Risk Assessment and Management of Gas Transmission Lines, in Alamout natural gas pipeline

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Abstract

Introduction: Using natural gas as a clean, plentiful and inexpensive source of energy in recent years has progressively increased in Iran. Pipelines are the most common system to transport natural gas from field to different regions of Iran. These pipelines always pose risks to surrounding population and environments. The aim of this study was to assess the potential health, safety, and environment risk of Alamout natural gas pipeline.

Methods and Materials: In this study Kent-Mauhlbauer method was used to assess risks of Alamout natural gas pipeline. Data collection was performed through field measurement and investigation.

Results: The results of the present study reveal that there are three level of risk in the path of pipeline including; high (10%), low (1%) and very low (89%). There is no moderate risk in the path of pipeline. Also there are seven high risk areas that must be considered as a target of risk control measures.

Conclusions: In this study, seven high risk areas were recognized that must be placed in the center of risk management programs. Also the highest risk of Alamout natural gas pipeline was related to third-party damages that can be reduced by public education programs, regular inspections and using enclosure in high population density areas.

Keywords: Safety, Kent-Mauhlbauer, Natural gas, Pipeline, Risk assessment.

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Introduction

Natural gas is a clean, plentiful and inexpensive source of energy that is used widely for domestic and industrial consumption in Iran. In comparison to other sources of energy, natural gas has advantages both in terms of energy and less pollution production[1,2].

Despite all of these advantages, extracting, transporting, distributing and using of natural gas, due to its energy content (about 30 kJ/m^3or 1000 Btu/ft^3), has many health, safety, and environment (HSE) risks for surroundings[3]. In Iran, natural gas is mostly transported by pipelines. Long-distance pipelines, commonly pipelines pass through the agricultural lands, population centers, power lines and cross rivers. Historical data proves that pipeline burst or natural gas leakage could lead to catastrophic accidents. In a study done by B. Sovacool, natural gas pipeline accidents occurred from 1907 to 2007, 81 natural gas pipeline accidents were found to lead to 709 deaths (i.e., 8.75 deaths per accident) and loss of over 3.7 billion dollars. Also In 2004, due to the explosion of a natural gas plant in Belgium, 14 people were killed and over 200 were wounded. In the same year, gas leakage in Paraguay caused a fire that led to the deaths of over 250 people. In 2009 gas leakage caused the biggest fire in Moscow after the Second World War[5]. In addition, pipeline failures have many adverse environmental consequences. Fleeger et al[6] explained that water contaminated with materials such as natural gas, has many direct and indirect effects on aquatic ecosystem and surrounding populations.

Looking back on these accidents and their potential consequences and to prevent such accidents, it is truly necessary to assess and manage the risks posed by natural gas pipelines. There are various methods for assessing risks associated with natural gas pipelines. For example Thomas method estimates the failure rate of gas pipelines based on empirical data, but because of ignoring the third-party damage factors this method could not be used for natural gas pipelines[7]. Third-party damages are caused by people out of pipeline organization and are very important in pipeline risk assessment because pipelines not located in controlled areas and they are accessible for humans living in the vicinity of it. In another study it has been said that external forces, material failure and corrosion are the first, second and third main causes of pipeline failures[8]. Kent-mauhlbauer method, an indexing method, covers all parameters that can cause pipeline failure also their potential consequences. This method was successfully used for a decade. Universality, low cost and no need of special software are of the most important features of this method [9–11]. Accordingly, in this study Kent-Mauhlbauer method was used to assess the risks associated with natural gas pipeline of Alamout, Iran. Thus the main aim of this study was to assess the potential health, safety, and environment risk of Alamout natural gas pipeline.

Case study

Alamout gas pipeline started from northwestern of Qazvin and ended in northwestern region of Alamout. This pipeline was designed to convey 1700000 (m^3) of natural gas per day. The pipeline length is 50 km and its diameter is 12 inches throughout the pipeline path. The pipeline is made of three layers of polyethylene. The pipeline passes through 12 population centers with a population of between 11 and 2748 people in the northwest area of Qazvin. The highest population density is located in kilometers of 9 to 16 with a total population density of 457 people per square kilometer. The distance between the population centers and the pipeline was between 600 to 1800 meters. Also this pipeline is located in the vicinity of high voltage power lines in kilometers of 7.168 to 7.752 and crosses north of Qazvin in three points (15.981, 17.224, and 18.589 km). The entire path of this pipeline is high and has a very high seismic potential, according to the seismic hazard map of Iran. The 46.951Km to

