Safety Assessment of the Buried Natural Gas Pipeline Based on Fault Tree and Fuzzy Neural Network

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***Abstract* — With the rapid development of natural gas pipeline, the safety of natural gas pipeline is paid more and more attention to. This paper presents a new safety assessment model based on fault tree and fuzzy neural network. Firstly, in the light of fault tree theory, fault tree analytical figure is established for buried natural gas pipeline system and the index system is established about buried natural gas pipeline safety assessment model. Secondly, Analytic Hierarchy Process has been used to improve to establish the weight of every influencing factor and adopted neural network to optimize the weight of every influencing factor, to eliminate objective factor affect in the process of establishing weight, therefore, the weight of every influencing factor is in accordance with objective, then, proceeding with safety assessment for single factor and comprehensive safety assessment for buried natural gas pipeline. Finally, the model which is applied to safety assessment of buried natural gas pipeline is based on fault tree and fuzzy neural network. The results show that the model applied to safety assessment of buried natural gas pipeline is not influenced by subjective factor and safety assesement result is objective, so the model has very important practical value.**

Keywords - Buried Natural Gas Pipeline;Fault Tree;Improved AHP;Fuzzy Neural Network;Safety Assessment

I. INTRODUCTION

In our country, 99% of the natural gas was transported via pipeline[1,2]. The natural gas pipeline is related to the economic life line of the country and the public security. In recent years, there are several accidents which threatened people's life and the environment occurred just because of the leakage of natural gas pipeline. Some of the accidents even have caused great casualties and property loss[3]. According to an incomplete statistics, during the period from 1970 to 1984, 5872 natural gas pipeline accidents occurred in the United States, 830 natural gas pipeline accidents occurred in Europe during the year 1970 to 1992, and during 1981 to 1990, there are 752 natural gas pipeline accidents occurred in the former Soviet Union[4]. Through the analyses of these natural gas pipeline accidents, four main reasons are mentioned[5]. There are corrosion of the pipeline, the third party damage, quality defects of the pipeline and poor management of the pipeline. So it is very important to make safety assessment to the buried natural gas pipeline.

At present, the methods of safety assessment model in the aspect of the buried natural gas pipeline are the gray relational analysis[6], the fuzzy comprehensive evaluation[7] and the function evaluation of relative difference[8,9]. All these methods are overdependence on the subjective factors when they are confirmed weight. And the safety assessment results of buried natural gas pipeline are lack of objectivity[10]. Firstly, this article uses the fault tree analysis method to analyze safety influencing factors on the buried natural gas pipeline and then establish the safety assessment index system of the buried natural gas pipeline. Secondly, confirm weight with improved AHP and then do the neural network optimization to the weight of the safety assessment index system to make the weight of every index more objective. At last, use the fuzzy evaluation method to make safety assessment of the buried natural gas pipeline.

II. FAULT TREE

In the fault tree, the top-level event is the result which the lower-level event creates and meanwhile the lower-level event is the reason for causing the top-level event[11,12]. Based on this theory and the statistical approach of the buried natural gas pipeline failure at home and abroad, make a comprehensive analysis about the design, the construction and the real operation situation of the buried natural gas pipelines which are required to do safety assessment[13]. And then get the four based factors which lead to the failure of the natural gas pipeline. They are the corrosion of the pipeline, the third party damage, quality defects of the pipeline and poor management of the pipeline.

