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RISK POTENTIAL OF PIPELINE GAS LEAKS IN DHAKA CITY: CAUSES, CFONSEQUENSES AND MITIGATION STRATEGIES

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Abstract

Gas transmission lines are some of the most essential parts of the infrastructure of an area as it plays an indispensable role in fulfilling the need for energy in households, shops, plants, and industries. In densely populated areas, such as Dhaka, Bangladesh, however, the possibility of gas ejection from these transmission lines is a major concern. This paper seeks to investigate the potential impact of gas pipelines leaks in Dhaka city, identify its causes, and suggest preventive measures. The study begins with a review of the existing research on gas pipeline leaks, focusing on their catastrophic effects on lives, households, and communities. Identification of the alarming increase in gas leakage incidents by analysing historical data and incident reports and highlighting the imperative need for preventative measures is the next step. The findings highlight the vulnerability of densely populated areas and the catastrophic effects of gas pipeline failures. A conclusion is supported with a variety of preventative measures and risk mitigation strategies to reduce the frequency and severity of gas leakage incidents in Dhaka city by implementing these strategies. This paper contributes to the field by increasing awareness of the rising risk of gas pipelines leakage and its potential effects on densely populated areas like Old Dhaka. The proposed preventive measures serve as the basis for policymakers, gas companies, and other relevant stakeholders to develop comprehensive strategies to ensure the safety and well-being of the community.

Keywords: Gas transmission system, natural gas, gas pipeline, corrosion, Fault Tree Analysis, Dhaka City, Titas gas, explotion

1. Introduction

Energy is the fundamental pillar of all the industrial operations of a nation and is pivotal in propelling the sustainable socioeconomic progress of a country. Furthermore, the production of energy relies on resources like- fossil fuels, renewable energy sources, nuclear energy, etc. Natural gas is one of the cleanest fuels ever to be used; compared to other fossil fuels, burning NG produces fewer air pollutants and greenhouse gas emissions. Therefore, natural gas has always had a high demand since its discovery. Natural gas reservation, production, and transmission - all have significantly increased in recent years to accommodate the rising demand for energy worldwide. The government-owned national oil and natural gas firm, PetroBangla, currently is made up of 11 companies that work in the production and distribution fields of natural gas in Bangladesh. Titas Gas Transmission and Distribution Company Limited (TGDCL), Bangladesh Petroleum Exploration Company Limited (BAPEX), Sylhet Gas Fields Limited (SGFL), Jalalabad Gas Transmission and Distribution Systems Limited (JGTDSL), Bakhrabad Gas Systems Limited (BGSL) are a few of them. Some of these companies operate gas processing facilities, while the rest are responsible for distributing gas fuel.

However, because of the high energy and pressure build-up within a long-distance gas transmission pipeline, combustible, poisonous, and hazardous properties of natural gas can cause rupture accidents. These catastrophes are more likely to happen due to various causes, including corrosion, erosion, failure of the construction material, damages from excavation, operational errors, or other factors. In the past few years, gas pipeline safety accidents have happened quite frequently in Bangladesh, causing many deaths and damage of property. Systematic and in-depth risk analysis has the potential to effectively prevent accidents and decrease the losses caused by accidents to a manageable level. Currently, various qualitative and quantitative methods are employed to assess risk associated with natural gas pipeline leakage. These methods include probability and statistics, analytic hierarchy process, Petri nets, operability study (HAZOP), fault tree analysis (FTA), event tree (ETA), Bow-tie model, and Bayesian network. Analyzing typical natural gas pipeline disasters makes it possible to determine the leading causes of leakage failures and accidents. Numerous studies have been conducted on gas pipeline leaks and mitigation methods, both locally and globally, emphasizing the importance of

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early leak detection systems and mitigation tools, such as automatic shut-off valves and remote-control systems, to prevent catastrophic failures.

An important study by Abdoul Nasser, Petro Dickson Ndalila, and Edem A. Mawugbe identified the potential causes of gas pipeline failures and used quantitative risk assessment (QRA), etc., techniques such as Pipeline Failure Frequency, Pipeline Failure Ignition Probability, Failure Consequence Ans, etc. to analyze natural gas pipeline operations. The study identified key hazards, such as leaks and ruptures, as well as risk factors as natural disasters and operational failures [1]. In another notable study, Hao-Peng Li and Liang-Chao Chen investigated gas gate wells within a large urban gas pipeline network using the Gaussian diffusion model. They aimed to develop a leakage model and analyze the changes in internal gas concentration within the gate wells. The study underscored the importance of real-time monitoring of pressure changes, wind speed, and pipeline conditions to mitigate the impact of leaks on urban populations [2].

