Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 14 (9): 955-959, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.955.959

Risk Assessment of Urban Gas Pipeline Network Based on Fuzzy Multi-attribute Method

[1,2]Qiuju You, [1]Jianchun Fan, [2]Wei Zhu and [3]Yongqiang Bai
[1]China University of Petroleum, Beijing, 102249, Beijing, People's Republic of China
[2]Beijing Key Laboratory of Operation Safety of Gas, Heating and Underground Pipelines, Beijing Research Center of Urban Systems Engineering, 100089, Beijing, People's Republic of China
[3]Beijing Municipal Institute of Lahour Protection, 100054, Beijing, People's Republic of China

Abstract: In order to realize more objective quantitative risk assessment of natural gas pipeline network systems, this study presents a model for risk assessment of natural gas pipelines based on the engineering fuzzy mathematical theory. The model can more accurately calculate the risk value of sections and network of pipeline and quantitatively determine the risk hierarchy. Regarding the risk hierarchy, the clear and consistent risk measurements are taken. The study thoroughly analyzes the possible factors causing pipeline network accidents by using fuzzy mathematical theory. By determining factor set, assessment grade set, factor weight set, factor assessment matrix, fuzzy comprehensive assessment, assessment index treatment and the like, a fuzzy comprehensive assessment system for the safety of urban gas network is established. Finally an application is provided in a real case so that the effectiveness of the assessment model could be verified.

Key words: Urban gas pipelines network, risk assessment, analytic hierarchy process, fuzzy multi-attribute

INTRODUCTION

The working environment of urban gas network is complicated and changeable, so there are many fuzzy factors which induce network accidents in pipe design, construction, operation and maintenance. In addition, the effects of the risk factors on pipe network are not necessarily independent but are correlated and the correlated relationship changes with different conditions such as time and location, which are fuzzy (Chen *et al*., 2003). Because of the objective reality of the fuzziness, various types of risk factors can't be precisely quantified and thus conventional methods cannot accurately represent the objective reality.

In recent years, the safety assessment techniques of gas network have developed rapidly (Wang and Li, 2005; Zhang *et al*., 2006). American Battle Columbus Institute published "Risk Survey Guide" (Guidelines for Hazard Evaluation Procedures), in which the pipeline was assessed by scoring method. WK Muhlbaucer edited "Pipeline Risk Management Manual", which discussed the pipeline risk assessment models and evaluation methodologies (Muhlbauer, 1996). However, the safety assessment of urban gas network is often limited to a certain category or categories of influencing factors and which cannot comprehensively and systematically reflect the security of gas network. In this study, a variety of factors are considered in assessing the security of urban gas network comprehensively. According to fuzzy mathematical theory Young and Daniel (2008), Xiao (2004) and Henselwood and Phillips (2006), a fuzzy comprehensive assessment system is established herein to make a preliminary study of the safety comprehensive assessment of urban underground gas network. The assessment process includes: determining factor set, risk assessment grade set, factor weight set, factor assessment matrix, fuzzy comprehensive assessment and assessment index establishment.

FUZZY COMPREHENSIVE ASSESSMENT METHODS

Determining factor set: A variety of factors for an object to be assessed form a factor set, namely Eq. 1:

$$U = \{u_1, u_2, ..., u_i, ..., u_m\}, (i = 1, ..., m) \quad (1)$$

where, U represents the factor set, u_i is the ith factor in the factor set, m is the total of factors in the factor set.

Determining risk assessment grade set: Assessment result of each factor generally is graded into four levels: low (v_1), medium (v_2), high (v_3), very high (v_4) and the finite set for assessment grades is Eq. 2:

$$V = \{v_1, v_2, v_3, v_4\} \quad (2)$$

Corresponding Author: Qiuju You, Beijing Key Laboratory of Operation Safety of Gas, Heating and Underground Pipelines, Beijing Research Center of Urban Systems Engineering, 100089, Beijing, People's Republic of China

Table 1: Scaling of judgment matrix and its meaning

f_{uij} (u_i) scaling	Meaning
1	Both factors are equally important
3	A factor is more important than another factor slightly
5	A factor is more important than another factor significantly
7	A factor is more important than another strongly
9	A factor is more important than another extremely
2, 4, 6, 8	The median between the above adjacent judgments

where, V is assessment grade set and v_1, v_2, v_3, v_4 are the first, second, third, fourth assessment set, that is low, medium, high, very high levels.

Determining factor weight set: The factor weight reflects the intrinsic relationship between factors, reflects the important degree of various factors in the factor set. The weights of various factors form factor weight set, as follows Eq. 3:

$$A = \{a_1, a_2, ..., a_i, ..., a_m\} \tag{3}$$

where, A represents the factor weight set, a_i is the weight of the i factor in the factor set.