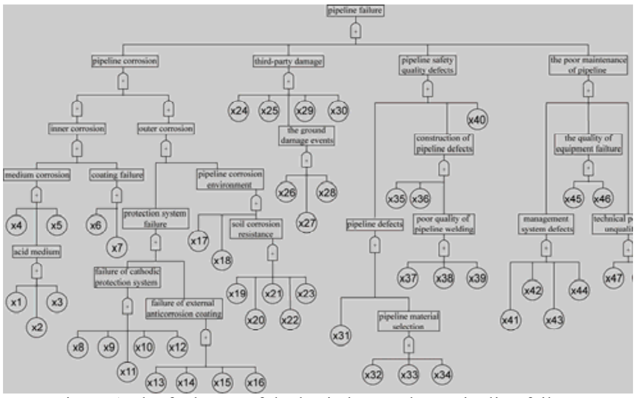

Figure 1.The fault tree of the buried natural gas pipeline failure

TABLE 1. THE BASIC EVENTS OF THE BURIED NATURAL GAS PIPELINE FAILURE FAULT TREE

sign	significance	sign	significance
X1	gas including water	X25	public awareness is not enough
X2	gas including hydrogen sulfide	X26	population density is big
X3	gas including carbon dioxide	X27	heavy traffic
X4	gas including sulfur dioxide	X28	construction is frequent
X5	gas quality monitoring is irrational	X29	pipeline depth is shallow
X6	inner coating damage	X30	the layout of the ground warning signs is unreasonable
X7	no inner coating	X31	additional safety margin is too small
X8	unqualified construction	X32	pipe mechanical properties is poor
X9	substandard production	X33	the part of the pipeline stress is concentrated
X10	cathodic protection distance is too short	X34	pipeline containing impurities
X11	line detection system is incorrect	X35	trench quality is poor
X12	protection potential is low	X36	overburden containing metal
X13	dsign selection is incorrect	X37	welder technology is weak
X14	poor construcion quality	X38	lack of preparation before welding
X15	poor product quality	X39	welding material is unqualified
X16	external injury	X40	pressure fluctuation
X17	effect of the other buried belt	X41	operating specification is unsound
X18	effect of the alternating current	X42	training system is unsound
X19	high salt content	X43	emergency plans is unsound
X20	high water content	X44	inadequate enforcement
X21	high sulfide content	X45	adequate equipment
X22	soil resistivity is low	X46	equipment failure
X23	PH is low	X47	low skills
X24	along whole line detect frequency is low	X48	responsibility is weak

According to the four based factors, establish a fault tree of the buried natural gas pipeline failure just as we can see in figure 1. Table 1 gives the basic events of the natural gas pipeline failure.

III. EVALUATION MODEL BASED ON FUZZY NEURAL NETWOR

Improved AHP. Based on the overdependence of the objective factors during the process of using the AHP to confirm the weight of every factor, this paper established an improved AHP to confirm the weight of the factors so as to eliminate the influence of the subjective factors just as follows:

Step1. the establishment of the two-two factor judgment matrix.

TABLE2. 0.1~0.9 SCALES

Scal e	definition	explanation
0.1, 0.2, 0.3, 0.4	Anti comparison	if element r_i compared with element r_j is judgment a , element r_i compares with element r_j is judgment $a = 1 - a$
0.5	Equally important	Two elements are equally important
0.6	Somewhat important	One element is a bit more important than the other element
0.7	Obviously important	One element is obviously more important than the other element
0.8	Much more important	One element is much more important than the other element
0.9	Extremely important	One element is extremely more important than the other element

Using the 0.1~ 0.9 Scales (table 2) which the specialists often use and on the condition of fully grasping the information of the object and the standard of the judgment to establish the judgment A by comparison separately just as follow:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

Where, $a_{ii} = 0.5, i = 1, 2, \cdots, n$, $a_{ij} = 1 - a_{ji}, i, j = 1, 2, \cdots, n$

Step2. the calculation of the importance sequence index e_i :

$$e_i = \sum_{j=1}^{n} a_{ij} \tag{1}$$

Step3. the construction of the judgment matrix B :

$$b_{ij} = \begin{cases} \dfrac{e_i - e_j}{e_{\max} - e_{\min}}(l_m - 0.5) + 0.5 & (e_i \geq e_j) \\ \left[\dfrac{e_j - e_i}{e_{\max} - e_{\min}}(l_m - 0.5) + 0.5\right] & (e_i \leq e_j) \end{cases}$$
(2)

Where： $e_{\max} = \{e_i\}; e_{\min} = \{e_i\}; l_m = e_{\max} / e_{\min}$

Step4. solve antisymmetric matrix B' of symmetric matrix B ,element b_{ij}' :

$$b_{ij}' = \lg b_{ij} \tag{3}$$

Step5. solve proposed optimal consistent matrix B^* of the B ,element b_{ij}^* :

$$d_{ij} = \frac{1}{n}\sum_{k=1}^{n}(b_{ik}' - b_{jk}') \tag{4}$$

$$b_{ij}^* = 10^{d_{ij}} \tag{5}$$

Step6.calculate n root of the proposed optimal consistent matrix B^* :

$$f_i = \prod_{j=1}^{n} b_{ij}^* \tag{6}$$

$$\beta_i = \sqrt[n]{f_i} \tag{7}$$

Step7.obtain element relative weights by normalization：

Process vector $\beta = (\beta_1, \beta_2, \cdots, \beta_n)$ by normalization,that is：

$$w_i' = \frac{\beta_i}{\sum_{i=1}^{n} \beta_i} \tag{8}$$

Vector $w' = (w_1', w_2', \cdots, w_n')$ is the feature vector we need to calculate and also the relative weight of this element.

