Natural gas pipeline leakage analysis based on Advance risk analysis and Analytic hierarchy process

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Abstract. As of 2019, my country's natural gas consumption will reach 310 billion cubic meters, and the proportion of natural gas consumption in energy will increase rapidly. In order to promote the long-term development of natural gas and prevent natural gas pipeline leakage accidents, the natural gas pipeline leakage accidents are analyzed. In this paper, through the pre-hazard analysis method, qualitatively analyze the 4 main factors and 14 sub-factors that cause the leakage of the natural gas pipeline. Then establish a hierarchical structure model by tomographic analysis, calculate the weight of each factor, and quantitatively analyze the cause of the leakage. Finally, according to the conclusion, corresponding measures are proposed.

1. Introduction
In recent years, more and more natural gas leakage caused great influence and affected social stability [1]. By analyzing natural gas pipeline leakage incidents, effective measures to prevent leakage are proposed to further improve the transportation method of natural gas pipelines and strengthen my country's infrastructure construction, which is conducive to the long-term development of natural gas transportation and enhances the security of my country's future energy transportation.

2. Advance risk analysis

2.1. define
Advance risk analysis analysis is a qualitative analysis method in safety system, which analyzes the risk factors and identify the potential risk factors of the system in advance, determine the risk level of the system, and then propose corresponding measures [2].

2.2. Steps and processes
Steps: First, the system is determined and all kinds of relevant data are collected and investigated. After the decomposition of system functions, risk analysis and identification are started. Then, the risk hierarchy can be determined[3].
2.3. Classification of risk levels

Table 1. Classification of risk.

| Level | Degree of danger | The consequences                           |
|-------|------------------|--------------------------------------------|
| I     | safe             | No threat                                  |
| II    | critical         | It is in the marginal state                |
| III   | dangerous        | It will cause threats or damage            |
| IV    | Catastrophic     | It will cause large-scale personnel damage|

Table 2. PHA analysis table of natural gas pipeline leakage

| Risk factors         | Potential accident                                      | Levels of danger |
|----------------------|--------------------------------------------------------|------------------|
| Natural gas leak     | The quality of anti-corrosion layer is not up to standard | III              |
|                      | The quality of anti-corrosion layer is not up to standard |                 |
|                      | The quality of anti-corrosion layer is not up to standard |                 |
|                      | The quality of anti-corrosion layer is not up to standard |                 |
|                      | The technical level of personnel is not enough          | III-IV           |
|                      | Human error                                             |                 |
|                      | The inspector did not inspect as required                |                 |
|                      | Improper management                                     |                 |
| Human cause          | Earthquakes, debris flows and other natural disasters   | III              |
|                      | Wet climate corrodes pipes                             |                 |
|                      | Located in the heavy salinity area                      |                 |
| Environmental reasons| Welding quality in construction is not close            | III              |
|                      | The design and construction of Yinbao system is unreasonable |            |
|                      | Not installed as required                               |                 |

The safety level of natural gas pipeline leakage is divided into four levels, as shown in Table 1.

2.4. Accident Cases

In this paper, through three typical natural gas pipeline leakage accidents and reading relevant literature, the causes of natural gas leakage accidents are analyzed with the method of advance risk analysis and the corresponding measures are proposed, hoping to have a certain positive significance for reducing the occurrence of such accidents.
2.4.1. Typical cases
On March 14, 2008, there was a natural gas leak in the corridor door of Zheng Wei’s building. The light was turned on after the entrance of the store, and an explosion occurred, causing four deaths and five serious injuries.

On August 1, 2014, a gas leak occurred in Kaixuan Road and Ersheng Road, Qianzhen District, Kaohsiung city, causing multiple explosions.

On June 2, 2019, due to improper operation, a natural gas pipeline was excavated at a construction site near Lingling District, causing a large number of natural gas leaks. The pipeline ruptured and the gas discharged was about 3 to 4 meters high.

2.4.2. PHA analysis on the causes of natural gas pipeline leakage
Through reading relevant literature and analyzing the causes of accidents, the risk factors causing pipeline leakage are mainly divided into pipeline reasons, human reasons, environmental reasons, installation and construction, etc. [4-7]. The results obtained by using the pre-risk analysis are shown in Table 2.

3. Analytic hierarchy process and its application

3.1. Establish the hierarchical structure model
Analytic hierarchy process (AHP) is mainly to find elements associated with the outcome, then broken down into three layers, they are is the target layer, criterion layer and plan, and carries on the quantitative analysis on this basis [8-9].

3.1.1. Establish a hierarchical structure model
According to the four main factors and 14 sub-factors obtained from the pre-hazard analysis above, combined with the hierarchical structure model, it is divided into the highest layer (layer A) is the natural gas pipeline leakage, and the middle layer (layer B) is the 4 main factors. The bottom layer (layer C) is a sub-factor under 14 main factors, as shown in Figure 1.

