Risk Assessment of Oil and Gas Pipelines Failure in Vietnam

Uyen Dao*, Zaman Sajid, and Yahui Zhang

***Abstract*—Pipelines in the oil and gas industry have been used as one of the most practical and inexpensive methods for large-scale oil and gas transportation. In harsh operating conditions, these pipelines are susceptible to failure, which causes leakage of oil and gas and a significant impact on the environment and economy. Therefore, operational failure risk in oil and gas pipelines is paramount. This paper proposes a model to study the risk assessment of natural gas release in onshore gas pipelines in Vietnam. The methodology analyzes the causes of the failure of the gas pipeline by integrating Fault Tree Analysis (FTA) and fuzzy theory. Monte Carlo simulation is used to evaluate the level of uncertainty. The study identifies 21 risk factors that lead to the failure of the pipelines. The results of a case study on two pipelines in Vietnam reveal that the risk of pipeline failure due to rupture is higher than the failure risk due to puncture. Results also show that corrosion has lower chances of pipeline failure. However, it carries catastrophic consequences.**

***Index Terms*—Fault tree analysis, gas pipeline failure, operational failure, risk assessment**

I. Introduction

Energy is the foundation of modern industry and the sustainable development of the economy. The energy consumption of natural gas has increased rapidly in recent years, which has led to significant growth in the natural gas industry. Thus, achieving a high production rate has gained much attention. However, an essential part easily ignored in the natural gas industry and transportation needs to be more focused on. As the natural gas consumer market becomes more mature, pipeline transportation, huge volume, and remote distance transportation have become a popular topic worldwide [1–3]. Natural gas is produced at a production site, or natural gas could be at a treatment plant, at a gas distribution center, or for industrial operations. Sometimes it is also called a gas transmission pipeline. On land, the primary transport method is through natural gas pipelines. Natural gas pipeline transportation has the benefits of fast construction, low transportation cost, less land occupation, high safety performance, large oil and gas transportation volume, less transportation loss, no wastewater emission, small leakage risk, little environmental pollution, little impact by adverse climate, easy management, a small amount of equipment maintenance, and remote centralized monitoring [4, 5]. Based on its use, there are three gas transmission pipelines: gathering pipeline, gas transmission pipeline, and gas distribution pipeline [6, 7]. Gas gathering pipeline: the pipeline from the wellhead of the gas field to the gas treatment plant.

Accidents in natural gas or oil pipelines may cause fatality and substantial economic loss [8]. Thus, this study aims to develop a risk assessment methodology for the failure of oil and gas pipelines due to different factors. A Fault Tree Analysis (FTA) is conducted to evaluate risk and associated components of risks. This conference paper uses a fuzzy method to transform the linguistic expressions of experts into subsequent failure probabilities.

The most crucial part of the FTA is to transfer a physical system into a well-organized, structured, logical probabilistic diagram utilizing quantitating the abstract concepts towards the miscellaneous events that might contribute to the downfall of a system [9, 10]. In the developed Fault Tree (FT), one can explicitly observe the various branches (certain specific causes) leading to one specified top event of interest. AND and OR gates are the two basic logic gates, and the hazard analysis done previously can be used to generate the TOP events.

In this study, Crystal Ball (CB) software, developed by Oracle, is used as a tool to perform Monte Carlo Simulation (MCS). The MCS predicts all possible results for a specific situation, uses charts to summarize the analysis, and displays the probability of each outcome [11, 12]. In addition to describing statistics, trend graphs, and related variable assignments, sensitivity analysis is also conducted.

