The improved analytic hierarchy process (ahp) based on accident tree is applied to the study of community gas risk assessment

Zhang Zheng Wen¹*

¹Emerging Risk Research Institute, North China University of Technology, Beijing, 100144, China

* Corresponding author’s e-mail: zzw10011@126.com

Abstract: Gas safety is related to every family in the community. In this paper, the structural importance in the accident tree is taken as the basis of analytic hierarchy process (ahp) judgment matrix. The improved ahp reduces human subjectivity. It is hoped to provide some reference for the risk assessment of gas leakage accident.

1. Research background

For community residents, gas is basically a daily necessity for every family. The safety of gas is not only related to personal safety, but also the safety of the entire community at all times. Once an accident occurs, it will cause serious Casualties and property damage. And from the statistics of gas accidents, the gas leakage accident accounts for the vast majority of the total number of accidents. Chinese scholars to a series of studies of gas risk, including the three-dimensional numerical simulation was carried out on the gas accident [1], and for the city gas pipeline risk assessment and from design to operation of the whole life cycle of the establishment of the index system of risk [2-3], some domestic scholars through the LS - SVM model bow - tie technology such as the quantitative study on the gas pipe network [4-5] and from the perspective of the research of city gas pipeline risk assessment [6].

2. Research model design

Firstly, the relevant concepts of accident tree and ahp are introduced. Based on the report of gas accidents in Beijing, an index system model of accident tree is established to search for the basic causes of gas leakage accidents and an ahp model is constructed by taking the basic causes of accident tree as the indicator layer of ahp.

2.1 accident tree analysis method

The accident tree is particularly common in the process of risk source identification and analysis. Its basic structure is a kind of chart that represents the possible incidence of each basic event through the logic gate relationship and then calculation. The top of the accident tree chart is the possible outcome event and then cause decomposition. The accident tree starts with the analysis of the topmost events and uses causality to find the basic events that may lead to the topmost events.

In the accident tree method, there are two definitions of the minimum cut set: one is that the analyst solves the fault sequence for each logical model of the accident tree; the other is the set of the minimum basic events that can cause the occurrence of the topmost event. In particular, if any basic event in the cut set does not occur, the topmost event will never occur. The more minimal cut sets there are in an
accident tree, the more likely it is that an incident will occur at the top and the more dangerous the system will be.

Each basic event has a certain impact on the top event, but the impact degree of each basic event on the top event is not the same, we call this impact degree as the structure importance, the structure importance analysis is to improve the system security to provide important information. The calculation formula of structural significance is as follows:

\[ I_\phi(i) = \frac{1}{m} \sum_{j=1}^{k} \frac{1}{Z_j^i} \]  

In the formula: \( I_\phi(i) \) is the approximate discriminant value of the importance degree of the \( i \) basic event; \( m \) is the number of minimum cut sets in the accident tree structure; \( Z_j^i \) is the number of basic events contained in the \( j \) minimum cut set containing the \( i \) basic event;

2.2 AHP

AHP was put forward by professor Sadie of the University of Pittsburgh in the mid-1970s. Commonly used to handle complex decision-making and evaluation, the analytic hierarchy process generally includes the target layer, criterion layer and index layer, the main analysis indicators layer of the relationship between various factors and other factors, will be a system problem is decomposed into several levels of problems, and to belong to a layer of factors are compared, and two more on the degree of impact on a layer of factors.

(1) establish a hierarchical model

The use of analytic hierarchy process needs to stratify the problem first, divide the whole problem into several factors according to logic and stratification, and arrange and establish the relationship according to the relationship between the target layer, the criterion layer and the index layer.

(1) target layer: problems that may occur in the system or goals that the system needs to achieve.

(2) criterion layer: it mainly subdivides the content of the target layer into several intermediate links that must be experienced.