Fig. 1. Hierarchical model of natural gas pipeline leakage

3.1.2. Construct judgment matrix
This paper establish the hierarchy, compare each factor belonging to the next layer or affecting the next layer, compare each factor on the same layer to determine its impact on the accident, and quantify it according to the pre-specified scale to form the corresponding matrix, that is, the judgment matrix.

3.1.3. Calculate the weight vector
By calculating the relative weight of each factor in each judgment matrix to its criterion, the maximum eigenvalue Max, the eigenvector W composed of the judgment matrix A, can be normalized to obtain
the ranking weight of relative importance corresponding to the corresponding factor in the same level and A factor in the previous level.

3.1.4. Consistency index test

Table 3. RI values of random consistency index.

| Dimension (n) | RI   |
|--------------|------|
| 1            | 0.00 |
| 2            | 0.00 |
| 3            | 0.58 |
| 4            | 0.90 |
| 5            | 1.12 |
| 6            | 1.24 |
| 7            | 1.32 |
| 8            | 1.41 |
| 9            | 1.45 |

In order to prevent the interference of other factors on the judgment matrix, it is necessary to make it meet the consistency requirement in the actual calculation. The following is the formula:

\[ CR = \frac{CI}{RI} \]  

In the formula, CR is the index to measure the consistency of the judgment matrix. If \( CI < 0.10 \), it is proved to satisfy the consistency of the judgment matrix; otherwise, the judgment matrix shall be modified. In this case, \( CI \) is the consistency index of the test judgment matrix, which is calculated according to the following formula:

\[ CI = \left( \lambda_{\text{max}} - n \right) (n-1) \]  

If \( \lambda_{\text{max}} = 0 \) and \( CI = 0 \), then the judgment matrix is completely consistent. If the \( CI \) value is higher, the judgment matrix is less completely consistent. In this case, the correction value RI needs to be introduced, which can be determined by looking up the table, as shown in Table 3 below.

3.2. Determine evaluation indexes and establish a hierarchical structure model

According to the previous risk analysis, the factors leading to natural gas leakage can be divided into four aspects. The target layer A: natural gas pipeline leakage, criterion layer B: pipeline leakage, B2, B3 environmental and B4 installation and construction.

3.3. Construct judgment matrix and check consistency

Use the 1-9 scale method shown in Table 4 below, and compare each pair separately. The relative importance of each factor can be judged and assigned according to the advice of experts.

Table 4. Significance of scale 1-9

| Degree of importance                                      | Scale value |
|-----------------------------------------------------------|-------------|
| equally important                                         | 1           |
| the former is slightly more important than the latter      | 3           |
| the former is more important than the latter               | 5           |
| the former is much more important than the latter          | 7           |
| the former is definitely more important than the latter    | 9           |
| Intermediate value of two adjacent judgments              | 2, 4, 6, 8  |
The judgment matrix formed between A and B is shown in Table 5:

| A   | B1   | B2   | B3   | B4   | wi |
|-----|------|------|------|------|----|
| B1  | 1    | 1/2  | 3    | 5    | 0.334 |
| B2  | 2    | 1    | 4    | 3    | 0.446 |
| B3  | 1/3  | 1/4  | 1    | 3    | 0.143 |
| B4  | 1/5  | 1/3  | 1/3  | 1    | 0.078 |
| CI  |      |      |      |      | 0.083 |
| CR  |      |      |      |      | 0.093 |

MATLAB software was used to calculate the corresponding characteristic values.

\[
W = (\omega_1, \omega_2, \omega_3, \omega_4) = (0.6240, 0.2270, 0.1220, 0.027) 
\]

\[ \lambda_{\text{max}} = 4.01 \]  \hspace{1cm} (4)

\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} = \frac{4.01 - 4}{4 - 1} = 0.00333 \] \hspace{1cm} (5)

Look-up table:

\[ RI = 0.90 \] \hspace{1cm} (6)

\[ CR = \frac{CI}{RI} = \frac{0.00333}{0.90} = 0.00370 < 0.1 \] \hspace{1cm} (7)

So this judgment matrix works.

According to the same method, the index layer judgment matrix is constructed, the weight of each factor, the consistency index CI and the consistency ratio CR are calculated, and the judgment matrix is tested for consistency. See Table 6-9 after sorting out the calculated data.