II. Risk Analysis of Natural Gas Pipeline Operation

A. Risk of Oil and Gas Pipeline Corrosion

Corrosion occurs due to the susceptibility of oil and gas pipelines to external environmental factors. In detail, pipelines in areas near high temperatures, cold day and night temperature differences are more significant; pipeline acid alkali, rain, and snow can lead to oil and gas pipeline corrosion. Before the pipeline is typically put into use, although the pipeline maintenance managers have made some preparations in advance, it also will be from corrosion. Because the pipeline is buried in the underground soil all year round, the pipe outside the area of the natural environment, temperature, and moisture changes will corrode on oil and gas pipeline. And because of the pipeline material selection, the construction technology, and the methods used during construction, this has a direct relationship with the corrosion of the pipeline. In addition, oil and gas resources contain various chemical substances, and all kinds of chemical components are more complicated and varied. For example, the hydrogen sulfate element in oil and gas resources can cause specific chemical reactions during transportation. It can change the crystal lattice of the oil and gas pipeline interior, directly leading to a significant reduction in the corrosion resistance of the pipeline [13].

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B. Risk of Pipeline Leakage

Because oil and gas pipelines have been put into use and have a long working life, they are also affected by various factors such as the local natural climate and environment, construction technology, and pipeline material. As a result, leakage occurs in addition to the corrosion of oil and gas pipelines. Once the oil and gas pipeline leaks, it will directly cause economic losses, and more serious will cause pollution and damage to the natural ecological environment.

C. Risk of Weather Conditions

During the pipeline construction, various climates will be encountered, such as high temperatures, severe cold, frost, rain, snow, dense fog, cold waves, and storms. Such climatic conditions not only cause serious harm to the body of the construction workers but also reduce the efficiency of the staff, slow down the construction process, and have a particular impact on the machinery and equipment and the construction work.

D. Oversight of Pipeline Management

First, there will be illegal buildings around the oil pipeline. The existence of these illegal buildings will significantly affect the maintenance of the pipeline. Secondly, before the pipeline is laid, facilitating the pipeline laying may satisfy all the demolition requirements, which will produce a large amount of cash impact. At the same time, to save money, inferior materials will be chosen in the pipeline.

In this work, CB software will simulate sensitivity analysis, input the basic event probability, and measure the sensitivity of important factors that affect the top event. After FTA, the primary events' probabilities are obtained. The next step is to input them all in the spreadsheet with Excel and then import data into CB software to perform a series of sensitivity analysis operations. Thus, the top event's probability density Function (PDF) and the Cumulative Distribution Function (CDF) are obtained, and the most important influencing factors affecting the top event are analyzed. The average and basic deviations of the top and base events are also attained. This step helps to identify the most critical factors in the pipeline risk analysis.

III. Methodology

A. Case Study

This case study represents the leakage of the objected two transmission pipelines in Vietnam named line 1 and line 2. The two underground lines are now submerged in the water due to diverting the fluvial river in the vicinity. The water is 1.5m to 6m deep, and the submerged length accounts for one-fourth of its total length. The following is the basic information about the two objected pipelines' condition. The designed pressure for line 1 is 10 MPa with a diameter of 711 mm and a length of 43.8 km. The designed pressure and diameter for line 2 are the same as line 1 but with a distance of 43.4 km.

Due to the original position of the pipelines, no extra protection measurements were implemented, and risk analysis is required in case of the rupture or burst of the pipelines. The top event is the gas release caused by rupture and puncture [14, 15]. To have an explicit visual comparison between the precedent and new methods, including the CB, the FT developed in the previous project will be simplified. The corresponding occurrence likelihood of each simplified event will still be considered the original one.

Step 1: Defining System

The study begins with defining the potential failure of a natural gas transmission underwater pipeline in one of the metropolises in a rural area in Vietnam.

Components operating and failure modes: two lines are investigated in this study. The buried environment of these two lines was radically changed, and the pipelines are now submerged due to the waterway realignment. Statistically, the maximum water level is up to 6 meters, and the submerged length underwater accounts for one-fourth of the total length with no supplementary anti-erosion and anti-corrosion protection which may lead to hang risk and finally yield rupture or puncture.

System boundary conditions: the gas release caused by rupture and puncture is considered the study's top event for the FTA. The underwater situation is confronted; therefore, the intermediate events for the FT can be corrosion, wrong operation, fatigue, etc. The number of primary events is cut down to 21 for simplicity.