Computer-aided tools such as PIPESAFE and ALOHA are used as comprehensive risk assessment tool, considering pipeline design, uprating, routing, and gas dispersion scenarios. These tools provide valuable insights for decision-making in pipeline management and safety. A study by Yong Kang, Shuye, and Zhuang Wu provides insights into the causes and consequences of buried gas pipeline accidents. The study is based on FLACS CFD software and applies the method to the gas pipeline leakage and explosion accident in Songyuan, Jilin. The researchers used numerical simulations to estimate explosion source strength, confinement, and crowding effects at different scales to determine the causes of a natural gas pipeline explosion. It also visualized the consequences and categorized failure risks and associated impacts, including fires, explosions, and toxic gas exposure [3]. Additionally, based on an investigation, the National Transportation Safety Board (NTSB) has recommended revising This initiative aims to fortify the safety of gas transmission and distribution systems, particularly in densely populated urban areas [4].

The main objective of our research was to gain a comprehensive understanding of the intricate dynamics of gas transmission line leakage and the methods developed for associated risk assessment. Our analysis will delve into the historical context of this issue, examine its current implications, and effective strategies that prioritize safety, sustainability, and progress. Our study not only analyses the potential disasters of gas line leakage, also it can serve as a sincere call to action, a tribute to preparedness, and the strength of a nation that values the energy potential of its pipelines and the lives they impact. As we embark on this journey of discovery, we try to identify the risks and develop guidelines for safety measures to ensure the future of gas transmission in Bangladesh.

2. Historical Case Study

Bangladesh has several natural gas fields due to the riverine geography that features porous and permeable rocks that trap the natural gas underground. Gas providers in Bangladesh, including Titas Gas Transmission, Karnaphuli Gas Distribution, and Jalalabad Gas Transmission, are responsible for collecting and processing natural gas from the gas fields and delivering that to regions such as Dhaka, Chattogram, Sylhet, and so on. Many of the gas pipelines operated by these providers have been in service for several decades, resulting in numerous gas leaks within this aging infrastructure. These leaks pose a significant safety hazard to both residential and commercial areas.

Titas, the largest gas transmission and distribution company in Bangladesh, identified a staggering 1,622 instances of gas leaks within its extensive gas distribution network, which spans a distance of 12,514 kilometres in and around Dhaka. This alarming number of leaks highlights a critical problem; residents and businesses in these areas are living and operating near a potentially volatile situation. Due to numerous leaks, the present living conditions in certain regions are similar to living near an erupting volcano, with the constant danger of an explosion. Additionally, the frequency of fires resulting from gas leaks has risen in recent years. In the 2018–2019 period, there were 204 such incidents, which increased to 306 the following year, 2019–2020. Titas now receives an annual total of 4,496 complaints related to gas leakage incidents. The scale of the problem becomes even more apparent when considering that from January 2017 to January 2018, Titas identified gas leakages in an astounding total of 35,101 risers within residential complexes [5]. Apart from the list, another incident took place on April of 2023, when the citizens of Dhaka were in a state of terror as the odor of natural gas permeated the streets of Eskaton, Green Road, Mohakhali, Azimpur, Dhanmondi, Malibagh, Rampura, and Badda, among others. This unsettling situation arose from an overflow, specifically an escalation in pressure within the transmission lines due to a shutdown of gas supply to industrial plants during the ongoing Eid vacation. There had been growing concern among experts about the potential occurrence of fire events stemming from gas leaks and the subsequent catastrophic consequences, though no serious incident took place, fortunately.

The issue of unauthorized gas connections has added to the complexity of the problem. In February 2019, it was revealed that there were approximately one million unauthorized gas connections across the country. This not only poses a safety risk but also places a significant financial burden on the government, primarily in the form of system loss

Table 1: Major gas explosion incidents in Dhaka and Narayanganj [5,6,7,8]

Incident	Date	Location	Fatalities	Injuries	Cause
Explosion	Feb-18	Rupnagar, Dhaka	13	50+	Pipeline leakage
Explosion involving bus and pick-up	Feb-19	Dhanmondi, Dhaka	0	8	Pipeline leakage
Explosion	4-Sep-20	Narayanganj	37	Unknown	Pipeline leakage
Series of explosions	2020	Narayanganj	44	26	Pipeline defects and cylinder explosions
Explosion explosion	2021	Narayanganj	20	50+	Pipeline defects
Series of explosions	2022	Narayanganj	18	25	Pipeline defects and other causes
Fire explosion	Aug-2022	Mandail Bazar, Dhaka	0	Unknown	Pipeline leakage
Explosion	May- 2023	Dhupkhola, Dhaka	0	8	Pipeline leakage
Fire explosion	13-Aug-23	Kadamtali-Jurain, Dhaka	3	5	Pipeline leakage