Table 6. Judgment matrix of indicator layer B1- C (1-4) and weight values of each factor.

| B1-C | C1   | C2   | C3   | C4   | wi |
|------|------|------|------|------|----|
| C1   | 1    | 2    | 1/3  | 1/3  | 0.1740 |
| C2   | 1/2  | 1    | 1/2  | 1/2  | 0.1465 |
| C3   | 3    | 2    | 1    | 1/2  | 0.3193 |
| C4   | 3    | 1/2  | 2    | 1    | 0.3602 |
| CI   |      |      |      |      | 0.0313 |
| CR   |      |      |      |      | 0.0352 |

Table 7. Judgment matrix of index layer B2- C (5-8) and weight value of each factor.

| B2-C | C5   | C6   | C7   | C8   | wi |
|------|------|------|------|------|----|
| C5   | 1    | 1/2  | 6    | 3    | 0.3352 |
| C6   | 2    | 1    | 3    | 6    | 0.4741 |
| C7   | 1/6  | 1/3  | 1    | 2    | 0.1117 |
| C8   | 1/3  | 1/6  | 1/2  | 1    | 0.0790 |
| CI   |      |      |      |      | 0.0831 |
| CR   |      |      |      |      | 0.0923 |

Table 8. Judgment matrix of B3 - C (9-11) index layer and weight values of each factor.

| B3-C | C9   | C10  | C11  | wi |
|------|------|------|------|----|
| C9   | 1    | 6    | 5    | 0.7096 |
| C10  | 1/6  | 1    | 1/2  | 0.1354 |
| C11 | 1/5 | 2 | 1 | 0.1550 |
|-----|-----|---|---|-------|
| C1  |     |   |   | 0.0091 |
| CR  |     |   |   | 0.0176 |

Table 9. B4 -C (11-13) index layer judgment matrix and weight values of each factor

| B4-C | C12 | C13 | C14 | \( \omega_i \) |
|------|-----|-----|-----|-----------|
| C12  | 1   | 4   | 3   | 0.6250    |
| C13  | 1/4 | 1   | 1/2 | 0.1365    |
| C14  | 1/3 | 2   | 1   | 0.2385    |
| CI   |     |     |     | 0.009     |
| CR   |     |     |     | 0.0176    |

In table 5, the cause of the people on the gas pipeline leakage caused by main proportion, pipeline own existence reason also accounted for a large proportion, and real life that led to a natural gas pipeline leakage accident investigation result is consistent, moreover leakage due to environmental reasons and installation construction also nots allow to ignore.

Data in table 6 and table 7 can see clearly that manufacturing process has obvious flaws (C3) and the weight of material itself problems (C4) were more than 0.3, the pipeline accounted for a large proportion in the reason, need to focus on for the pipeline itself.. Staff and technical level is not pass (C5), operational errors (C6) are man-made natural gas pipeline leakage accident, the main factors in the actual investigation of third party damage and cross construction reason is also a common problem, due to human factors in the process of running left a lot of hidden trouble, directly or indirectly caused the accident. Due to gas pipelines buried underground, to a large extent by the earthquake, natural disaster such as mud-rock flow (C9), so the loss caused by these conditions is very big still, damp climate corrosion pipe (C10) and heavy saline area (C11) to a certain extent, also affect the safety of the pipeline itself, are to be reckoned with. Poor welding quality in construction (C12) plays a very important role in installation and construction. Poor welding quality indirectly affects the whole installation process and directly leads to pipeline leakage.

4. Analytical applications
Enterprises should strengthen the management of personnel, continuously improve the management level, adapt to the development of the times, take the initiative to prevent and take the initiative, strengthen the safety awareness of personnel, and establish and improve the production responsibility system [10].

Strict quality control shall be carried out in the production process of pipelines, key supervision and examination shall be carried out on the sources and enterprises of materials used in the manufacturing of pipelines, and it is forbidden for enterprises to cut corners on materials and replace them with substandard ones. In addition, protection technology and improvement measures shall be improved, and some anticorrosive coatings with better quality shall be selected.

Gas pipelines buried underground for a long time, because of various factors of public role will produce different degrees of corrosion, the damp climate and heavy saline area, more should choose to choose high anticorrosion coatings, improving pipe material [11], not only more for inspection and maintenance, pipeline and pipeline construction unit must communicate more and municipal urban construction units, [12], the linkage of pipeline integrity management idea.

Enterprises should also effectively avoid man-made damage, strengthen publicity and strengthen legal awareness of pipeline protection [13-14]. In the process of pipeline construction, there must be a special technical department for strict supervision and control of key parts. The production enterprises related to steel pipes should also continuously improve their own technology, so as to reduce the cost of steel pipes on the premise of ensuring the quality, so as to widely use seamless steel pipes in more places, save economic costs and reduce local safety hazards.
5. Conclusion
In the process of qualitative analysis, the complicated factors in the natural gas pipeline leakage are summarized into 4 main factors and 14 sub-factors by using the pre-risk analysis. It is simple, economical and effective to identify possible risks and then improve them. In the process of quantitative analysis, through the calculation of the weight of each factor through the hierarchical structure model, we can efficiently and objectively find the cause of the pipeline in the main factors and the cause of human beings have the greatest impact on the leakage of the natural gas pipeline. According to this relatively high weight, effective measures are proposed to prevent and reduce the existence of corresponding problems.

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