Step 2: FT Construction and Analysis

The FT is constructed. The procedures are presented in Appendix. The probabilities of each primary event are given in Appendix, developed based on the judgment of different prestigious safety experts. The qualitative and quantitative FTA were combined with the CB software results discussed in the results section.

Step 3: Conversion from FTA to Crystal Ball Analysis

Based on the above method, we obtain the deterministic top-event probability. However, getting historical data under actual conditions is impossible, and there are errors in the deterministic probability of many basic events. Using the CB software to analyze the likelihood. The PDF of the top event (Gas release) and the CDF are obtained and analyzed at a confidence interval of 95%, and the most important influencing factors affecting the top event are analyzed [16, 17]. The average and basic deviations of the top and basic events are also obtained. For this simulation, 10,000 trials are applied to forecast the top event. Import the data from the FTA into an Excel spreadsheet and set the Standard deviation as ten percent of the corresponding basic event probability. Data from this step is presented in Appendix.

Step 4: Use of Logic Gates and Defining Assumptions

Probabilities of top and intermediate events were calculated using logic gates in an FTA. In FTA, logic gates deal with deterministic relationships [18]. Each basic event has a certain failure probability based on experience and previously available data. Risk in this study is defined as the probability of gas release. Therefore, the top event in FT is "Gas release". The top event and intermediate events are calculated by using the equation of the OR and AND gates [19]. For the OR logic gate, the equation is shown below:

$$P = P(X1) + P(X2) + \ldots\ldots + P(Xn) = \sum P(Xi) \ldots\ldots (1)$$

For the AND logic gate, the equation is shown below:

$$P = P(X1).\ P(X2) \ldots\ldots\ \ldots.\ P(Xn) = \prod P(Xi) \ldots\ldots (2)$$

Probabilities of basic events are taken as the mean values for each basic event. The standard deviation is ten percent of the corresponding basic event probability. The green color of the cell in CB software indicates assumptions. This step is repeated for all input data sets. The model's output is the top event, "Gas release," defined as a forecast in CB. The color of the cell turns blue, indicating an output. Simulation is repeated in 10,000 trials, and simulation is run. Input data of top and intermediate events and assumptions defined in CB are presented in Appendix.

IV. Results And Discussions

The constructed FT is shown in Appendix. The number of primary events is 21, and their contributions to the top events are displayed by 'AND' and 'OR' gates.

The results after performing the analysis are presented below. The unreliability value is 0.02429, meaning the gas release probability in these underwater pipelines is 0.02429. The frequency of the top event is 0.02675, and the expected number remains the same as the frequency, whereas the CFI is 0.02742. The probability of failure and frequency can be used as the input for the risk assessment tool (Excel coding). The value of the importance of GT2 (0.7296) is much higher than that for GT1 (0.2704); thus, the rupture (GT2) of the underwater pipelines is more likely to happen as compared to the puncture (GT1), which means more attention should be placed on the measurements to prevent the rupture of the pipelines instead of puncture of the pipelines. Because these measurements can vastly reduce the probability of failure of the top event. As shown in FTA, the minimum cut sets are GT1 and GT2, corresponding to the Q value is 0.0066 and 0.01781, respectively. The gate time profile result indicates that the unreliability does not change with time.

The risk assessment tool is then supplemented to assess the risk of the gas release. The severity level is taken as significant as the released gas can cause an explosion or fire, given the ignition source, and the environment may be contaminated.

The probability from the FTA is 0.02429, so the impact likelihood is considered unlikely; therefore, the risk is medium and needs to be remedied, after which the residual risk is low because the severity level is lowered to 2 with the supplemented additional measurement, such as crossing the pipelines and cover the surface with a copper alloy to prevent the pipelines from being corroded.