Neural network. BP neural network belongs to a kind of multilayer artificial neural network model. The theory of the BP neural network based on the Error Back Propagation is the simplest one and is widely applied into numerous neural network models. BP neural network is composed of an input layer, one or more hidden layers, and an output layer. Every layer of the network includes several neurons. Although the upper layer and the lower layer of the neurons interconnected through linking weight, the neurons in the same layer has no connection. You can see the structure of typical 3-layer BP neural network model in the figure 2.

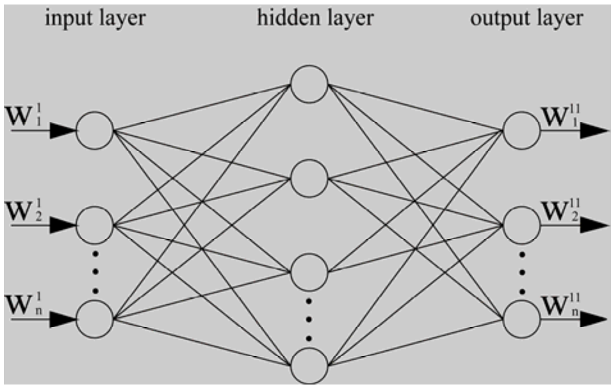

Figure2.BP neural network

Safety evaluation. Firstly, in the light of fault tree theory, fault tree analytical figure is established for buried natural gas pipeline system and index system is established about buried natural gas pipeline safety assessment model. Secondly, used improved Analytic Hierarchy Process to establish the weight of every influencing factor and adopted neural network to optimize the weight of every influencing factor, to eliminate objective factor affect in the process of establishing weight, therefore, the weight of every influencing factor is in accordance with objectiveness, then, proceeding with safety assessment for single factor and comprehensive safety assessment for buried natural gas pipeline. Finally, the model which is applied to safety assessment of buried natural gas pipeline is based on fault tree and fuzzy neural network.

IV. APPLICATION

Take high-pressure natural gas pipeline project of Jinzhou Huarun Gas Co. Ltd. as an example. The high-pressure natural gas pipeline whose pressure rating is 4.0 MPa and length is 12 KM is constructed in 2008 year. 3PE reinforced anticorrosive is applied to the high-pressure natural gas pipeline, 3PE reinforced anticorrosive is adopted. The whole line uses the catholic protection of artificial anode which crosses the road 3 times and rivers 1. The pipe class is L360 level and the diameter of the pipe is D323.9. So we will make the safety assessment analysis based on the poor pipe-line maintenance to illustrate the process of the safety assessment of the model which has established in this paper.

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Step1.establish risk factors set

According to the result of the buried natural gas pipeline fault tree analysis, the main influence of the bad maintenance of the pipeline has eight factor. Operating specification is unsound, training system is unsound, emergency plan is unsound, inadequate en-for cement, adequate equipment, equipment failure, low skills and responsibility is weak. So the bad maintenance of this buried pipeline' risk factor is???

Divide every factor into 5 grades. So we can get the influencing factors' grades just as shows in Table 3.

The safety of the 5 grades from Ⅰ to Ⅴ is relatively poor, poor, general, good, and relatively good. Basedon the distribution statistics rules which influence these factors, we get the membership rade of the buried pipeline just as Table 4, 5, 6 shows.

TABLE 3. MEMBERSHIP EVERY MISMANAGEMENT INFLUENCING FACTOR

Factor scale	Membership vector
Ⅰ	(1,0.5,0.25,0.125,0)
Ⅱ	(0.5,1.0,0.5,0.25,0)
Ⅲ	(0.25,0.5,1.0,0.5,0.25)
Ⅳ	(0.125,0.25,0.50,1.0,0.5)
Ⅴ	(0,0.125,0.25,0.5,1)

According to the principle of consistency, after normalization,we obtain every factor's level membership matrix:

$$R = \begin{bmatrix} 0.533 & 0.267 & 0.133 & 0.068 & 0.000 \\ 0.211 & 0.421 & 0.211 & 0.105 & 0.053 \\ 0.100 & 0.200 & 0.400 & 0.200 & 0.100 \\ 0.053 & 0.105 & 0.211 & 0.421 & 0.211 \\ 0.000 & 0.067 & 0.133 & 0.267 & 0.533 \end{bmatrix}$$

TABLE 4. SECURITY LEVEL OF INFLUENCING FACTOR ABOUT THE MANAGEMENT SYSTEM DEFECTS

Influencing factor	Probability scale
Operating specification is unsound	Ⅱ
Training system is unsound	Ⅳ
Emergency plans is unsound	Ⅰ
Inadequate enforcement	Ⅲ

