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A Method for Grading the Hidden Dangers of Urban Gas Polyethylene Pipelines Based on Improved PLC Methods

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Abstract: The classification of hidden dangers in urban gas pipelines plays a vital role in the smooth operation of urban gas pipelines and in solving the problem of hidden safety dangers in urban gas pipelines. In recent years, the number and proportion of polyethylene (PE) pipelines in urban gas pipelines are increasing day by day, but the current classification of hidden dangers in urban gas pipelines is still based on steel pipelines, and the classification method is highly subjective. Therefore, this paper proposes an improved PLC method that integrates the use of a risk matrix and compensation coefficient to solve the problem of grading the hidden dangers of PE pipelines of urban gas. The improved PLC method is based on the failure database of urban gas PE pipelines to obtain the vulnerability and severity of consequences when determining the initial level of hidden dangers, and the compensation coefficient is modified according to regional vulnerability, ease of rectification, condition around the pipeline, positioning technology, leak detection technology, and emergency ability, which can effectively reduce the subjectivity of hidden danger classification. Using the improved PLC method to classify urban gas pipelines for hidden dangers can provide pipeline operating companies with a basis for decision making in the process of hidden danger disposal and effectively reduce pipeline safety risks.

Keywords: urban gas pipelines; polyethylene; hidden dangers classification; failure database of pipelines; compensation coefficient

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1. Introduction

Urban gas mainly includes artificial gas, liquefied petroleum gas, and natural gas [1]. Artificial gas is gradually drawing people's attention due to its high cost, poor gas quality, and the pollution in the environment during the production process of gas source plants. Promoting the development and utilization of clean energy is the current trend of energy policy in all regions [2,3] and has led to numerous related technological studies [4,5]. Compared with liquefied petroleum gas, natural gas is gaining popularity as a cleaner, more efficient, and cheaper energy source, and is currently the main transmission medium for urban gas pipelines. Natural gas, as an effective solution for energy saving and emission reduction, has huge room for development and will be the most consumed energy source in the foreseeable future. As the popularity of natural gas increases [6], it is inevitably accompanied by more frequent pipeline accidents [7]. From the perspective of the laying environment of urban gas pipelines, most of them are in densely populated areas, and once an accident occurs, it is very easy to cause significant casualties and property damage. Therefore, the entire distribution area of the urban gas pipeline is all high-consequence areas [8]. This has put forward higher requirements for the safe operation of urban gas pipelines [9], and as a key part of the daily management and maintenance of urban gas pipelines, the importance of the classification of hidden pipeline dangers has become increasingly prominent.

With the rapid development of technologies related to urban gas pipelines in recent years, polyethylene gas pipelines have been widely used in urban gas transmission pipelines for their good anticorrosive properties, long service life, convenient construction, and economic cost, which have become the most remarkable achievement in the field of "plastic instead of steel" [10].

In this context, the gradual replacement of metal pipes by PE pipelines, coupled with the continuous development of urban gas pipeline networks, have put forward new requirements for urban gas pipeline management, which will inevitably bring new challenges to urban gas pipeline management. The original urban gas pipeline management method is more suitable for a steel pipeline [11], and it is inevitable that there will be a problem of maladaptation. Therefore, it is necessary to accelerate the construction of a classification method for PE gas pipelines with hidden dangers to achieve the goal of scientific management of pipelines according to hidden danger levels and further reduce the possibility of failure of urban gas pipelines, thus ensuring a safe, economical, and smooth operation of pipelines and escorting the smooth work of gas enterprises.

2. Literature Review

At present, scholars in the field have relatively more research on the problem of long-distance pipelines' hidden danger classification, but relatively less research on urban gas pipelines, especially PE pipelines, which is very unfavorable to the safe operation of urban gas PE pipelines [9]. There are three general categories of technical research methods for classifying hidden dangers: qualitative, semiquantitative, and quantitative analysis. Qualitative research methods generally use the direct determination method to classify hidden dangers, which is currently used by most companies and legal codes to determine hazard levels [12]. The quantitative hidden dangers' classification method can accurately calculate the probability of each hazard causing an accident while accurately assessing the outcome of the accident, but the calculation process using this method alone is complex and the risk analysis process is demanding [13]. While the qualitative research method is simple and convenient, it is not very reliable. Therefore, a semiquantitative method with a high degree of objectivity and operability is needed for the classification of hidden dangers.