(3) indicator layer: the criterion layer is divided into several factors, such as specific policies, policies and problems

(2) establish a judgment matrix and weight division

Analytic hierarchy process (ahp) the main idea is to decompose step by step a complex problem and, at last, by comparing the relationship of the basic events can be measured, in turn, build a layered structure model, to compare between the various factors of tree and compare to the importance of the rule of each factor for layer, thus a quantitative form of matrix, usually takes 1 ~ 9 scaling method, called the judgment matrix.

\[ A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \]

| scale \( a_{ij} \) | meaning |
|-------------------|---------|
| 1                 | They're equally important |
| 3                 | \( i \) is slightly more important than \( j \) |
| 5                 | \( i \) is more important than \( j \) |
| 7                 | \( i \) is more important than \( j \) |
| 9                 | \( i \) is absolutely more important than \( j \) |
| 2, 4, 6, 8        | Intermediate state |

\( a_{ij} \) is the comparison result between two factors \( i \) and \( j \) that belong to the same layer, that is, the important situation of \( i \) factor compared with \( j \) factor; similarly, \( a_{ji} \) is the situation of \( j \) factor compared with \( i \) factor, and
\[ a_{ij} = \frac{1}{a_{ji}} \]

In order to lower the influence degree of factors on the above factors, the first thing we should validate the consistency of judgement matrix. If the judgment matrix satisfies the consistency requirement, its maximum eigenvalue and eigenvector can be obtained. Then the weight vector of the single hierarchical order, the weight vector represents the influence degree of the underlying factors for the upper. If the judgment matrix does not meet the need to adjust the consistency judgment matrix until satisfies the requirement of consistency check, calculate the level of single after sorting, we further calculate the influence degree of the index of target layer, this time we need to calculate index layer for the target weight vector then the comprehensive weights of indicators for the target layer is the result. The weight of each factor in ahp for the target layer is between 0 and 1. The closer the weight is to 1, the more important the factor is to the system target.

2.3 build an evaluation model

2.3.1 construct the accident tree model

Reported through the safety accidents of the gas accident is analyzed, it can be seen that the probability of gas in gas leakage accident is highest, this paper mainly study of community gas leakage risk events, constructing community gas leakage accident as the top event of fault tree, intermediate events into the pipeline itself problems, human error, the third party damage, including pipeline itself problems including design, construction, corrosion events among the three, finally and then divided into 13 basic event.

| Basic event symbol | meaning | Basic event symbol | meaning |
|--------------------|---------|--------------------|---------|
| \( x_1 \)         | Improper design load | \( x_7 \)         | Improper supervision and supervision |
| \( x_2 \)         | Calculation error   | \( x_8 \)         | Failure of corrosion protection mechanism |
| \( x_3 \)         | Improper model simplification | \( x_9 \)         | Internal and external environmental media corrosion |
| \( x_4 \)         | The designers were not thoughtful | \( x_{10} \)   | Improper personnel inspection and maintenance |
| \( x_5 \)         | Using inferior materials | \( x_{11} \)     | Residents operating in the process of error |
Improper construction process $x_6$ Natural disasters $x_{12}$ Improper movement of vehicles and personnel $x_{13}$

2.3.2 establish the ahp model
Will be the basic event of the fault tree model as index layer factors of analytic hierarchy process (ahp), the basic event of the fault tree for clustering analysis, to determine each type of rule layer, the target layer for community safety gas pipeline system, index layer judgment factor for the structure importance ratings of the basic events in fault tree model of analytic hierarchy process (ahp) in table 3.

| The target layer | Rule layer | Index layer |
|------------------|------------|-------------|
| Community gas pipeline system is safe | $x_1$ Improper design load | $x_{12}$ Natural disasters |
| | $x_2$ Calculation error | |
| | $x_3$ Improper model simplification | $x_9$ Internal and external environmental media corrosion |
| | $x_4$ The designers were not thoughtful | |
| | $x_5$ Using inferior materials | |
| | $x_6$ Improper construction process | |
| | $x_7$ Improper supervision and supervision | |
| | $x_8$ Failure change of corrosion protection mechanism | |
| | $x_{10}$ Improper personnel inspection and maintenance | |
| | $x_{11}$ Residents operating in the process of error | |
| | $x_{13}$ Improper movement of vehicles and personnel | |

①The structural importance of the basic event
There are many basic events in the accident tree, and the structural significance represents the influence degree of each basic event on the top event. This paper focuses on taking the structural significance as the judgment factor of each factor in ahp and the judgment factor of the criterion layer is the sum of the factors of each indicator layer in the same criterion layer.