TABLE 5. SECURITY LEVEL OF INFLUENCING FACTOR ABOUT THE MANAGEMENT SYSTEM DEFECTS

Influencing factor	Probability scale
Adequate equipment	Ⅲ
Equipment failure	Ⅰ

TABLE 6. SECURITY LEVEL OF INFLUENCING FACTOR ABOUT TECHNICAL PERSONNEL UNQUALIED

Influencing factor	Probability scale
Low skills	Ⅲ
Responsibility is weak	Ⅱ

Step2.establish comment set

Comment set a collection combined with the all kinds of results of the assessment which evaluator may do to the evaluation objects. Generally taking the extent of language or the assessment interval as evaluation target to divide the failure of the buried natural pipeline into 5 grades which can express in fuzzy language just as follow:

V={relatively poor,poor,general,good,relatively good}

Step3.establish factor weight set

According to improved AHP calculation results,every factor weight:

$$\{W_{41},W_{42},W_{43},W_{44}\} = \{0.208, 0.292, 0.406, 0.094, 0.482\}$$

$$\{W_{45},W_{46}\} = \{0.482, 0.518\} \ \{W_{47},W_{48}\} = \{0.475, 0.525\}$$

Step4.establish fuzzy judgment array of risk factors

$$B_1 = (W_{41},W_{42},W_{43},W_{44}) \begin{bmatrix} R_2 \\ R_4 \\ R_1 \\ R_3 \end{bmatrix} = (0.208, 0.292, 0.406, 0.094) \begin{bmatrix} 0.211 & 0.421 & 0.211 & 0.105 & 0.053 \\ 0.053 & 0.105 & 0.211 & 0.421 & 0.211 \\ 0.533 & 0.267 & 0.133 & 0.068 & 0.000 \\ 0.100 & 0.200 & 0.400 & 0.200 & 0.100 \end{bmatrix}$$
$$= (0.285, 0.245, 0.197, 0.191, 0.082)$$

$$B_2 = (W_{45},W_{46}) \begin{bmatrix} R_3 \\ R_1 \end{bmatrix} = (0.482, 0.518) \begin{bmatrix} 0.100 & 0.200 & 0.400 & 0.200 & 0.100 \\ 0.533 & 0.267 & 0.133 & 0.068 & 0.000 \end{bmatrix}$$
$$= (0.324, 0.235, 0.262, 0.132, 0.048)$$

$$B_3 = (W_{47},W_{48}) \begin{bmatrix} R_3 \\ R_2 \end{bmatrix} = (0.475, 0.525) \begin{bmatrix} 0.100 & 0.200 & 0.400 & 0.200 & 0.100 \\ 0.211 & 0.421 & 0.211 & 0.105 & 0.053 \end{bmatrix}$$
$$= (0.157, 0.314, 0.302, 0.151, 0.076)$$

Step5.fuzzy comprehensive judgment

According to the equation: $C = W'B$, we can get the set of the fuzzy evaluation in the third party damage of the pipeline:

$$C_4 = (W', W'', W''') \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = (0.492, 0.202, 0.306) \begin{bmatrix} 0.285 & 0.245 & 0.197 & 0.191 & 0.082 \\ 0.324 & 0.235 & 0.262 & 0.132 & 0.048 \\ 0.157 & 0.314 & 0.302 & 0.151 & 0.076 \end{bmatrix}$$
$$= (0.254, 0.264, 0.242, 0.167, 0.073)$$

$$C_1 = (0.097, 0.164, 0.235, 0.256, 0.175)$$

$$C_2 = (0.219, 0.265, 0.195, 0.173, 0.104)$$

$$C_3 = (0.115, 0.226, 0.267, 0.177, 0.103)$$

Step6. fuzzy comprehensive judgment of the buried natural gas pipeline failure

$$W = (W_1, W_2, W_3, W_4) = (0.107, 0.323, 0.336, 0.234)$$

$$D = (W_1, W_2, W_3, W_4)\begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix} = (0.107, 0.323, 0.336, 0.234)\begin{bmatrix} 0.254 & 0.264 & 0.242 & 0.167 & 0.073 \\ 0.097 & 0.164 & 0.235 & 0.256 & 0.175 \\ 0.219 & 0.265 & 0.195 & 0.173 & 0.104 \\ 0.155 & 0.226 & 0.267 & 0.177 & 0.103 \end{bmatrix}$$

$$= (0.168, 0.223, 0.230, 0.200, 0.123)$$

In the light of the maximum membership principle $v_k = 0.230$, the safety assessment grade of the buried natural gas pipeline is □, which means the safety is just so so.

