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Assessing and classifying risk of pipeline third-party interference based on fault tree and SOM

Wei Liang [a], Jinqiu Hu [a,*], Laibin Zhang [a], Cunjie Guo [b], Weipeng Lin [a]

[a] College of Mechanical and Transportation Engineering, China University of Petroleum, Beijing, China
[b] PetroChina Beijing Natural Gas Pipeline Co. Ltd., Beijing, China

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ABSTRACT

Accidents to pipelines because of the third-party interference have been recorded and they often result in catastrophic consequences for environment and society with a great deal of economic loss. The third-party interference resulting from complicated origins occurs randomly, and is hard to be forecasted or controlled in advance, so it becomes a serious threat to the safe operation of long transmission pipeline. This paper focuses on the application of self-organizing maps (SOMs) to assess the risk of third-party interference and classify their risk patterns. In this work, fault tree is used first to establish the risk assessment index system, and then SOM is used in multi-parameter risk pattern classification approach, which is proposed to present various risk maps, incorporating the factors of pipeline laying conditions, historical damage records, safety-related actions, management measures and the environment around the underling pipeline. A field case study of Shaanxi–Beijing gas pipeline in China is undertaken so that the effectiveness of the proposed approach could be verified. By taking the classification results into consideration, the decision maker may well get precious and differentiated information about the pipeline risk distribution of third-party interference and make appropriate safety-related actions to prevent the damage.

1. Introduction

Transmission pipelines carrying natural gas or oil are not on secure industrial site as a potentially hazardous plant, but are routed across the land or river, i.e., busy city, a network of superhighways, tunnel, farmland or railways. Consequently, there is the ever-present potential for third parties to interfere with the integrity of these pipelines. In addition, the combination of third-party interference and pipeline route might suggest that people around the pipelines are subject to significant risk from pipeline failure. The hazard distance associated with the pipeline ranges from under 20 m for a smaller pipeline at lower pressure, up to over 300 m for a larger one at higher pressure (Jo and Ahn, 2002). Taking Shaanxi–Beijing gas pipeline in China for example, it is not only the longest so far of land-based transmission pipeline for natural gas, but also China's first large diameter, long distance and fully automated gas pipeline. The pipeline starts from west of Shaanxi to the east Beijing, with length of about 860 km, diameter of 660 mm, across three provinces and one city, i.e., Shaanxi, Shanxi, Hebei and Beijing. It goes across large rivers 5 times, medium-sized rivers 238 times, large and medium-sized loess gullies 15 times, railways 15 times and trunk highways 86 times. The safety issues of such gas pipeline due to the third-party interference are more prominent with increasingly high occurrence probability and severe disaster consequence. A major pipeline failure caused by third-party interference is shown in Fig. 1. Therefore, regulatory authorities and pipeline managers have endeavored to improve the level of safety of the pipeline by protecting it from third-party interference.

Gas transmission pipelines are buried in utility right-of-ways marked with warning signs. These right-of-ways are well maintained. Nevertheless, pipelines are sometimes damaged by construction equipment not owned by the pipeline company, such as mechanical interference during excavations and other activities close to the pipelines. Referred to as third-party damage, it is the major cause of damage to natural gas transmission pipelines (National Transportation Safety Board, 1994). A single incident can be devastating, causing death and millions of dollars in property loss. One highly publicized incident occurred in Edison, NJ, in 1994. Flames shot 125–150 m (400–500 feet) into the air near an apartment complex. Nearly 100 people were treated in hospitals as a result of the accident. Damage from the incident exceeded $25 million (Miura and Mishima, 1995).

Active propaganda about the importance of pipeline, advanced pipeline damage inspection technology and greater legal penalties have reduced, but not eliminated, the number of incidents. A backhoe,

* Corresponding author.
E-mail address: hjqcup@hotmail.com (J. Hu).

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Fig. 1. Gas pipeline failure caused by third-party interference to Shaanxi–Beijing gas pipeline.

Fig. 2. Illegal valves and hoses installed in the pipeline by stealers.

trencher, or auger (for digging post holes) can move into the right-of-way, begin excavation, and damage the pipeline in less than 30 min. A boring machine can travel beneath the surface of the ground for greater than 30 m. This type of equipment can damage the pipeline without ever having the aboveground portion of the equipment in the right-of-way.

While third-party damage can be devastating, it occurs infrequently much less than one hit per kilometer of pipeline a year. Every year, many intrusions occur in the right-of-way. Most of these are benign with no possibility of injuring the pipeline (e.g., mowing the right-of-way, people walking, motorcycle and ATV traffic).

Another important type of incident inducing pipeline leakage is caused by illegal gas theft. During the pipeline construction, a number of extra valves beyond the scope of official design are embedded through drilling pores by illegal individuals, which help them to steal gas in the future when the pipeline is put into operation after construction. These illegal activities directly cause gas leakage in a large area, and further result in a large area contaminated land, which is easy to cause fire and explosion. In the meantime the pipeline engineers have to shut down or adjust the corresponding upstream and downstream stations rushing to deal with the emergency and repair the pipeline as soon as possible. Each incident due to gas or oil stealer usually causes as little as tens of thousands, and as many as hundreds of thousands, millions or even billions of RMB in economic losses and serious environmental pollution. The site of oil steal is shown in Fig. 2 and the repaired pipeline is shown in Fig. 3, which provoke safety engineer to take proactive safety-related actions to prevent impacts of third-party interference, not detect after they occur.

The third typical pattern of third-party interference can be shown in Fig. 4, i.e., the relative and crossing projects, which are

Fig. 3. Drilled holes had been repaired by welding hats.

Fig. 4. Third-party interference in the pipeline crossing project.

very close to the underlining pipeline, and become a serious threat to the existing pipeline. Taking Shaanxi–Beijing gas pipelines as an example, there are 19 intersections between lines 2# and line 3#.

A cost-effective risk management scheme that can successfully identify the pipeline sections having high risk of third-party interference and recognize the possible risk sources with field data. The safety operators can make corresponding safety-related actions to reduce risk in advance, which will solve a long-standing problem of the natural gas industry. Concepts have been suggested and are in various states of development.

The strength degradation of oil transmission pipeline by third-party damages was studied by Cao et al. (2010a, 2010b) trough hydraulic pressure tests and finite element method (FEM) analysis were performed, which manifested the ultimate pressure that the damaged pipeline could bear after being repaired. Brito and de Almeida (2009) present a decision model for risk assessment and for risk ranking of sections of natural gas pipelines based on the multi-attribute utility theory to support the prioritizing of critical sections of pipeline in natural gas companies, and also to allow sections of pipeline to be ranked into a risk hierarchy.