The next step is to calculate leak impact factor (LIF). LIF is representative of accident consequences and evaluates impacts of probable accidents on surrounding environment and people. This factor is calculated by following equation;

$$LIF = (Product\ hazard) \times (Leak\ volume\ index) \times (Dispersion\ index) \times (Receptor\ index) \quad (2)$$

In equation 2 product hazard depends on natural properties of carried gas. Product hazard is composed of acute hazard and chronic hazard score. Acute hazard itself is sum of the three properties of product; flammability (0-4 pts), reactivity (0-4pts) and toxicity (0-4 pts). Chronic hazard score depends on long term effects of product and range from zero to one. Leak volume index represents the amount of carried matter that leak out of the pipe in form of gas, liquid or combination of them. The total amount of leakage is calculated by summing leaks volume before insulation (including leak detection and reaction to it), leak volume after isolation (drainage or decompression time) and reduced spill volume (secondary containment). A release of carried matter in pipelines can affect a region that depends on both characteristics of carried matter and receptive environments. Also pipeline parameters including pipe diameter and internal pressure flow rate is important. Dispersion index evaluates the relative size of affected region. Types and quantities of recipient surrounding environment were evaluated as receptor index. Receptors include creatures, structures, agricultural land and so on. Receptor index is sum of the population density, environmental considerations and high value area scores.

Through field study, all required parameters were determined and final risk score for each segment of pipeline were calculated using equation 3.

$$Final\ score\ of\ risk = sum\ index/leak\ impact\ factor \quad (3)$$

Based on final score of risk, pipeline sections were classified in four groups; 49Km of the pipeline path is located adjacent to the Shahrood River.

Methods and Materials

In this study Kent-Mauhlbauer method was used to HSE risk assessment of Alamout pipeline [9]. **Error! Reference source not found.** shows the diagram of this method. Equations 1, 2 and 3 were used to calculate final score of risk.

In the above equation

Third-party damage factor: Any damage caused by people out of the pipelines organization is known as third-party damage factor. At first, index sum must be determined. This index is representative of accident probability and sum of four parameters. Equation (1) shows these parameters.

$$Index\ sum = (Third - party\ damage) + (Design\ index) + (corrosion\ index) + (Incorrect\ operation\ index) \quad (1)$$

Table 1 lists some variables that must be considered in the calculation of the third-party damage factor score.

Corrosion index: The failure caused by corrosion is one of the most common mechanisms of pipelines failure. There are three types of corrosion; Atmospheric corrosion, internal corrosion and subsurface corrosion. Atmospheric corrosion deals with pipeline components that are exposed to the atmosphere. Internal corrosion deals with the potential for corrosion originating within the pipeline. Subsurface pipe corrosion is the most complicated of the categories, reflecting the complicated mechanisms underlying this type of corrosion.

Design index: This index evaluates whether design criteria and principles are considered. There are several detrimental factors in design index, these factors and their scores are shown in Table 3

Incorrect operation: This parameter evaluates and quantitaties pipeline failures caused by pipeline employees in phases of system life cycle range from design to operation and maintenance.

Also GIS software was used to depict the risk map of pipelines. At the end of this study control measures and activities were suggested in order to achieve risk assessment objectives.

high, moderate, low and very low risk as shown in **Error! Reference source not found.**. This classification helps management to prioritize risks and allocate resources for risk control.

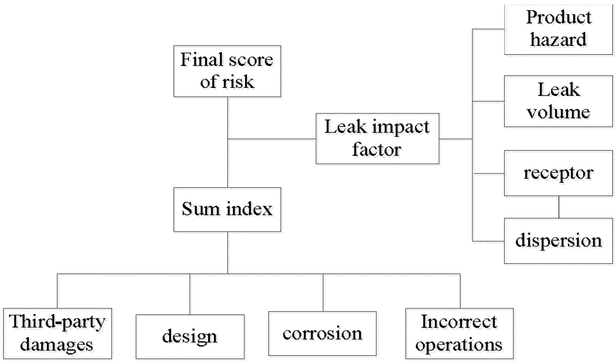

Figure 1: Diagram of Kent-mauhlbauer method

At first, index sum must be determined. This index is representative of accident probability and sum of four parameters. Equation (1) shows these parameters.