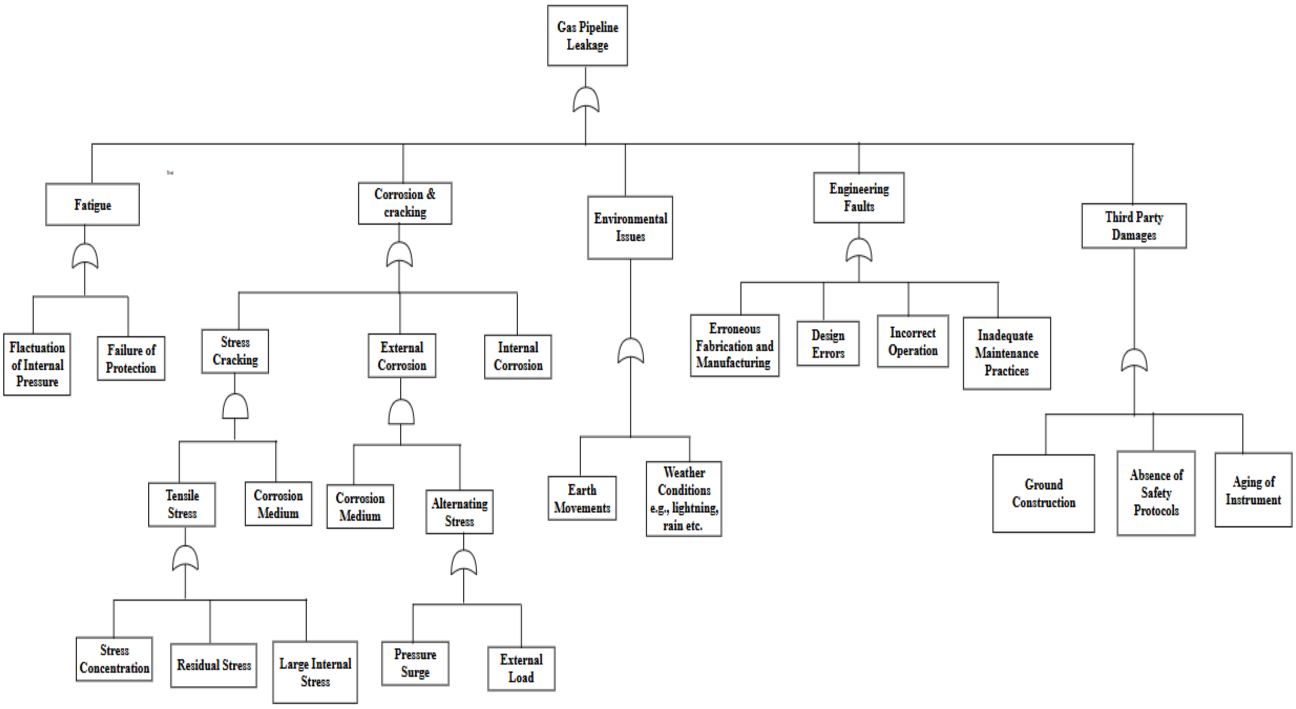
3. Methodology

3.1 Case Study

Dhaka, a densely populated city, is prone to gas line explosions. This case study investigates the root causes, potential consequences, and risk mitigation strategies associated with these incidents. Widely accepted Fault Tree Analysis (FTA) assessment technique is employed for both qualitative and also for quantitative risk assessments and DNV GL's uptime modelling approach for risk detection is acquainted. Due to data limitations, literature values from high-risk case Uptime risk modelling approach are applied to estimate the average annual casualties.

3.2 Fault Tree Constrution

With failure probability literature data listed in the appendix for the basic events, fault tree is constructed for further probability estimation of intermediate and top events in the tree causing gas leakage.



3.3 Risk Assessment

Risk Assessment is a systematic process to identify, assess, and mitigate potential risks. It involves both qualitative and quantitative methods. Qualitative risk assessment relies on expert judgment and techniques like HAZOP, Bowtie Analysis, and FMEA. It helps identify potential hazards but lacks numerical precision for probabilities. Quantitative risk assessment, on the contrary, uses data-driven methods like FMECA, ETA, FTA, and PRA. It assigns numerical values to both probabilities and consequences, enabling more precise risk evaluation [11].

