model can be validated and improved to improve the applicability and accuracy of the model. The development of intelligent risk assessment tools is also a worthy research direction, the use of artificial intelligence and big data analysis technology, can improve the efficiency and effect of risk assessment. The impact of environmental factors on risk coupling is also an important part of future research, and researchers can further explore how to reduce the risk of oil and gas accidents by improving environmental management. Finally, the comparative analysis of international oil and gas accident cases can provide reference for oil and gas safety management in different countries and regions.

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