Commonly used semiquantitative hazard classification methods include layers of protection (LOP), the MES evaluation method, the PLR method, and the PLC method. The LOP model classifies accident hidden dangers into seven categories according to their impact on the safety function of the protection layer of the system: design-build accident hidden dangers, basic process control accident hidden dangers, over-run alarm accident hidden dangers, safety control accident hidden dangers, active protection accident hidden dangers, passive protection accident hidden dangers, and emergency response accident hidden dangers. It is further classified into three levels according to the degradation of safety protection function caused by the hidden danger: level 1 accidental hidden danger significantly affects the safety function of LOP, causing the loss of its main function or overall paralysis; level 2 accidental hidden danger causes partial loss of LOP's function; and level 3 accidental hidden danger affects only one or a few functions of LOP, and the overall function of LOP can still be maintained. Among them, level 1 hidden dangers correspond to major accident hidden dangers, and levels 2 and 3 correspond to general accident hidden dangers [14]. This classification is based on the nature of accident hidden dangers that can degrade or even disable LOP safety protection, facilitating system analysis. However, the definition, classification, and grading of accident hidden dangers based on the accident doctrine are increasingly unable to meet the needs of safe production practice [15]. The MES evaluation method classifies the status of control measures M, the frequency of exposure E, and the consequences of loss S from hidden dangers, leading to accidents at several levels. For specific operating conditions, the values of M, E, and S are selected appropriately, and the level of hidden dangers is determined according to the product of the multiplication. The method is mainly aimed at the hidden dangers that cause personal injury accidents and occupation-related diseases and is not well adapted to the pipeline hidden danger classification situation [16]. The PLR method combines three evaluation factors, namely, the probability (P) of an accident caused by hidden dangers, the potential loss (L) of an accident, and the affect region (R), and proposes the "PLR Hidden Hazard Rating Scale" to represent the results of classifying accident hidden dangers [17]. The pipeline hidden danger classification results obtained by this method cannot be further adjusted and still require the assistance of other appropriate control and correction measures to obtain the final hidden danger classification results. In contrast to the above methods, the PLC method is a hidden danger grading evaluation method specifically proposed for urban gas enterprises. The determining factors of the hidden danger grade under this method are the possibility of accident P, the degree of accident loss L, and the compensation coefficient C. First, the initial level of hidden dangers is determined by P and L, and the initial level of hidden dangers is flexibly modified by the compensation coefficient C in terms of the material characteristics of the pipeline and management focus and so on. This is a relatively effective method of grading hidden dangers in urban gas pipelines at present [18]. However, the traditional PLC method has a strong subjective initial grade and cannot highlight the management characteristics of urban gas PE pipelines, which cannot be clearly distinguished from traditional steel pipelines.

To address this issue, this paper proposes an improved PLC method applicable to the classification of hidden dangers of urban gas PE pipeline, and establishes its pipeline failure database based on historical accident data of urban gas PE pipelines in the industry. Based on the failure database, this paper can use a quantitative method to determine the P and L values of the major hidden dangers and obtain the initial hidden danger classification. Then on the basis of considering the environment of the pipeline and the characteristics of PE pipeline management, this paper puts forward six compensation coefficient indexes, which can reasonably modify the initial grade. Finally, the effectiveness and feasibility of the proposed method are proved through practical application.

3. Hidden Danger Grading Method

3.1. Database Construction

Statistical analysis of pipeline failure data is an important tool to understand the trend of pipeline failure, which can assess the overall pipeline safety situation from a macroscopic perspective [19], and has practical significance for pipeline hazard classification [20], risk identification [21], accident prevention, and mitigation measure formulation [22]. The collection and analysis of failure data is commonly emphasized by pipeline companies, such as the Pipeline and Hazardous Materials Safety Administration (PHMSA) [23], the National Energy Board (NEB) [24], the European Gas Pipeline Incident Data Group (EGIG) [25], the United Kingdom Onshore Pipeline Operators Association (UKOPA) [26], and the Australian Pipeline Industry Association (APIA) [27], which have all established proprietary pipeline failure databases. Among them, the PHMSA database in the United States clearly indicates the data related to PE pipelines for urban gas. Therefore, this paper establishes a failure database specifically for urban gas PE pipelines by referring to existing databases and combining the availability of Chinese accident report data and US PHMSA database data, as shown in Table 1.

Table 1. Urban gas PE pipeline failure database composition.

