Natural Gas Pipeline Failure Risk Consequences Modeling: A Potential Threat to the Airport and Its Surrounding Infrastructures

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Abstract

Natural gas is widely used in Bangladesh for industrial goods manufacturing, captive power generation, transportation, domestic cooking, etc. As per current statistical analysis, Bangladesh consumes 1,042,864 million cubic feet (MMcf) of natural gas yearly. However, unplanned installation and poor maintenance of gas pipelines can lead to deadly explosions, causing severe casualties, infrastructure damage, financial losses, and environmental pollution every year. According to the report from Bangladesh Fire Service and Civil Defense, incidents related to gas pipeline failure have been tentatively 18% among all the fire-related incidents in recent years. In this study, ALOHA simulation modelling has been developed to predict the failure risk consequences analysis, especially adjacent to airport infrastructures. By using this hazardous modelling software, it is possible to anticipate the highly risked zone surrounding the airport. Therefore, the policymakers, stakeholders, local gas companies, and airport authorities can be benefited from this study by identifying the failure consequences beforehand and avoiding gas pipeline hazards in the future.

Keywords
Natural Gas Pipeline, Consequence Analysis, ALOHA, Airport Infrastructure.

1. Introduction

An airport is a very important place for a growing economy because it connects a nation with the outside world. It is particularly vital for the economic growth of a developing country. Hazrat Shahjalal International Airport (HSIA) is capable of hosting 8 million annually (Japan International Cooperation Agency, 2017), and with the expansion of the new terminal (Figure 1), the passengers and the flight are likely to increase significantly (Khan et al., 2021). IATA suggests this increased traffic demand will increase the airport revenue by US$ 2.1 billion of Gross Domestic Product (GDP) in Bangladesh (International Air Transport Association, n.d.). A recent study shows that the U.S. has a collective national output of $1.4 trillion from commercial airports, which contributes to more than 7% of the GDP (Kevin, 2018). Aviation's global economic impact is approximately U.S. $2,960 billion, equivalent to 8% of world GDP (Air Transport Action Group, n.d.). Therefore, it is quite evident that airport plays a significant and crucial role in the growing economy.

Urbanization is a product of a nation's growing economy, and Bangladesh is one of the fastest-growing economies in the South East Asia region. As a result, the capital city, Dhaka, is seeing the growth in urbanization the most. Many habitats are increasing around the airport area due to the expansion of the city, growing economy, and population. However, this growth is mostly unplanned (Mahmud and Hoque, 2010) for which different safety hazards are surfacing and causing deaths of many lives. Besides, it became a hub for fire hazards, and these hazards occur mostly because of the gas pipeline leakage in a local area. Bangladesh Fire Service and Civil Defense statistics show that gas pipeline failure causes fire hazards tentatively 18% among all incidents every year (Bangladesh Fire Service & Civil Defence, 2020)

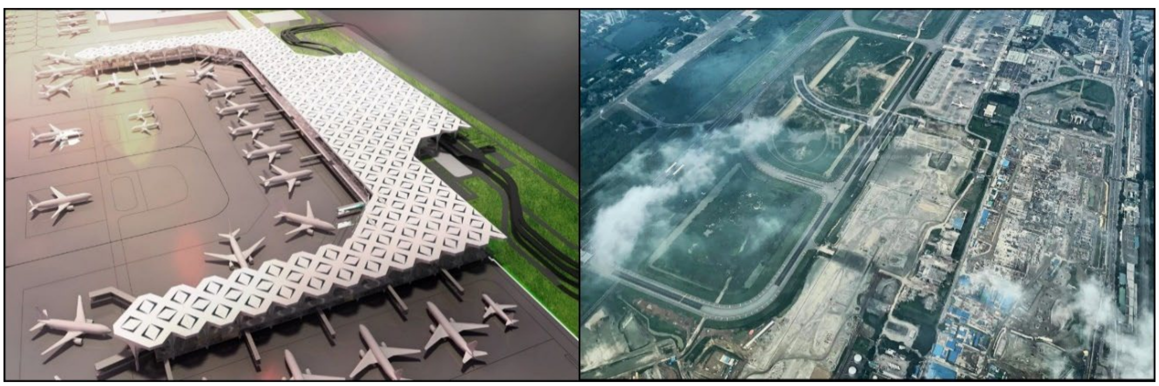

Figure 1. Third Terminal of HSIA Airport: proposed model (left), construction site (right)

Figure 2. Gas explosion aftermath at Dhaka city

On August 25, 2021, at least five people died when a gas pipeline incident occurred at Mirpur. Additionally, seven people were being admitted to the hospital (*"Mirpur gas line blast",* 2021*; "Another gas line explosion",* 2021). Almost a similar but more devastating explosion happened at Moghbazar, Dhaka, on July 27, 2021. At least 11 people were killed, and 50 or more people suffered a severe injury because of the explosion (Molla and Khan, 2021). The explosion was so devastating that nearby buildings (50 meters from the explosion) and moving vehicles on the road were destroyed (Figure 2), and many people on the street got injured and lost their lives (Wahra, 2021). In 2020, a three-year-old child died, and three other members of his family were hurt in a gas pipeline explosion in July 2020 in Bongshal, Old Dhaka (*"Boy killed"*, 2020) The same year another gas pipe explosion took at least 31 or more lives at a mosque in Narayanganj (*"Death toll in Bangladesh mosque",* 2020), and the list of gas pipeline explosions has been increasing alarmingly in last few years (Mahmud, 2020).