The results from the CB simulations at the 95 percentiles show that the probability of gas release from the oil and gas pipeline ranges between 0.02272 to 0.02689. Results of sensitivity analysis show that the defect in both pipelines is the most significant factor, contributing to 37.8% of releasing gas, while the fluid impact is only 7.5%. This study analyzes all the natural gas and oil pipeline situations, vital installations, and factors affecting the gas release event. Using the FTA as the core, the deterministic calculation method is used to calculate the probability of the event, and the Monte Carlo simulation is performed using the CB software. The simulation is a normal distribution. After 10,000 trials, the mean value of the top event is 0.024782, the Median Value is 0.024770, and the Standard Deviation of the top event is 0.001084. The top event's maximum and minimum occurrence probabilities are 0.028545 and 0.0208806. Results also show that the 90th percentile is 0.023379. The likelihood of top and intermediate events solved the uncertainty that may arise without historical data. The probability of the top event ranges from 0.02272 to 0.02689 with a certainty of 95%. Through analysis, the main factors affecting the gas release incident are the Defect of pipe (type 1 and 2), fluid impact, and dredging.

V. Conclusion

Natural gas or oil release accidents of underwater transmission pipelines have constantly happened over the past few years, which are deemed as the most critical factor affecting the economic growth and ocean environment; hence, to prevent accidents from arising, an adequate risk assessment is necessary to mitigate or eliminate the potential hazards. In this case study, the data, especially the risk characteristics, from the previous case study on the underwater pipelines in Vietnam were used to construct a simplified FT by regarding some intermediate events as the basic events from which the input data for the subsequent CB simulation were generated. FTA and CB simulation results show that a comprehensive understanding of the hazards that may cause the gas release in the underwater pipelines can be drawn out so additional protection measurements can be implemented in time.

The FTA is an advantageous and convenient risk assessment method where each primary event and its contribution to the top event are listed explicitly. Determining the most significant hazards amongst miscellaneous events is challenging, so taking one imperative measurement to assess risk could be misleading. Given the predicament that a safety engineer in oil and gas industries might have, a combination of FTA and CB simulation was applied in this case study by which the most sensitive factor (event) can be found in basic event sensitivity figure and the most likely tope event probability can be obtained from forecast frequency view. Using multiple risk assessment methods to deal with unpredictable working situations is monotonous and unreliable; thus, the recommendation is made that various risk assessment methods should be used when dangerous conditions are confronted with the best-predicting results.

Appendix

TABLE A: List All the Primary Events for the Construction of the FT

EV	Detailed description	Failure rate
1	A defect is a deviation from the original pipeline configuration	6.61×10^{-3}
2	The diameter of the pipe is thinned because of corrosion	1.24×10^{-5}
3	Pipeline interfering due to ship anchor	9.80×10^{-4}
4	Pipeline interference due to	1.42×10^{-3}

	sabotage	
5	Pipeline interference due to fishing	2.13×10^{-3}
6	Pipeline interfering due to river dredging	2.70×10^{-3}
7	The diameter of the pipe is thinned because of corrosion	1.24×10^{-5}
8	Pipeline corrosion (because of corrosion medium number 1)	4.18×10^{-3}
9	Pipeline crack corrosion (stress concentration)	8.31×10^{-3}
10	Pipeline crack corrosion (residual stress)	3.47×10^{-3}
11	Pipeline crack corrosion (high internal stress)	5.50×10^{-4}
12	Pipeline corrosion (corrosion medium number 2)	4.18×10^{-3}
13	Pipeline fatigue corrosion (pressure surge)	9.77×10^{-3}
14	Pipeline fatigue corrosion (external load)	1.10×10^{-3}
15	A defect in a deviation from original pipeline configuration	6.61×10^{-3}
16	Pipeline failure (incorrect operation)	3.00×10^{-5}
17	Pipeline failure (inappropriate maintenance)	1.10×10^{-4}
18	Pipeline fatigue (internal pressure fluctuation)	9.90×10^{-4}
19	Pipeline fatigue (fluid impact)	3.55×10^{-2}
20	Pipeline fatigue (protection failure)	5.33×10^{-2}
21	Pipeline fatigue (hanging)	3.32×10^{-2}