②construct the judgment matrix of analytic hierarchy process
The judgment matrix of index layer and criterion layer can be obtained by pairwise comparison between the judgment factors calculated for structural importance.

③hierarchy total sort
The weight vectors of the index layer and the criterion layer are obtained through the judgment matrix, and then the comprehensive weight of the index layer factors relative to the target layer can be determined.
3. Model calculation
Firstly, the significance of the basic event structure of the accident tree is calculated. Because the index level factor of AHP is related to the basic event of the accident tree, it can be used as the judgment factor of AHP to obtain the judgment matrix of each level and the influence degree of the index level on the target level.

(1) Calculation of accident tree model
In this paper, it is concluded that community gas leakage risk events as the top event of fault tree model of a total of 10 minimum cut sets were

\[ E_1 = \{X_1, X_2\}, \quad E_2 = \{X_3\}, \quad E_4 = \{X_4\}, \quad E_5 = \{X_{10}\}, \quad E_6 = \{X_{11}\}, \quad E_7 = \{X_{12}\}, \quad E_8 = \{X_{13}\}, \quad E_9 = \{X_5, X_6, X_7\}, \quad E_{10} = \{X_8, X_9\} \]

The structural significance of each basic event can be obtained by using formula (1), as shown in Table 4.

| Basic event | Structural importance | Basic event | Structural importance |
|-------------|-----------------------|-------------|-----------------------|
| \( X_1 \)   | 1/10                  | \( X_7 \)   | 1/30                  |
| \( X_2 \)   | 1/10                  | \( X_8 \)   | 1/20                  |
| \( X_3 \)   | 1/10                  | \( X_9 \)   | 1/20                  |
| \( X_4 \)   | 1/10                  | \( X_{10} \)| 1/10                 |
| \( X_5 \)   | 1/30                  | \( X_{11} \)| 1/10                 |
| \( X_6 \)   | 1/30                  | \( X_{12} \)| 1/10                 |
|             |                       | \( X_{13} \)| 1/10                 |

(2) AHP model calculation
From the structural significance of the basic event, we can obtain the criterion layer's judgment factor of \[\frac{3}{20} \quad \frac{2}{5} \quad \frac{9}{20}\]. By pairwise comparison between the judgment factors, we can obtain the criterion layer's judgment matrix and the index layer's judgment matrix.

| Natural factors | The design factors | Management factors |
|-----------------|-------------------|--------------------|
| Natural factors | 1                 | \( \frac{3}{8} \) | \( \frac{1}{3} \) |
| The design factors | \( \frac{8}{3} \) | 1 | \( \frac{8}{9} \) |
| Management factors | 3 | \( \frac{9}{8} \) | 1 |

The weight vector \( \omega = (0.15, 0.40, 0.45)^T \) of the criterion layer can be obtained through AHP calculation, and the judgment matrix can pass the consistency test. In the same way, the judgment matrix of the index layer can be calculated and the judgment matrix of the index layer can all meet the consistency test.

(1) For natural disasters in \( A_1 \), the weight vector is \( \omega_21 = (0.100, 0.050)^T \).
(2) For design factors \( A_2 \), the weight vector is \( \omega_22 = (0.1000, 0.1000, 0.1000, 0.1000)^T \).
(3) For management factors \( A_3 \), the weight vector is \( \omega_23 = (0.0333, 0.0333, 0.0333, 0.0333, 0.0500, 0.1000, 0.1000, 0.1000)^T \).