General Information	Information about the Consequences of Failure	Related Sources
Date of expiration Name of pipelines Cause of failure Failure part Type of failure leak Fire and explosion situation	Number of injured Number of deaths Number of households affected Economic loss	Press releases Gas industry website Accident investigation report PHMSA

The current accident management mechanism specifically for PE material urban gas pipelines is not yet mature and lacks standardized, accurate, and systematic guidance [28]. Therefore, this paper investigates and statisticizes the accident data of urban gas

PE pipelines from the China and US PHMSA databases, and forms the failure database of urban gas PE pipelines, providing support for the following initial classification of hidden dangers in this paper. This failure database contains 465 pipeline failure samples, including 57 from China and 408 from the US PHMSA database. More specifically, the database uses relevant websites of the Chinese gas industry as a source of accident data in China, supplemented by accident investigation reports published on the official websites of counties and cities as well as provincial people governments, and screens out a total of more than 5000 urban gas pipeline accidents from 2010 to the present. After screening by pipeline material, 57 accidents were clearly indicated to be PE pipelines, caused by the low coverage of PE pipelines in China and the short duration of the operation. Second, 408 cases of urban gas PE pipeline accidents were screened from the US PHMSA database from 2010 to the present. By analyzing the established failure database, the following five categories of major hidden dangers (cause of pipeline failure) were obtained: third-party damage, material/equipment failure, force majeure, improper operation, and unknown reason, as shown in Table 2. In addition, from the perspectives of Chinese samples and American PHMSA database samples, there is little difference in the proportion of accident failure reasons, and it is not necessary to display them separately. The specific statistics of failure reasons in the failure database of urban gas PE pipelines are shown in Figure 1.

Table 2. Major hidden dangers of urban gas PE pipelines (cause of pipeline failure).

Cause of Pipeline Failure	Detailed Interpretation
Third-party damage	Damage to the urban gas pipeline caused by the actions of non-gas pipeline personnel.
Material/equipment failure	Pipeline failure caused by unqualified material performance and abnormal operation of equipment. For example, pipe manufacturing defects and weld defects.
Force majeure	Pipeline failure due to unforeseen, unavoidable, and insurmountable circumstances. For example: lightning strike, typhoon, and rainstorm.
Improper operation	Pipeline failure due to improper operation of pipeline operators.
Unknown reason	Cases of pipe failure whose cause has not been identified.

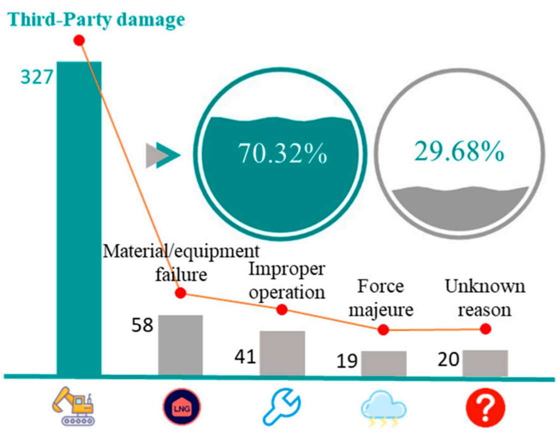

Figure 1. Statistical chart of the causes of failure of PE pipeline accidents in urban gas.

3.2. Grading Model

The determinants of the hidden danger level of the PLC method are divided into the following three categories: Possibility of accident P, accident loss degree L, and compensation factor C. The hidden danger level R can be expressed as:

$$R = P \times L \times C \quad (1)$$

The specific steps are to determine the initial level of accident hidden dangers by the position of P and L in the risk matrix and then correct the initial level by C to get the actual level of hidden dangers. The improved PLC method can quantitatively determine the possibility of accident P and the accident loss degree L by establishing the failure database of the PE pipeline of urban gas, and reduce the subjectivity of determining the initial level of hidden danger. After that, the compensation coefficient C is determined to modify the initial level by testing the specific situation of the evaluation object, and the actual level of hidden danger is obtained. The characteristics of the urban gas PE pipeline and the influence of the external system on the hidden dangers are fully considered to construct the detectability classification index of the compensation factor C, and the hidden dangers of the urban gas PE pipeline are more comprehensively classified.

In this paper, the improved PLC method is used to classify the four types of PE pipeline major hidden dangers, which are calculated from the failure database. The numerical analysis of the failure database of urban gas pipelines is used to obtain the possibility P and the degree of accidental loss L. The initial level of the hidden dangers is then determined with the help of a risk matrix. Finally, the final grade of hidden dangers is determined by the compensation coefficient C. The process of hidden danger grading is shown in Figure 2.