Establish the weight set by using the Analytic Hierarchy Process (AHP) (Cagno *et al*., 2000; Wang, 2006; Yu, 2005).

Determining the judgment value of two-factors comparison: Before determining the judgment value of two factors, a hierarchical structure drawing of objects to be assessed must be found. According to the drawing, every two factors of each layer are separately analyzed and a judgment matrix is set up. When the judgment matrix is set up, there are integral numbers 1 to 9. These numbers are the relative important degree of a factor compared to another factor. Assumed that f_{uj} (u_i) expresses the judgment value of the "importance" of factor u_i relative to factor u_j, the judgment value and determining method are shown in Table 1.

Constructing the judgment matrix: If the scaling f_{uj} (u_i) of the factors u_i and u_j is a_{ij}, the important degree of the factors u_j and u_i to be compared is $1/a_{ij}$. For the assessment problem of m factors, based on the above principle of taking values, the judgment matrix of two-factors comparison is obtained: $\bar{A} = (a_{ij})_{m\times m}$

Determining the coefficient of the factor important degree: After the judgment matrix is obtained, the product M_i of each row elements for the judgment matrix can be calculated, as well as the m root of M_i:

$$W_i = \sqrt[m]{M_i}$$

Table 2: Mean random consistency index RI

m	1	2	3	4	5	6	7
RI	0	0	0.58	0.90	1.12	1.24	1.32

obtaining the vector $[W_1, W_2, ..., W_m]^T$ and further obtaining the eigenvector after Normalization processing Eq. 4:

$$a = \left[\frac{W_1}{\sum_{i=1}^{m} W_i}, \frac{W_2}{\sum_{i=1}^{m} W_i}, \cdots, \frac{W_m}{\sum_{i=1}^{m} W_i}\right] \tag{4}$$

Whether the result is reasonable depends on whether the judgment matrix accords with the matrix consistency. After the weight matrix is obtained, the inspection may be performed in the following testing process:

- Calculating the largest eigen value of the judgment matrix:

$$\lambda_{max} = \sum_{i=1}^{m} \frac{(\bar{A}a)_i}{mW_i}$$

- Defining the consistency index CI and the mean random consistency index RI:

$$CI = \frac{\lambda_{max} - m}{m-1}$$

For 1-9 orders the judgment matrix, Saaty gives a value of RI, as shown in Table 2.

- Defining the consistency ratio CR:

$$CR = \frac{CI}{RI}$$

it is generally believed that, if $CR<0.1$, the consistency of the judgment matrix are acceptable. As such, the eigenvector *a* of the consistency judgment matrix is the weight A of various factors.

Determining the factor assessment matrix: The factor assessment matrix expresses the fuzzy mapping relation from the factor set U to the assessment grade V, as follows Eq. 5:

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \cdots \\ R_i \\ \cdots \\ R_m \end{bmatrix} = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & r_{1,4} \\ r_{2,1} & r_{2,2} & r_{2,3} & r_{2,4} \\ \cdots & \cdots & \cdots & \cdots \\ r_{i,1} & r_{i,2} & r_{i,3} & r_{i,4} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m,1} & r_{m,2} & r_{m,3} & r_{m,4} \end{bmatrix} \tag{5}$$

