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A comprehensive probabilistic analysis model of oil pipelines network based on Bayesian network

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Abstract. Oil pipelines network is one of the most important facilities of energy transportation. But oil pipelines network accident may result in serious disasters. Some analysis models for these accidents have been established mainly based on three methods, including event-tree, accident simulation and Bayesian network. Among these methods, Bayesian network is suitable for probabilistic analysis. But not all the important influencing factors are considered and the deployment rule of the factors has not been established. This paper proposed a probabilistic analysis model of oil pipelines network based on Bayesian network. Most of the important influencing factors, including the key environment condition and emergency response are considered in this model. Moreover, the paper also introduces a deployment rule for these factors. The model can be used in probabilistic analysis and sensitive analysis of oil pipelines network accident.

1. Introduction

Oil pipelines network is one of the most important facilities of energy transportation. Nowadays, it has been used widely in China [1]. Meanwhile, oil pipelines network accident may result in serious consequences, such as casualties, economic loss, environment pollution, social disorder, and so on.

Many researchers have established analysis models for oil pipelines network accidents. Event-tree method, accident simulation method, Bayesian network method and some other methods are used as the basic method for these models.

An event-tree (Bertolini and Bevilacqua, 2006 [2]; Wang, et al., 2017 [3]) model focuses on the events and consequences which may occur in the accidents. But it is not suitable for multi-state issues. This makes it suitable for qualitative analysis. An accident simulation model aims to simulate the development and evolution process of the accident based on the corresponding physical model (Buzna, et al, 2006 [4]; Peters et al., 2008 [5]; Ji, et al., 2008 [6]). The quantitative result of consequences can be calculated by this kind of models. But it should be executed for each hazard and accident scenario. If there are any changes in accident scenario, the physical simulation model should be executed again.

Bayesian network (BN) is an effective method for probabilistic analysis (Joseph et al., 2010 [7]; Yuan et al., 2015 [8]). It is based on Bayesian conditional theory. Nodes and directed links are the two types of elements in BN diagram. A node represents a factor of the accident. And a directed links represents the
causal relationship of two related factors (Heckerman et al., 1995 [9]; Cheng et al., 2002 [10]). It can be used to estimate the incident occurrence (Li et al., 2016 [11]), the consequences (Kabir, et al., 2015 [12]), and the risk (Shabarchin and Tesfamariam, 2016 [13]). Although it has been used to solve various issues about the oil pipelines accident, there are still some disadvantages. Some important influencing factors, such as key environment conditions, secondary events and emergency response may not be referred in some models. And the deployment rule of BN nodes has not been established yet.

This paper proposed a probabilistic analysis model of oil pipelines network based on BN. It refers most of the important influencing factors, including time & location, hazard property, incident cause, key environment condition, initial event, secondary events, hazard-affected carries and emergency response. Moreover, the deployment rule of the factors is also introduced. This model can be used in probabilistic analysis and sensitive analysis of oil pipelines network accident.

2. Methodology

2.1. Bayesian network

The basic of BN is Bayesian condition probability theory. It contains conditional independence and joint probability distribution:

\[ P(V_1, V_2, \ldots, V_k / v) = \prod_{i=1}^{k} P(V_i / v) \quad (i = 1, 2, \ldots, k) \]  

\[ P(V_1, V_2, \ldots, V_k / v) = \prod_{i=1}^{k} P(V_i / Parent(V_i)) \quad (i = 1, 2, \ldots, k) \]  

Where \( V_1, V_2, \ldots, V_k \) represent various variables, \( v \) is the normal node, which facilitates the expression of the conditional probability, and Parent(\( V_i \)) is the parent nodes of \( V_i \).

2.2. Dempster-Shafer evidence theory

The Dempster-Shafer (DS) evidence theory is a method for quantitative analysis of system uncertainty (Dempster, 2008 [14]). It can be used to calculate the conditional probabilities of BN factors (Wu, et al., 2017 [15]).

3. Bayesian network model for oil pipelines network

3.1. Factor node

For a public safety issue, the factors may refer to environment, hazard, incident, hazard-affected carries, emergency response, and consequences. Furthermore, for an oil pipelines network accident issue, the factors should be made more detailed as Table 1.

| category       | factor node                                |
|----------------|--------------------------------------------|
| environment    | 1) time & location
                 | 1) occurrence time
                 | 2) accident location
                 | 2) key environment condition
                 | 1) immediately ignition
                 | 2) ignition
                 | 3) confined space nearby
                 | 4) water area nearby |
| hazard         | 1) hazard property
                 | 1) pipeline pressure
                 | 2) pipeline flux |
| incident       | 1) incident cause
                 | 1) failure causes for initial event
                 | 2) initial event
                 | 1) initial event: oil leaking |
3.2. Deployment rule
A practical BN model may have dozens of nodes. These nodes should be deployed following the rule. The deployment rule is important to make the BN model integrated and well-organized. The paper introduces the deployment rule of BN model for oil pipelines network as Fig. 1.

3.3. Occurrence probability and conditional probability
BN nodes include independent nodes and dependent nodes. The factors of occurrence time, accident location, hazard property, incident cause and key environment condition are independent nodes. Their occurrence probabilities are based on experts’ estimation and statistics. The factors of initial event, secondary events, hazard-affected carries, emergency response and consequences are dependent nodes. Their conditional probabilities are based on experts’ estimation using DS methods. BN probabilities are showed as Fig. 2.