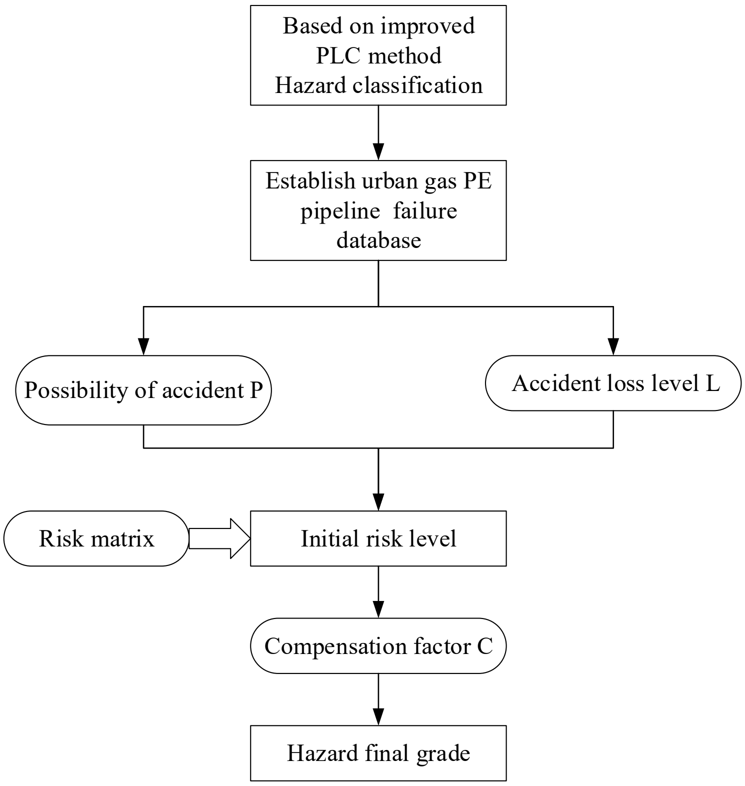

Figure 2. The process of hidden danger grading.

3.3. Indicator Determination

3.3.1. Possibility of Accident (P)

In order to solve the shortcomings of the traditional PLC method of qualitative analysis, and effectively use the urban gas PE pipeline failure database. Referring to the concept of basic failure probability in quantitative risk assessment of oil and gas pipelines [29]: the number of accidents per kilometer per year on average in the oil and gas pipeline system. This paper proposes to divide the possibility of accidents caused by hidden dangers into four grades according to the annual average number of accidents caused by hidden dangers, namely, the average number of cases per year. The four levels are detailed as shown in Table 3: (A) unlikely to happen, (B) less likely to happen, (C) likely to happen, and (D) very likely to happen. According to this analysis, the possible level of accidents caused by hidden dangers can be obtained as shown in Table 4.

Table 3. Reference standard of the possibility of a hidden danger causing an accident level.

Accident Probability Level	Average Number of Cases per Year
A (unlikely to happen)	[0, 0.5)
B (less likely to happen)	[0.5, 2)
C (likely to happen)	[2, 5)
D (very likely to happen)	≥5

Table 4. Urban gas PE pipeline database possibility rating for hidden dangers.

Typical Hidden Dangers		Average Number of Cases per Year	Rating
Force majeure	Earthquake	0.333333	A
	Heavy rain/flood	0.25	A
	Lightning	0.416667	A
	Temperature	0.083333	A
	High wind	0.25	A
	Other	0.25	A
Third-party damage	Third-party excavation damage	19.5	D
	Nearby fire/explosion damage	1.583333	B
	Vehicle accidents	1.333333	B
	Equipment arc damage	0.75	B
	Vandalism	0.166667	A
	Excavation damage repair failure	0.166667	A
	Other external damage	3.75	C
Material/equipment failure	Pipe failure	1.166667	B
	Flange connection failure	0.916667	B
	Fused joint failure	1.583333	B
	Other connection failures	0.58333	A
	Control/pressure relief equipment failure	0.333333	A
	Failure of threaded connections	0.166667	A
	Other equipment failures	0.083333	A
Improper operation	First-party excavation damage	0.583333	B
	Second-party excavation damage	0.583333	B
	Improper operation by contractor	0.5	B
	Pipeline or equipment overpressure	0.166667	A
	Improper equipment installation operation	0.333333	A
	Other improper operation	1.25	B
Other accident causes	Other causes	0.583333	B
	Unknown causes	1.083333	B

3.3.2. Accident Loss Degree (L)

The degree of accidental loss refers to the severity of accidental consequences that may result from hidden dangers. In this paper, according to the characteristics of the urban gas pipelines field, we refer to the grading of the severity of consequences of Zhejiang Energy Natural Gas Group Co., Ltd, Hangzhou, China. (Table 5), and the Regulations on the Reporting and Investigation of Production Safety Accidents (Table 6), and combine the statistics of the average damage of gas accidents in China and the United States to give the qualitative consequence grade reference standards, as shown in Table 7. The final grade is determined based on the maximum grade of the four indicators.