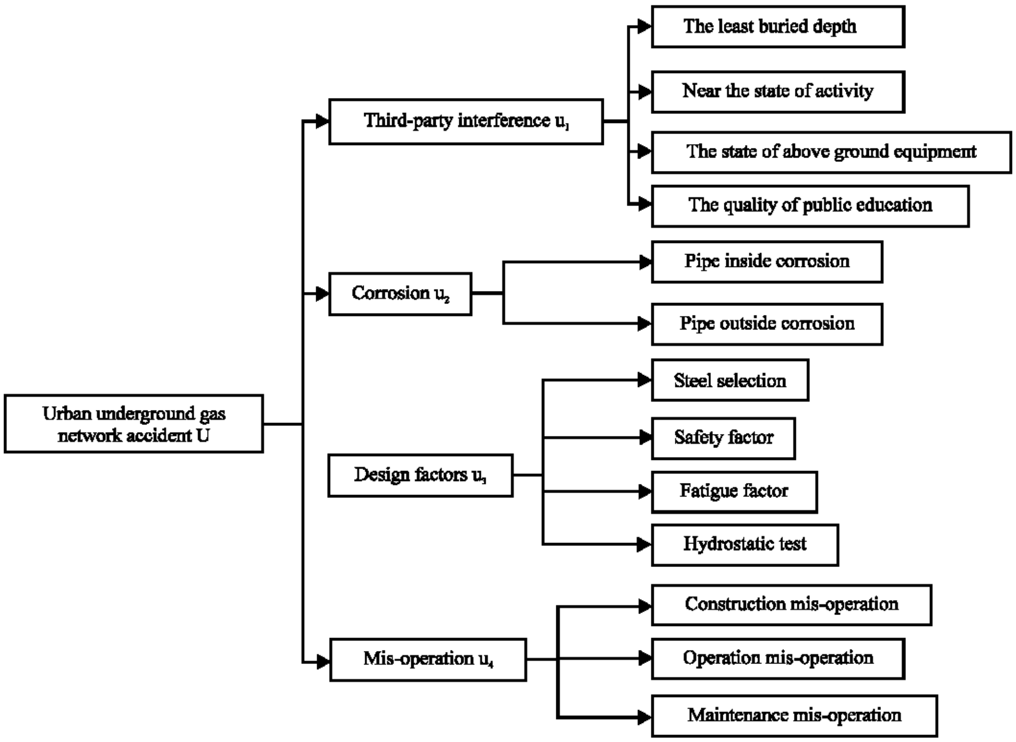

Fig. 1: Hierarchy structure figure of the accident factor for the urban underground gas network

where, R is the factor assessment matrix, $r_{i,j}$ is the membership of the j assessment grade with respect to the assessment factor u_i. According to the engineering practical experience, the membership function to fit gas network-triangle function is determined and then the $r_{i,j}$ of the assessment matrix is determined.

Fuzzy comprehensive assessment: The fuzzy comprehensive assessment refers to a comprehensive analysis of all factors ui in the assessment factor set, as follows Eq. 6:

$$B = A \circ R = (b_1, b_2, ..., b_m) \quad (6)$$

where, B is the vector of the fuzzy comprehensive assessment, A is the vector representation of the factor weight set.

The assessment index is determined by using the maximum membership degree principle and the assessment grade set is expressed by V, as follows Eq. 7:

$$C = B \circ V^T \quad (7)$$

where, C generally reflects the assessment index of the pipe network security, i.e., the comprehensive assessment index.

Urban gas network risk assessment: Taking two pipe sections A, B (located in different areas of the same urban) as an example, the urban underground gas network is assessed by using the fuzzy comprehensive assessment. The number of users to be supplied with gas through the pipe section A (a cast iron pipe of 5 km) is 30000; The number of users to be supplied with gas through the pipe section B (a cast iron pipe of 3 km) is 10000. Analysis on risk factors (Jo and Ahn, 2005; You and Zhu, 2009; You *et al*., 2011), is made, obtaining the hierarchy structure drawing of the urban underground gas network, as shown in Fig. 1.

Building the weight set A by the analytic hierarchy process: Based on practical experience and statistical data, scaling is selected and the judgment matrix U is set up:

$$\begin{bmatrix} U & u_1 & u_2 & u_3 & u_4 \\ u_1 & 1 & 1/6 & 1/2 & 1/4 \\ u_2 & 6 & 1 & 5 & 4 \\ u_3 & 2 & 1/5 & 1 & 1/2 \\ u_4 & 4 & 1/4 & 2 & 1 \end{bmatrix}$$

Calculated eigenvector: a = (a_1, a_2, a_3, a_4) = (0.068, 0.597, 0.121, 0.214).

The eigenvalue of the judgment matrix: $\lambda = 4.1$, $CI = 0.035$. For fourth-order matrix, $RI = 0.90$, thus $CR = CI/RI = 0.039<0.1$. As a result, it is thought that the distribution A of weights is reasonable.

Determining the factor assessment matrix: The group of experts evaluates the two pipe sections A, B and it is scored for low, medium, high, very high grades, so as to assess the pipe network. According to expression (5) calculation is made as follows:

$$R_A = \begin{bmatrix} 0.3 & 0.2 & 0.3 & 0.1 \\ 0.4 & 0.3 & 0.2 & 0.0 \\ 0.1 & 0.2 & 0.4 & 0.2 \\ 0.1 & 0.3 & 0.4 & 0.1 \end{bmatrix}, R_B = \begin{bmatrix} 0.4 & 0.3 & 0.2 & 0.1 \\ 0.3 & 0.3 & 0.1 & 0.0 \\ 0.2 & 0.3 & 0.3 & 0.1 \\ 0.1 & 0.4 & 0.2 & 0.2 \end{bmatrix}$$

Fuzzy comprehensive assessment: The vectors of fuzzy comprehensive assessment for two pipe network A, B are obtained from the factor assessment matrix R and the factor weight set A according to expression (6), respectively:

$$B_A = A \circ R_A = (0.4, 0.3, 0.2, 0.1);$$
$$B_B = A \circ R_B = (0.3, 0.3, 0.1, 0.2)$$

Assessment index establishment: The assignment is firstly given by using the weighted average method, such as "low" for 90 scores, "Medium" for 80 scores, "high" for 60 scores and "very high" for 40 scores.