TABLE B: PROBABILITY OF TOP AND INTERMEDIATE EVENTS

EV#.	Top and Intermediate events	Probability
TP	Gas release	2.48×10^{-2}
GT1	Puncture	6.62×10^{-3}
GT2	Rupture	1.81×10^{-2}
GT3	Interference from third party	7.23×10^{-3}
GT4	Corrosion	1.09×10^{-4}
GT5	Incorrect operation	1.40×10^{-4}
GT6	Fatigue	4.06×10^{-3}
GT7	Stress corrosion cracking	5.15×10^{-5}
GT8	Corrosion fatigue	4.54×10^{-5}
GT9	Tensile stress	1.23×10^{-2}
GT10	Alternative stress	1.09×10^{-2}
GT11	External factor	3.07×10^{-3}
GT12	Bare pipe	8.64×10^{-2}

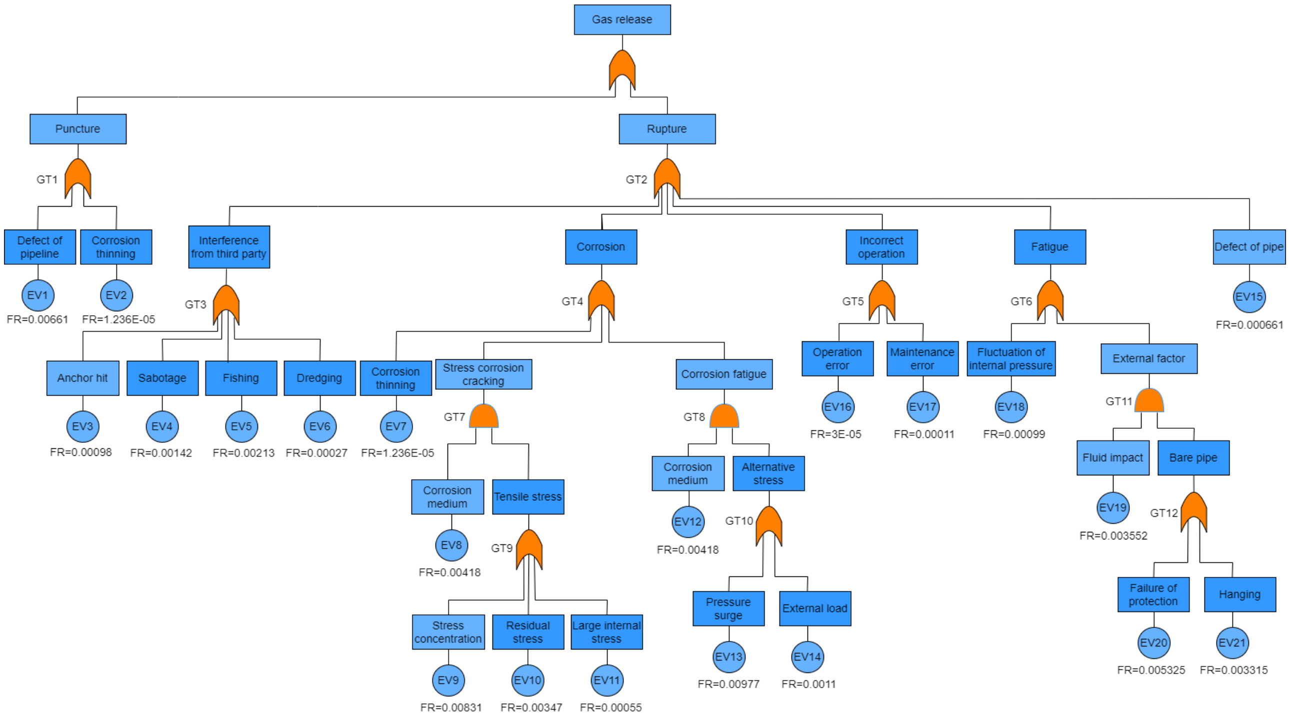

Fig. A. FT of the underwater pipelines.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

UD and ZS conducted the research; UD, ZS, and YZ analyzed the data; UD and ZS wrote the paper; UD, ZS, and YZ revised the paper; all authors had approved the final version.

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