Table 5. Zhejiang Energy Natural Gas Group Co., Ltd., consequence severity grading.

Value	Legal Provisions and Other Requirements	Loss of Life and Personal Injury	Financial Loss	Lockout	Corporate Image
5	Violation of laws, regulations, and standards	Death	More than 500,000 yuan	More than two sets of equipment shutdown	Significant domestic impact
4	Potential violations of regulations and standards	Loss of labor force	250,000–500,000 yuan	Two units shutdown	Influence within the industry and province
3	Does not conform to the safety policy, system, and regulation of the superior company or industry	Amputations, broken bones, hearing loss, chronic diseases	100,000–250,000 yuan	One set of equipment shutdown	Regional influence
2	Does not comply with the safety operation procedures and regulations of the enterprise	Minor injury, intermittent discomfort	Less than 100,000 yuan	The impact is minor, and there is almost no work stoppage	Company and surrounding area
1	In full compliance with	No casualties	No loss	No shutdown	No damage

Table 6. Grading of the severity of consequences of the Regulations on the Reporting and Investigation of Production Safety Accidents.

Level of Accident	Seriously Injured People	Death Toll	Direct Economic Loss
Extremely serious accident	>100	>30	>100 million yuan
Major accident	50–100	10–30	50–100 million yuan
Larger accident	10–50	3–10	10–50 million yuan
General accident	≤10	≤3	≤10 million yuan

Table 7. Accident loss degree reference standard.

Level of Accident	Number of Injuries	Death Toll	Number of Households Affected	Direct Economic Loss
1	0–1	0	[0, 200]	[0, 100]
2	1–2	0	(200, 2000]	(100, 200]
3	2–3	0–1	(2000, 4000]	(200, 500]
4	≥3	≥1	>4000	>5 million yuan

According to the grading criteria, combined with the relevant data from the pipelines' failure database, the grades of the accident loss degree of the main hidden dangers were obtained, as shown in Table 8.

Table 8. Typical hidden danger accident loss level.

Typical Hidden Dangers		Average Number of Injured	Average Number of Deaths	Average Number of Households Affected	Average Direct Economic Loss	Grade
Force majeure	Earthquake	12	2	73.5	999.7974	4
	Heavy rain/flood	0	0	25.6667	25.15817	1
	Lightning	0	0	3.2	62.60206	1
	Temperature	0	0	1722	81.64027	1
	High wind	0	0	224.333	10.33467	1
	Other	0.5	0	520.3333	344.2792	3

Table 8. *Cont.*

Typical Hidden Dangers		Average Number of Injured	Average Number of Deaths	Average Number of Households Affected	Average Direct Economic Loss	Grade
Third-party damage	Third-party excavation damage	0.83663	0.11442	407.2966	474.0416	3
	Nearby fire/explosion damage	0.36842	0.15789	39.7368	486.756	3
	Vehicle accidents	0.4375	0.0625	8	91.9003	3
	Equipment arc damage	0	0	68	607.9666	4
	Vandalism	0	0	400	—	2
	Excavation damage repair failure	0	0	259.5	385.9823	3
	Other external damage	0.51111	0.02222	87,063.56	304.7586	4
Material/equipment failure	Pipe failure	0.92857	0.07142	599.4286	357.9	4
	Flange connection failure	0.5	0.1	5.9	499.0177	3
	Fused joint failure	0.36842	0.05263	104	127.8127	3
	Other connection failures	0.42857	0.142857	219.8571	62.50435	3
	Control/pressure relief equipment failure	0	0	1.333	61.88006	2
	Failure of threaded connections	0.5	0	515.5	145.5496	2
	Other equipment failures	0	0	74	350.6485	3
Improper operation	First-party excavation damage	0.16666	0	659.333	100.7885	2
	Second-party excavation damage	0.28571	0	147	121.2928	2
	Improper operation by contractor	16.2	1.4	0.5	1065.102	4
	Pipeline or equipment overpressure	0	0	1	118.7649	2
	Improper equipment installation operation	0.5	0	62	48.30912	1
	Other improper operation	0.73333	0.13333	86.8	89.68208	1
Other accident causes	Other causes	0.85714	0	125.4286	30.11153	1
	Unknown causes	0.6	0.1	3.4	177.9907	2

Most of the legal norms divide the level of hidden dangers into three levels, so the initial level of hidden dangers is determined according to the risk matrix (as shown in Figure 3) by combining the levels of P and L. Level III is a major hidden danger, level II is a large hidden danger, and level I is a general hidden danger.