Step1: Failure Frequency Calculation

With the help of the fault tree event constructed combining 16 basic events, the value of intermediate and top events can be obtained via OR and AND gate operation. In FTA, logic gates deal with probabilistic relationships as each basic event has failure probability data based on judgement of safety experts. Equation for OR logic gate, P= P(E1) + P(E2) + P(E3) +…+ P(En) = ∑ P(Ei) and equation for AND logic gate, P= P(E1) × P(E2) ×P(E3) ×…× P(En). Based on these equation, failure probability of top and intermediate events can be obtained.

Figure 1: Fault tree analysis of gas transportation line failure incident

Table 2: Failure probabilities of top and intermediate events

Event Description	Probability
Corrosion and cracking	1.09E-04
Fatigue	0.006315
Engineering Fault	6.75E-03
Third party interference	6.72E-03
Gas Release	1.99E-02

Step2: Ignition Probability Calculation

The ignition probability [12] is calculated in terms of the pipeline diameter D(m) and pressure P(bar),

$$\boldsymbol{P_{(ign)}} = \begin{cases} \mathbf{0.0555 + 0.0137}\boldsymbol{PD^2};\ \boldsymbol{if}\ \mathbf{0} \le \boldsymbol{PD^2} \le \mathbf{57} \\ \mathbf{0.81};\ \boldsymbol{if}\ \boldsymbol{PD^2} > 57 \end{cases}$$

Step3: Event Frequency Calculation

F = FF × P (ign)

Where, FF= Failure frequency (yr^{-1} km^{-1}) and F= Failure event frequency (yr^{-1} km^{-1})

Step4: Average Casualty Calculation

$$\boldsymbol{EV} = \sum_{i=1}^{k} \boldsymbol{L_i} \times \boldsymbol{F_i} \times \boldsymbol{N_i}$$

Where, Ni is the average casualties per incident of specific encroachment area, Fi is the event frequency per length specified area and Li is pipeline length of specified area

4. Result:

Based on the fault tree analysis constructed calculated probability of top event 'Gas release' is calculated to be 0.0199, so the impact likelihood ibn considered unlikely as per the table shown:

Table 3: Qualitative Probability Description of IPCC [13]

Probability Interval	Description	Probability interval	Description
＜1%	Extremely unlikely	66–90%	Likely
1–10%	Very unlikely	90–99%	Very Likely
10–33%	Unlikely	＞99%	Virtually certain
33–66%	Medium likelihood		

For a Titas gas transportation pipeline of 14inch diameter and operating at 1000 psi [14] the calculated ignition probability value is 0.391. Furthermore, the value of probable event failure is predicted to be 0.00779 km-1 yr-1 from the risk assessment model approach abovementioned. As the regional average causality per incident value is highly sensitive, average causality calculation couldn't be performed due to data scarcity. Being one of the most populated cities in the globe (75,290/mi²), the index for area specific average causality rate is significantly high which results higher average casualty per year. he consequences of gas line leakage are severe, encompassing safety, health, environmental, and economic impacts. Explosions, fires, asphyxiation, and environmental contamination are significant risks. The socio-economic impact includes property damage, displacement, and disruption of services [15,16].

5. Mitigation Strategies

Gas line leakage mitigation is a critical aspect of ensuring public safety and preventing potential hazards. In seeking effective hazard assessment procedures, it is imperative to adapt such approaches to the unique conditions prevailing in Bangladesh. This customization must consider the challenges posed by the nation's aging infrastructure and its remarkably high population density. A comprehensive hazard assessment should encompass many facets, including, but not limited to, rigid leak detection mechanisms, precise maintenance protocols, and a well-organized emergency response plan. By integrating such elements into the assessment process, authorities have the potential to gain a comprehensive understanding of the hazards associated with gas pipeline leaks and develop specific mitigation plans.
A foundational step in this process involves the careful selection, proper installation, and consistent maintenance of gas line leakage detectors. These detectors serve as essential tools in identifying gas leaks promptly, allowing for swift intervention and mitigation. Piping systems vary widely in their physical properties and operational functionalities, and neither the external nor the internal procedure is universally applicable. However, the chosen leak detection system should have the following performance criteria; sensitivity, reliability, accuracy and robustness. Real time monitoring and enhanced patrolling are next to selecting the suitable detector.

Gas line leakage poses a significant risk of fire and explosion. The escape of flammable gases into the environment creates a volatile atmosphere that can ignite from even a small spark or heat source. In confined spaces, this can lead to explosive conditions, endangering lives and causing extensive property damage. Swift and effective mitigation measures are crucial to minimize the potential for fire and explosion resulting from gas line leakage incidents. In Dhaka, the densely populated city, coordinate approaches are less visible within difference service providers. But there's no alternative of combined approach in terms of emergencies and to ensure a safer Dhaka for future.