According to expression (2), V = (90, 80, 60, 40). According to expression (7) $C_A = B_A \circ V^T = 76$; $C_B = B_B \circ V^T = 65$.

Analysis of calculated results:

- The security of the pipe section A is better than the pipe section B, which is in line with the practical repair data. Because the old pipe network of the B pipe section has not been reformed comprehensively, it should strengthen inspection to guarantee the safe operation of pipe networks
- The overall indexes of the two pipe sections both are within the range of 60 to 80, showing that the security of the urban underground gas network is at the middle level and further improvement is still needed

Multi-hierarchy fuzzy risk assessment: The effect of the second-level factors on the corresponding first-level factors can be calculated by using the above method and the relative risk value of the each pipe sections can be obtained by finally comprehensive analysis, which is not enumerated herein.

CONCLUSION

- Applying analytical hierarchy process (AHP) and fuzzy mathematics method to set up the Multi-hierarchy fuzzy risk assessment model, can fully consider the various factors that impact the safety of gas network. Organically combining the qualitative and quantitative analysis, is able to not only fully reflect the assessment factors and the fuzzy of the assessment process, but also try to reduce the disadvantage resulting from the personal subjective assume. The method is more in line with the objective reality than the average scores of experts and other methods. Therefore, the assessment results are more credible and reliable
- Multi-hierarchy fuzzy risk assessment methods provide the methods that calculate the weights between various factors and the weights of the upper factors and based on these methods, the major risk factors can be identified which affect the urban underground gas network security, thereby targeting to take measures to prevent accidents
- The method can be used to calculate the relative risk values of the various pipe sections and distinguish the high-risk or low-risk segments, which is helpful to treat high-risk segment timely and to long-term monitor the low-risk segment. It is also possible to calculate the risk values of the underground pipe network of different cities and different areas and compare the safety

ACKNOWLEDGMENTS

This project was supported by National Science and Technology Program of China (No. 2011BAK07B00-03 and No. 2012BAK27B01-04). We also thank the anonymous reviewers for their insightful and valuable hints.

REFERENCES

Cagno, E., F. Caron, M. Mancini and F. Ruggeri, 2000. Using AHP in determining the prior distributions on gas pipeline failures in a robust Bayesian approach. Reliab. Eng. Syst. Saf., 67: 275-284.

Chen, L.Q., P. Zhang and J.L. Ma, 2003. Study on fuzzy evaluation of municipal underground gas pipeline. Nat. Gas Ind., 23: 117-119.

Henselwood, F. and G. Phillips, 2006. A Matrix-based risk assessment approach for addressing linear hazards such as pipelines. J. Loss Prev. Process Ind., 19: 433-441.

Jo, Y.D. and B.J. Ahn, 2005. A method of quantitative risk assessment for transmission pipeline carrying natural gas. J. Hazardous Mater., 123: 1-12.

Muhlbauer, W.K., 1996. Pipeline Risk Management Manual. 2nd Edn., Gulf Publishing Co., Houston.

Wang, L. and F. Li, 2005. Reliability assessment of gas transmission and distribution systems in city. Gas Heat, 25: 5-8.

Wang, X.M., 2006. Risk assessment of urban underground gas pipeline. M.Sc. Thesis, Nanjing University of Technology, China.

Xiao, C.Y., 2004. Fuzzy Systems Engineering. Science Press, Beijing.

You, Q. and W. Zhu, 2009. Fault tree analysis on risk factors of underground gas networks of Beijing city. Oil Gas Storage Trans., 28: 27-30.

You, Q., J. Fan and W. Zhu, 2011. Risk assessment and control measures of accident gas in Beijing. J. Saf. Sci. Technol., 7: 93-99.

Young, D.J. and A.C. Daniel, 2008. Individual risk analysis of high-pressure natural gas pipelines. J. Loss Prev. Process Ind., 21: 589-595.

Yu, S.R., 2005. Determination of the weights on pipe risk factors based on AHP. Nat. Gas Ind., 25: 132-133.

Zhang, Y., F. Li and Y.W. Guan, 2006. Fuzzy comprehensive assessment of soil corrosivity for buried gas steel pipeline. Gas Heat, 26: 12-14.