$$Index\ sum = (Third - party\ damage) + (Design\ index) + (corrosion\ index) + (Incorrect\ operation\ index) \quad (1)$$

Table 1: Third-party damage varibles and calculation

Variable	Range of score
Minimum depth of cover	0-20 pts
Activity level	0-20 pts
Aboveground facilities	0-10 pts
Line locating	0-15 pts
Public education programs	0-15 pts
Right-of-way condition	0-5 pts
Patrol frequency	0-15 pts
Total score	0-100 pts

Table 2: Corrosion index calculation: sum of the atmospheric corrosion (0-10), internal corrosion (0-20) and subsurface corrosion (0-70) scores

Atmospheric corrosion	Atmospheric corrosion		0-5 pts
	Atmospheric type		0-2 pts
	Atmospheric coating		0-3 pts
Internal corrosion	Product corrosivity		0-10 pts
	Preventions		0-10 pts
Subsurface corrosion	Subsurface condition	Soil corrosivity	0-15 pts
		Mechanical corrosion	0-5 pts
	Cathodic protection	Effectiveness	0-15 pts
		Interference potential	0-10 pts
	Coating	Fitness	0-10 pts
		Condition	0-15 pts
Total score			0-100 pts

Table 3: Design index calculation

Variables	Range of scores
Safety factor	0-35 pts
Fatigue	0-15 pts
Surge potential	0-10 pts
Integrity verification	0-25 pts
Land movement	0-15 pts
total	0-100 pts

Table 4: Incorrect operation index is calculated by summing design (0-30), construction (0-20), operation (0-35) and maintenance (0-15) scores

Design (0-30 pts)					Construction (0-20 pts)						Operation (0-35 pts)							Maintenance (0-15 pts)		
Hazard identification	MOP potential	Safety systems	Material selection	checks	Inspections	Materials	Joining	Backfill	Handing	coating	Procedure	SCADA/communications	Drug testing	Safety programs	Surveys/maps/records	Training	Mechanical error preventer	Documentation	Schedule	Procedures
0-4 pts	0-12 pts	0-10 pts	0-2 pts	0-2 pts	0-10 pts	0-2 pts	0-2 pts	0-2 pts	0-2 pts	0-2 pts	0-7 pts	0-3 pts	0-2 pts	0-2 pts	0-5 pts	0-10 pts	0-6 pts	1-2 pts	1-3 pts	1-10 pts

Table 5: *LIF* calculation

Risk index		range
Product hazard	Acute hazard	0-12 pts
	Chronic hazard	0-1 pts
Leak volume		0-1 pts
Dispersion		0-1 pts
Receptor		0-1 pts

Table 6: Classification of risks based on their scores

Level of risk	range of risk score
High	6600-6896
Moderate	6897-7193
Low	7194-7490
Very low	7491-7787

Results

Risk assessment results showed that there are seven high risk areas in the path of Alamout pipeline that are 5+300-5+885 Km, 14+300-14+700 Km, 15+980-16+550 Km, 17+730-18+350, 34+230-34+825, 44+930-45+400 and 47+000-49+000 Km. These seven areas formed 10% (5 kilometers) of the total path of pipeline. Also low and very low risk areas consist of 1% (500 meters) and 89% (44.5 kilometers) of pipeline path, respectively, while there is no moderate risk section in pipeline path (Figure 2).

In the present study the risk map of pipeline path was depicted using GIS software. This map shows the risk associated with each section of pipeline by color codes. Also in this map the location of 8 at risk population centers are shown.