Emergency Response:
To ensure effective emergency response to gas line accidents, immediate public safety awareness is crucial, including timely alarms and increased surveillance, implementing fire retardant coatings and dispersing leaked gas can mitigate risks. Moreover, having a robust plan for mass evacuations is essential to safeguard lives and property.

Preventive Measures:
To enhance gas line safety, a multi-faceted approach is crucial. This includes implementing advanced leak detection technologies, methane detection systems, and automated shutoff mechanisms. Regular pipeline inspections, maintenance, and infrastructure upgrades are essential. Proper risk evaluation, personnel training, and community education are vital. Promoting safety precautions at home and work further reinforces the commitment to gas line safety.
The government and regulatory bodies play a crucial role in this. They should rigorously enforce safety regulations, hold negligent parties accountable, establish efficient monitoring systems, and promote collaboration among utility companies, local authorities, and communities. They must develop additional guidance for gas distribution operators so they can safely respond to leaks, fires, explosions, and emergency calls. This joint effort enhances gas line safety and management.

6. Conclusion

Being one of the most populated cities in the world, Dhaka possess a significant risk of heavy casualty corresponding to incidents related to gas pipeline leakage. A significant number of incidents occur every year around the city which next significant strategy and planning to overcome. It is now evident that proactive measures are necessary to mitigate the associated risks caused by leakages in gas transmission lines. Risk assessment approach utilized

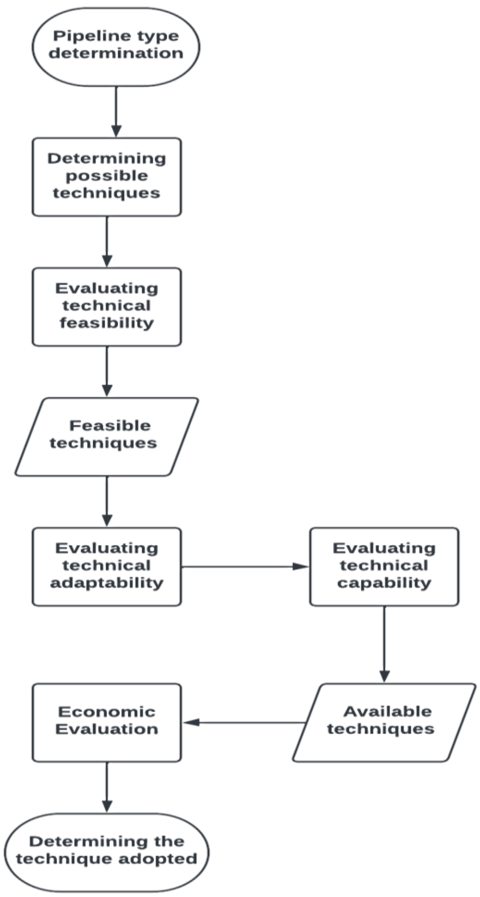


Figure 2: Algorithm of mitigation strategy (Lu et al., 2020)

in this article gives an understanding of associated risk hazard. With appropriate statistics the accurate values can be predicted by this approach. Industry stakeholders, regulators, and policymakers must take note of these findings and prioritize safety culture and continuous improvement in pipeline management. By implementing effective risk reduction measures, we can safeguard our environment and communities against the detrimental effects of pipeline leakages.

Appendix

Table 4 : List of failure probability of all primary events for the construction of the fault tree [17, 18]

Event	Event Description	Failure Rate, μ	Probability ($1-e^{-\mu t}$)
1	Internal Corrosion	1.24001×10^{-5}	1.24×10^{-5}
2	Corrosion Medium	0.004188761	4.18×10^{-3}
3	Pressure Surge	0.00981804	0.00977
4	External Load	0.001100605	0.0011
5	Corrosion medium	0.004188761	4.18×10^{-3}
6	Stress concentration	0.008344721	0.00831
7	Residual stress	0.003476034	0.00347
8	Large internal stress	0.000550151	0.00055
9	Fluctuation of internal pressure	0.00099049	0.00099
10	Failure of protection	0.005339228	0.005325
11	Design and manufacturing	0.006631943	6.61×10^{-3}
12	Incorrect operation	3.00005×10^{-5}	3.00×10^{-5}
13	Inappropriate maintenance process	0.000110006	1.10×10^{-4}
14	Design and manufacturing error	0.006631943	6.61×10^{-3}
15	Inappropriate maintenance process	0.00011	1.10×10^{-4}
16	Environmental Issues	3.90001×10^{-6}	3.90×10^{-6}

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