3.4. Bayesian network
As the factor nodes have been identified and deployed, and the occurrence probability and conditional probability have been estimated, then the BN can be constructed as Fig. 2. It is a snapshot by the BN software Netica.
4. Results and discussions

4.1. Probabilistic analysis for consequences

BN model can be used for probabilistic analysis for consequences. For the oil pipelines network shown as Fig. 2, the probabilistic analysis result is as Table 2.

| consequence node | state of consequence node | estimated probabilities (%) |
|------------------|---------------------------|----------------------------|
| casualties       | ① <5 persons              | 71.3                       |
|                  | ② 5 to 10 persons         | 19.5                       |
|                  | ③ 10 to 30 persons        | 6.7                        |
|                  | ④ >30 persons             | 2.5                        |
| economic loss    | ① <10 millions            | 66.2                       |
|                  | ② 10 to 50 millions       | 25.9                       |
|                  | ③ 50 to 100 millions      | 7.2                        |
|                  | ④ >100 millions           | 0.7                        |
| environment pollution | ① <1 km² water area      | 50.4                       |
|                  | ② 1 to 10 km² water area  | 18.5                       |
|                  | ③ 10 to 50 km² water area | 24.1                       |
|                  | ④ >50 km² water area      | 7.0                        |
| Social order influence | ① <100 persons       | 59.5                       |
|                  | ② 100 to 1000 persons     | 24.3                       |
|                  | ③ 1000 to 10000 persons   | 10.6                       |
|                  | ④ >10000 persons          | 5.6                        |
4.2. Sensitivity analysis
The effective of influencing factors to consequences can be estimated by sensitivity analysis. Take the “casualties” as the target to analyse the effect of “emergency response”. The sensitivity analysis result is as Fig. 3.

![Fig. 3 The sensitivity analysis result for “emergency response” VS. “Casualties”](image)

5. Conclusion
A comprehensive probability analysis model of oil pipelines network has been proposed in this paper. It is based on the Bayesian network theory. Most of the influencing factors, such as time & area, key environment condition, emergency response, are referred. Meanwhile, four types of consequences including casualties, economic loss, environment pollution and social order influence can be estimated. Moreover, the deployment rule of BN nodes is introduced. It is helpful to make the BN model integrated and well-organized.

This probabilistic analysis model can be used not only in probabilistic analysis for consequences, but also for sensitivity analysis for influencing factors.

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References
[1] Gao P, Tan Z, Liu G, et al 2017 China's oil and gas pipeline construction in 2016 Int. Pet. Econ. 3 26-33.
[2] Bertolini M, Bevilacqua M 2006 Oil pipeline spill cause analysis: A classification tree approach. J. Qual. Maint. Eng. 12 2 186-198.
[3] Wang D, Liu E, Huang L 2017 Event Tree Analysis of Xinda Oil Pipeline Leakage Based on Fuzzy Set Theory Open Civ. Eng. J. 11 1 101-108.
[4] Buzna, L, Peters, K, Helbing D 2006 Modeling the Dynamics of Disaster Spreading in Networks Phys. A: Stat. Mech. Appl. 363 1 132-140
[5] Peters K, Buzna L, Helbing D 2008 Modeling of Cascading Effects and Efficient Response to Disaster Spreading in Complex Networks Int. J. Crit. Infrastruct. 4 46-62.
[6] Ji X W, Weng W G, Fan W C 2008 Cellular Automata-Based Systematic Risk Analysis Approach for Emergency Response Risk Anal. 28 5 1247−1260.
[7] Joseph S A, Adams B J, McCabe B 2010 Methodology for Bayesian belief network development to facilitate compliance with water quality regulations J. Infrastruct. Syst. 16 58-65.
[8] Yuan Z, Khakzad N, Khan F, Amyotte P 2015 Risk analysis of dust explosion scenarios using Bayesian networks. *Risk Anal.* 35 2 278-291.

[9] Heckerman D, Geiger D, Chickering D M 1995 Learning Bayesian networks: the combination of knowledge and statistical data. *Mach. Learn.* 20 3 197-243.

[10] Cheng J, Greiner R, Kelly J 2002 Learning Bayesian networks from data: an information-theory based approach. *Artif. Intell.* 137 1-2 43-90.

[11] Li X, Chen G, Zhu H 2016 Quantitative risk analysis on leakage failure of submarine oil and gas pipelines using Bayesian network. *Process Saf. Environ. Prot.* 103 163-173.

[12] Kabir G, Tesfamariam S, Francisque A, et al. 2015 Evaluating risk of water mains failure using a Bayesian belief network model. *Eur. J. Operational Res.* 240 220-234.

[13] Shabarchin O, Tesfamariam S 2016 Internal corrosion hazard assessment of oil & gas pipelines using Bayesian belief network model. *J. Loss Prev. Process Ind.* 40 479-495.

[14] Dempster A P 2008 Classic Works of the Dempster-Shafer Theory of Belief Functions *Springer, Berlin Heidelberg*.

[15] Wu J, Zhou R, Xu S, et al 2017 Probabilistic analysis of natural gas pipeline network accident based on Bayesian network. *J. Loss Prev. Process Ind.* 46 126-136.