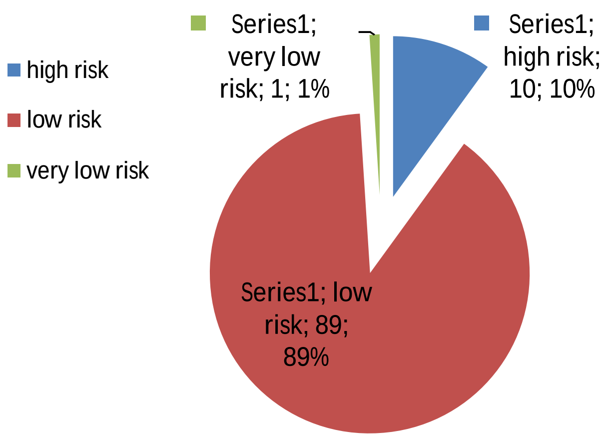

Figure 2: Risk distribution across the pipeline path

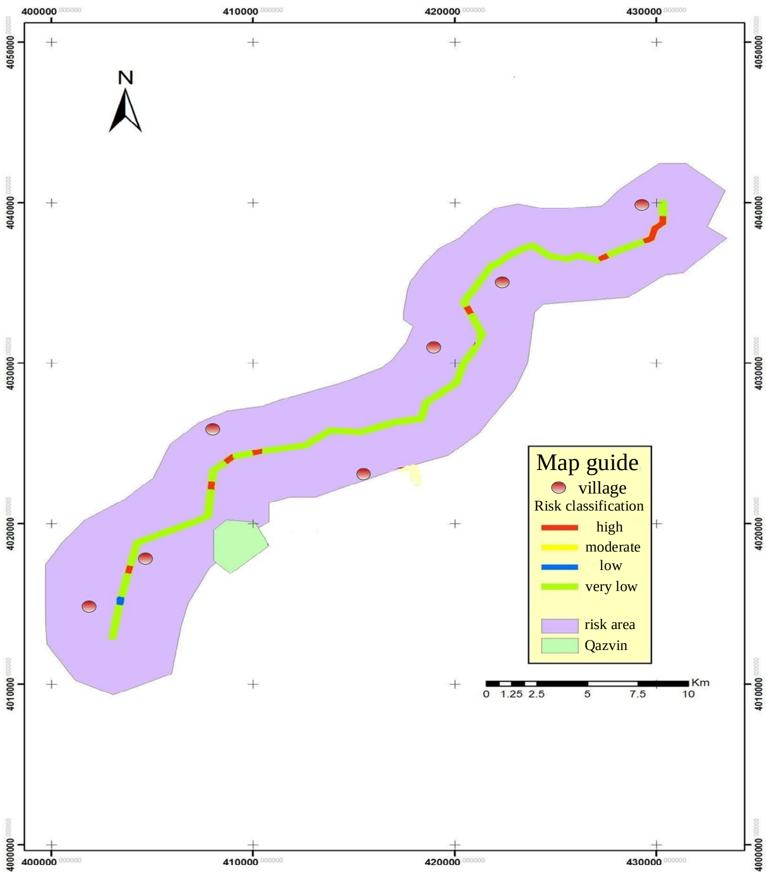

Figure 3: risk map of Alamout pipeline

Discussion

The main issue of Alamout pipeline is the high third party damages index score. Because of being located in uncontrolled areas, proximity to population centers and crossing the main road in eleven points, the traffic of people in the immediate vicinity of the pipeline is high. Bajcar et al[12] reported that too much traffic on route of gas pipeline as a third-party damage can cause fatigue in the pipelines due to dynamic tension in the soil, and lead to gas release in the surrounding environments. Jo et al[13] expressed that third-party activities in the pipeline path increases the probability of pipeline failure. Public education programs and regular inspection are two common ways to reduce third-party index score. Another way is to enclose the pipeline with protective fences that is impractical for all path of pipeline but very helpful in the area with high population density.

SCADA (supervisory control and data acquisition) systems fitted with optical fiber are critical to real-time monitor and protect pipeline condition. These systems are very helpful in the case of pipeline failure and can facilitate emergency responses.

Shahrood River is the main ecological concern that needs special attention in the operation phase of pipeline life cycle.

Risk management prioritizes their activities based on results of risk assessment then selecting proper risk assessment method is very important. Kent-Mauhlbauer method is a powerful tool in the long distance pipeline risk assessment, this method is very comprehensive and considers nearly all factors that can cause pipeline failure but it has limitations. For example the calculation of *LIF* is complex and need some assumptions. Recently Kalatpoor et al.,[14] used ALOHA software to simplify some part of *LIF* calculations but this approach needs more studies. Another limitation of this method is its deficiency in assessing risk associated with urban natural gas pipeline networks, for this purpose several methods are proposed by Han and Weng[5].

Conclusions

Literature review showed 8.75 deaths per each natural gas pipeline accident. It means all natural gas pipelines need proper risk management. In this study, seven high risk areas were recognized that must be considered in the center of risk management programs. Also the highest risk of Alamout natural gas pipeline was related to third-party damages that can be reduced by public education programs, regular inspections and using enclosure in high population density areas.

Acknowledgements

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