The above results represent single hierarchical ordering. The total hierarchical ordering can be calculated by the calculation principle of analytic hierarchy process. The specific calculation results are shown in Table 6 below.

| Index layer factor | The weight of the criterion layer and the indicator layer | Hierarchical total ordering |
|--------------------|--------------------------------------------------------|-----------------------------|
| \( X_{13} \)       | \[ A_1 = 0.15, A_2 = 0.40, A_3 = 0.45 \]             | 0.015                       |

Table 4. Structure importance of base events

Table 5. Judgment matrix of criterion layer

Table 6. Influence degree of indicator layer relative to target layer
| $X_0$ | 0.050 | 0.0075 |
|-------|-------|-------|
| $X_1$ | 0.1000 | 0.04 |
| $X_2$ | 0.1000 | 0.04 |
| $X_3$ | 0.1000 | 0.04 |
| $X_4$ | 0.1000 | 0.04 |
| $X_5$ | 0.0333 | 0.014985 |
| $X_6$ | 0.0333 | 0.014985 |
| $X_7$ | 0.0333 | 0.014985 |
| $X_8$ | 0.05 | 0.0225 |
| $X_{10}$ | 0.1 | 0.045 |
| $X_{11}$ | 0.1 | 0.045 |
| $X_{12}$ | 0.1 | 0.045 |

4.10 the gas explosion accident in Beijing is mainly caused by the construction party unfortunately excavating the natural gas pipeline in the process of water pipeline construction and causing an explosion when it meets an open fire. The main reason for the "6.6" gas deflagging production safety accident in Beijing is that the natural gas equipment inspection is not in place and the staff operates in violation of regulations. In 2011, the main reason for the gas accident in heping street, chaoyang district, Beijing was the insufficient inspection of gas equipment by the staff. Therefore, it can be seen from table 6 that improper maintenance of personnel inspection, improper operation of residents and improper activities of vehicles and personnel have the greatest impact on the target layer. The next is improper simplification of the model in design factors, improper design load value, calculation error, and inadequate consideration of designers, which are basically consistent with the actual situation

4. Summary and Suggestions

The accident tree and the AHP are widely used in the field of risk. This article combines the accident tree and the analytic hierarchy process to evaluate the risk of community accidents. Through the establishment of fault tree to find the basic events, will be the basic event of the fault tree clustering as index layer in the analytic hierarchy process (ahp), the emphasis is on the structure importance of fault tree as the judgment factor in analytic hierarchy process (ahp), through the judgment in between the two comparison judgment then the index the influence degree of each factor relative to the target layer, to avoid the subjectivity of the analytic hierarchy process (ahp).

reference

[1] Xia Yong, Lu Pengfei, Pang Lei. Numerical simulation of three-dimensional risk of urban gas pipeline leakage and explosion [J]. Journal of safety and environment, 2016, 16:11-115.
[2] Chen Meihong, Chen Beisong, Jing Jing, Qiao Chuan, Liao Kai. Environmental risk evaluation index system for the whole process of urban gas pipe network from design to operation [J]. China population. Resources and environment, 2016, 26 (11): 53-56.
[3] Liu MAO, Liu Fei. Risk assessment of urban gas pipeline [J]. Journal of natural disasters, 2009, 18 (4): 84-91. (in Chinese with English abstract)
[4] Jia pengmei, Yu xiaochun, Song qianfu. Application of Bow_tie technology in risk management of urban gas pipeline [J]. Industrial safety and environmental protection, 2014, 40 (2): 14-17.
[5] Wang xinxin, Song xingshui, Yang taiwang, Chen haiqun, Wang kaiquan. Application of LS_SVM model in risk assessment of urban gas pipeline [J]. Fire management research, 2017, 36 (11): 1598-1601.
[6] Cao zheng, Liu MAO, Zhang xiuhua, Lu yan, Xu wei. Quantitative risk assessment of urban gas pipeline accidents caused by earthquakes [J]. Journal of safety and environment, 2010, 10 (4): 204-209.