According to this risk matrix, the initial level of each hidden danger can be derived, as shown in Table 9.

Table 9. Typical hidden danger initial grading table.

Typical Hidden Dangers		Grade
Force majeure	Earthquake	I
	Heavy rain/flood	I
	Lightning	I
	Temperature	I
	High wind	I
	Other	I

Table 9. *Cont.*

Typical Hidden Dangers		Grade
Third-party damage	Third-party excavation damage	III
	Nearby fire/explosion damage	II
	Vehicle accidents	II
	Equipment arc damage	II
	Vandalism	I
	Excavation damage repair failure	I
	Other external damage	III
Material/equipment failure	Pipe failure	II
	Flange connection failure	II
	Fused joint failure	II
	Other connection failures	I
	Control/pressure relief equipment failure	I
	Failure of threaded connections	I
	Other equipment failures	I
Improper operation	First-party excavation damage	II
	Second-party excavation damage	II
	Improper operation by contractor	II
	Pipeline or equipment overpressure	I
	Improper equipment installation operation	I
	Other improper operation	I
Other accident causes	Other causes	I
	Unknown causes	II

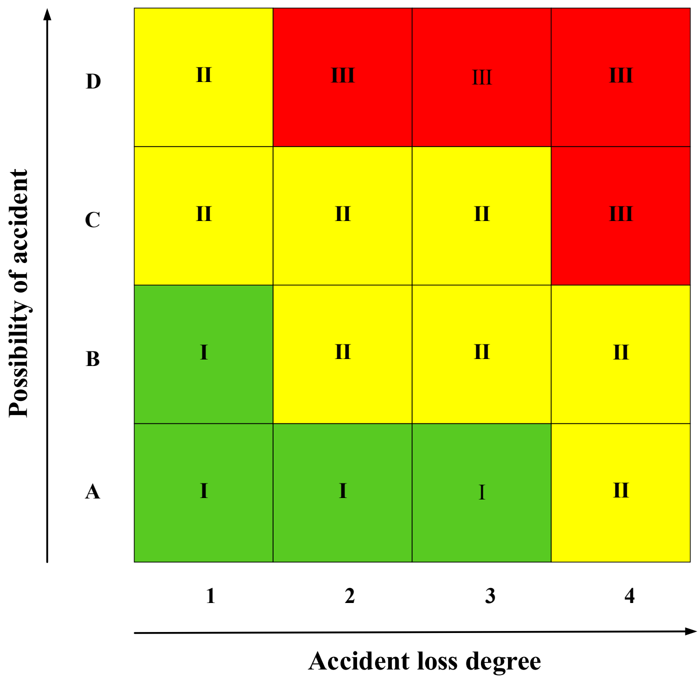

Figure 3. Risk matrix of hidden danger classification.

3.3.3. Compensation Factor (C)

The compensation coefficient can be adjusted to the initial level of the hidden danger according to the environment in which the pipeline is located, making the level of the hidden danger more in line with the actual situation and facilitating the enterprise to make corresponding disposal measures and emergency measures for the level of the hidden danger. In order to ensure the scientific integrity of the method, this paper summarizes and condenses six compensation coefficient indexes from the existing hidden danger classification methods, such as the Interim Provisions on Hidden Danger Investigation and Management of Safety Production Accidents and the Hidden Danger Classification of China National Offshore Oil Corporation, combined with the characteristics of urban gas PE pipelines, such as difficulty in locating, complex pipelines, and difficulty in determining the leak location.

The compensation coefficient value of the unit is calculated according to the six compensation coefficient indexes, and the calculation formula is as follows:

$$C = \prod_{i=1}^{6} C_i \tag{2}$$

where C_i is the value of the compensation coefficient for each cell, and the details are shown in Table 10.

Table 10. Compensation factor values for each unit.