VI. CONCLUSION

In this paper, we established a safety assessment model of the buried natural gas pipeline based on the fault tree and fuzzy neural network. First, based on this theory and the statistical approach of the buried natural gas pipeline failure at home and abroad, we make a comprehensive analysis about the design, the construction and the real operation situation of the buried natural gas pipelines which are reuired to do safety assessment. And then we get the four based factors which lead to the failure of the natural gas pipeline. They are the corrosion of the pipeline, the third party damage, quality defects of the pipeline, and poor management of the pipeline. Then according to all these factors above，we establish a fault tree of the buried natural gas pipeline failure which uses the buried natural gas pipeline as the top event. Second, apply the improved AHP to confirm the weight of every factor and then the neural network optimizes the weight of all the factors. At last, take a buried natural gas pipeline as example to use the fuzzy evaluation method to make safety assessment and then get the safety grade of this buried natural gas pipeline. So we can see that the safety of the pipeline is acceptable from the safety assessment of the buried natural gas pipeline which we used as an example.

CONFLICT OF INTEREST

The author confirm that this article content has no conflicts of interest.

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REFERENCES

[1] Chen, Y., Wang, W, M., Jiang, D, F, et al, "Safety Assessment of the CNG station in city based on faulty tree and fuzzy-grey theory", *Journal of Safety Science and Technology*, Vol. 29, pp. 123-129, (2011).

[2] Zhao, J. P. "Fuzzy Comprehensive Analysis Method and Its Application in the Third-Party Damage Assessment of the Buried Gas Piping", *Natural Gas Industry*, Vol. 123, pp. 103-105, 2008.

[3] Zhao, J. P., Liao, C, S., Sun, T. " Fuzzy Integrated Evaluation of Buried In-Service LPG Pressure Pipeline Quality", *Natural Gas Industry*, Vol. 145, pp. 152-154, 2005.

[4] Wu, C., Lv, J. J., Pan, Q,S., et al. "Study on Credit Risk Assessment Model of Commercial Banks Based on Fuzzy Neural Network", *Systems Engineering-Theory & Practice*, Vol. 173, pp. 1-8, 2011.

[5] Chen, S., Y., Li, Y,.W,. "Water Quality Evaluation Based on Fuzzy Artificial Neural Network", *Advances in Water Science*, Vol. 168, pp. 88-91, 2005.

[6] Chen, Y., Wang, W, M., Chen, W, C, et al.(2011). "The Application of Fuzzy Assessment Technique in the Assessment of the Third-party Damage of Buried Pipelines", *Journal of Beijing Institute of Petro-chemical Technology*, Vol. 189, pp. 38-41, 2011.

[7] Wang X, Zhang J, Zhu G. "Application of pre-stressed technology in the China-Myanmar cable-suspended gas pipeline crossing construction", *Natural Gas Industry*, Vol. 34, pp. 113-117, 2014.

[8] Han Z Y, Weng W G. "Comparison study on qualitative and quantitative risk assessment methods for urban natural gas pipeline network[J]. *Journal of Hazardous Materials*, 2011, 189(1–2):509-518.

[9] Han Z Y, Weng W G. "An integrated quantitative risk analysis method for natural gas pipeline network", *Journal of Loss Prevention in the Process Industries* , Vol. 23, pp. 428-436, 2010

[10] Yaping J U, Hui L, Yao Z, et al. "Fluid-structure Interaction Analysis and Lifetime Estimation of a Natural Gas Pipeline Centrifugal Compressor under Near-choke and Near-surge Conditions", *Chinese Journal of Mechanical Engineering*, Vol. 28, pp. 1261-1268, 2015.

[11] Zhang H, Zhang S, Liu S, et al. "Chatter vibration phenomenon of pipeline inspection gauges (PIGs) in natural gas pipeline", Journal of *Natural Gas Science & Engineering*, Vol. 27, pp. 1129-1140, 2015

[12] Mohsin R, Majid Z A, Yusof M Z. "Safety distance between underground natural gas and water pipeline facilities", *Reliability Engineering & System Safety*, Vol. 131, pp. 53-60, 2014.

[13] Zhang J W, Lei D. "Risk analysis of jet fire radiation in the leakage accident of natural gas pipeline", *Journal of Safety & Environment*, Vol. 11, pp. 233-236, 2011.