Level Indicators	Secondary Indicators	Data Range
Regional vulnerability	There are 2 or fewer densely populated areas within the 50 m range on both sides of the pipeline centerline	0.7–1.0
	There are 3 densely populated areas within the 50 m range on both sides of the pipeline centerline	1.0–1.2
	There are 4 or more densely populated areas within the 50 m range on both sides of the pipeline centerline	1.2–3.0
Ease of rectification	Small business/branch can take care of itself	0.3–0.5
	Need group company/head office coordination to solve	0.5–1.0
	Need district county gas office to coordinate solution	1.0–1.6
	Need to be coordinated by the municipal gas office	1.6–3.0
Condition around pipeline	There are other pipes around, and they are not up to standard	1.4–2.5
	Other lines around but up to standard	1.0–1.4
	There is no other pipeline around	0.5–1.0
Positioning technology	High positioning accuracy	0.4–1.0
	Average positioning accuracy	1.0–1.4
	Poor positioning accuracy	1.4–2.0
Leak detection technology	High positioning accuracy	0.4–1.0
	Average positioning accuracy	1.0–1.4
	Poor positioning accuracy	1.4–2.0
Emergency ability	Have a complete emergency plan and emergency supplies	0.7–1.0
	Inadequate emergency plans or lack of emergency supplies	1.5–1.8
	Inadequate emergency plans and lack of emergency supplies	1.8–3.0

Note: densely populated areas refer to schools, hospitals, shopping malls, famous scenic spots, entertainment places, residential areas with more than 100 households, and so on.

According to the value of the compensation coefficient to adjust the initial level of accident hidden dangers to get the final level of accident hidden dangers, the adjustment method is shown in Table 11.

Table 11. Accident potential initial level adjustment method.

Compensation Factor	Adjustment Method
$C \leq 0.5$	Hidden danger level reduced by 2 levels
$0.5 < C \leq 1.0$	Hidden danger level reduced by 1 level
$1.0 < C \leq 1.2$	Hidden danger level is not adjusted
$1.2 < C \leq 2.5$	Hidden danger level is increased by 1 level
$C > 2.5$	Hidden dangers level is increased by 2 levels
Hidden danger to level I or III, no adjustment will be made.	

4. Example Applications

4.1. Basic Information

The busy section of Songyuan City, Jilin City (Ulan Street to the Fifth Ring Street section), is equipped with an urban medium pressure gas pipeline made of PE, with a pipe diameter of 110 mm, a working pressure of 0.3 MPa, and a burial depth of 3.9 m. Having other underground spaces around the pipeline makes it easier for gas to leak. There are buildings above the pipeline, such as the Ningjiang First Primary School, Songyuan People's Hospital, Oriental Home, and Social Security Home, which are densely populated areas. The pipeline was constructed and operated by Jilin Haoyuan Gas Co., Ltd. The person in charge of the area did not conscientiously fulfill his responsibilities as the first responsible person for safety production, and the gas pipeline protection measures were not implemented. The safety management of gas equipment operation was not implemented, and emergency preparedness was lacking. The company's pipeline positioning technology and leak detection technology both use the most advanced technical means and testing instruments in the current market, and can achieve a high degree of accuracy.

4.2. Hidden Danger Grading

Jilin Haoyuan Gas Co., Ltd., finds three hidden dangers here in the process of identifying hidden dangers for this pipeline: third-party excavation damage, vandalism, and improper operation by the contractor. The hidden danger level is shown in Table 12.

Table 12. Typical hidden danger grading.

Typical Hidden Dangers	P	L	The Initial Level	Compensation Factor							The Final Grade
				C1	C2	C3	C4	C5	C6	C	
Third-party excavation damage	D	3	III	1.2	0.8	1.4	1.0	1.0	1.8	2.0	III
Vandalism	A	2	I	1.2	1.2	1.4	1.0	1.0	1.8	3.6	III
Improper operation by contractor	B	4	II	1.2	0.3	1.4	1.0	1.0	1.8	0.9	I

The final results show that for this pipeline, third-party excavation, vandalism, and contractor improper operation hidden dangers are major, major, and general hidden dangers, respectively. In addition, it can be seen from Table 12 that the initial grades of the three typical hidden dangers found on the pipeline were adjusted according to the compensation coefficient C, which proves that the traditional classification method that only considers the failure possibility and failure consequence has considerable disadvantages. Considering six types of external factors, such as the real environment in which urban gas PE pipelines are located and the unique characteristics of PE gas pipelines, has an important impact on the accuracy of the hidden hazard classification, while proving that the PLC method is necessary.

4.3. Disposal of Hidden Dangers

The third-party excavation, intentional damage, and the contractor's improper operation of hidden dangers of PE pipelines in the prosperous section of Jilin Songyuan

City are major hidden dangers, significant hidden dangers, and general hidden dangers, respectively. Therefore, the hidden danger management plan for PE pipelines in the busy section of Songyuan City, Jilin City, is shown in Table 13, and the targeted management measures are shown in Table 14.

Table 13. Hidden danger classification disposal management scheme.

Typical Hidden Dangers	Head	Time Limit	Objectives, Management Plan	Basic Management Measures
Third-party excavation damage	Senior management	Immediately corrective	Immediately stop the operation, listed in the enterprise supervision and rectification hidden trouble governance project, develop a target plan to control hidden trouble, and re-evaluate the hidden trouble after the hidden trouble governance measures are implemented. Listed in the list of major hidden dangers of enterprises, focus on monitoring.	(1) Pipeline protection publicity and public education (2) Setting and maintenance of pipeline warning marks (3) Establishment, implementation, and assessment of pipeline inspection and care management system (4) Regular inspection of pipelines (5) Formulate and drill safety plans
Vandalism	Senior management	Immediately corrective	Immediately stop the operation, listed in the enterprise supervision and rectification hidden trouble governance project, develop a target plan to control hidden trouble, and re-evaluate the hidden trouble after the hidden trouble governance measures are implemented. Listed in the list of major hidden dangers of enterprises, focus on monitoring.	
Improper operation by contractor	Middle management	Immediately corrective	To be listed as a department-level hidden trouble control project, develop a target plan to control hidden trouble, and re-evaluate hidden trouble after the implementation of hidden trouble control measures.	

Table 14. Specific measures for graded disposal of hidden dangers.

Typical Hidden Dangers	Hazard Level	Treatment Measure
Third-party excavation damage	Major	A1 signing of pipeline protection agreements A2 development of special plans and regular drills for hidden pipeline sections A4 increasing the means of operational monitoring A5 increasing the density of warning signs A6 conducting high-consequence area management A7 reporting to the relevant local government departments B1 increasing the burial depth of pipelines B9 installing additional monitoring or security surveillance systems C7 construction call-off C9 establishing special funds
Vandalism	Major	A1 signing pipeline protection agreements A2 developing special plans and regular drills for hidden pipeline sections A3 shortening the inspection interval A4 increasing the means of operational monitoring A5 increasing the density of warning signs A6 conducting high-consequence area management A7 reporting to the relevant local government departments B1 increasing the burial depth of pipelines B3 shortening the inspection cycle C4 dismantling or removing the occupants

Table 14. *Cont.*

Typical Hidden Dangers	Hazard Level	Treatment Measure
Improper operation by contractor	General	A1 Sign pipeline protection agreement A2 Formulate special plans for hidden dangers and conduct regular drills A3 Shorten the inspection interval A4 Add operation monitoring means A5 Increase the density of warning labels A6 High-consequence zone management A7 Report to relevant local government departments

Note: Class A, class B, and class C measures can be used for the disposal of hidden dangers at all levels. As the level of measures increases from A to C, lower-level measures can be replaced by appropriate and effective higher-level measures.

5. Conclusions and Recommendations

5.1. Conclusions

This paper establishes a pipeline failure database based on domestic and international statistics of PE accidents in urban gas and obtains the following four categories of typical hidden dangers for PE gas pipelines, third-party damage, material/equipment failure, force majeure, and improper operation. Among them, third-party damage hazards account for more than 70% of all accident hidden dangers. To address the grading of four typical hidden dangers, this paper proposes an improved PLC method based on existing research on the hidden danger grading method for urban gas pipelines, in which the initial grade of hidden danger grading is determined by obtaining the grade of hidden danger susceptibility and the grade of the severity of accident consequences through the analysis of the pipeline failure database, which greatly reduces the subjectivity of the original method. In setting the compensation coefficient, the influences of external factors, such as regional vulnerability, ease of rectification, condition around the pipeline, positioning technology, leak detection technology, and emergency ability, are considered, respectively, so as to determine the corrected hidden danger level and make the corrected hidden danger level more in line with the real situation. Finally, the practicality and feasibility of the method are tested by applying the method in this paper to a field example.

5.2. Recommendations

For PE pipeline common typical hidden dangers, gas pipeline operating enterprises must strengthen the awareness of prevention for different hidden dangers to take corresponding disposal measures, but also pay special attention to the impact of third-party damage on buried PE pipeline. Enterprises should form a special third-party damage protection manual from a comprehensive system to reduce the probability of accidents. The improved PLC method is a new grading management technique for urban gas pipelines with hidden dangers. Through hidden danger grading assessment, pipelines can be classified, management can be focused on pipelines worthy of attention, and investment in pipelines safe for the operating environment can be reduced, thus reducing risks and management costs, minimizing economic losses caused by sudden accidents in buried PE pipelines of urban gas, and improving the safety of pipelines.

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