If similar disasters were to happen near HSIA airport, it would cause a domino effect of fires and blazes. Kurmitola Aviation Depot is an oil depot situated near the south face of the airport (Figure 3). Any explosions near that area can cause huge damage to the airport and the private property (119.51m away from the depot) of the local population. Now, suppose we shift our focus to the eastern side of the airport near the runaway. In that case, any gas pipeline (distribution or transmission line) explosion at Bawnia will cause civilian casualties and affect the air traffic movement of the airport. If any incidents were to happen near the major international airport such as HSIA airport, these would definitely affect the lives of many, and the economy of the nation will come to a halt.

Figure 3. HSIA and the surrounding structures (Google Earth view)

Even though transmission lines usually are built far from the airports; nevertheless, due to demographical changes, new pipelines may require near the airport. As a result, fire hazards due to gas pipeline leakage are likely to increase every year. In this study, a hypothetical transmission pipeline has been considered. If any disasters were to happen around that region, what kind of impact it would have on the airport and surrounding areas has been discussed. Therefore, proper measures and initiatives could be taken beforehand to make the airport safe and sound for traveling without any disasters in the future.

1.1 Objectives

The main motivation of this study stems from the fact that Bangladesh is very prone to gas pipeline disasters. If we could predict the impact of these explosions on the building structures, the number of casualties could be reduced significantly by taking necessary precautions. This research aims to predict the failure risk consequences analysis by implementing the Areal Location Hazardous Atmosphere (ALOHA) simulation software near the airport area. ALOHA simulation software can predict the impact of an explosion; therefore, it has a significant impact on finding out the risk zone area during the incident.

2. Literature Review

Gas pipeline disasters are not a new thing near the airports either. One report from the Times of India says that the gas pipeline near the airport is a ticking time bomb, which can cause significant damage to the infrastructure of the airport (*"Gas pipelines near airport",* 2019). One of the major incidents was reported at San Bruno, California, in 2010, which is 2 km away from the San Francisco International Airport (Berkeley Engineering and Research, Inc., n.d.). This disaster led to the death of 8 people and an earthquake of 1.1 magnitudes (The United States Geological Survey, 2010). In 2017, a DCP pipeline explosion left a 12-foot deep and 30-foot diameter crater on the northernmost end of runway

17 of Panola County Airport runway (Figure 4), which resulted in the shutting down of the airport for a month (*"Runway closed at Panola County",* 2017). One explosion in airport hills, Alberta-Eastern Canada, created a 150 feet long hole in the ground; the flames could be seen 25 miles away (North Bay Museum, n.d.).

Figure 4. Panola County pipeline disaster

Previously, different researchers have conducted their research on various aspects of gas pipeline failure. Ahmed and Kabir (2021) worked on different causes of pipeline failure, which concludes that the failure criteria for a natural gas pipeline disaster can differ from nation to nation. Chen et al. (2019) have utilized the Fuzzy Analytic Hierarchy Process (FAHP) to identify the reputation loss in oil and gas pipeline disasters. Santarelli (2019) used Fault Tree Analysis and Quantitative Methods for risk and damage analysis for distribution gas pipeline failure. However, none of them have utilized ALOHA modeling in their studies.

Ramli et al. (2018) used ALOHA Simulation and Modeling to assess sulfuric acid plant disaster. This work laid down a model for safety and evacuation protocols during chemical hazards in Malaysia, which reduced property loss and human casualties during the incident. Similar work has been conducted by Ilic et al. (2018) that discusses the level of concern (LOC) using ALOHA simulation software during an accidental release of chlorine gas disaster.

Hanafia et al. (2015) calculated the damaged explosion area during a gas pipeline explosion using ALOHA. This study assessed and differentiated the consequences of Human health and safety loss in the rural and urban areas due to pipeline failure. This study concludes that a traditional approach to calculating damage area, i.e., radius equation, is not as accurate as ALOHA simulation software.

The radius of the toxic material spreading area (threat zone) from the source can be determined using ALOHA modeling software. These results from the ALOHA software simulation can help improve emergency preparedness. (US Environmental Protection Agency, n.d.). The ALOHA software dataset contains information on 1000 chemicals that can be used to alter or amend existing chemical information (Jovanović, 2013). The emergency response planning for the affected area has been analyzed by using ALOHA so that the emergency evacuation response team can determine the safest evacuation procedure by map. Mainly evacuation emergency maps will be planned on the basis of ALOHA simulation graphical results from MARPLOT, Google Earth, etc. An accountable person will coordinate the emergency action plan for evacuation, based on ALOHA simulation (US Environmental Protection Agency, n.d.).

However, the geographical location of these studies is outside of the subcontinent, and none of these studies shows the impact of a gas pipeline explosion at an airport. So, the focus of this study is based on the ALOHA Simulation on HSIA, Dhaka.

3. Methods

ALOHA simulation software has been implicated in this study. It is broadly used to study chemical and hazardous materials emergencies in any particular location. This software can easily create a model for the toxic area of the vapor cloud, flammable zone of the vapor cloud, blast area of vapor cloud explosion, etc. Any simulated model embodies three different zones illustrated in red, orange, and yellow colors, whereas the red zone characterizes the most dangerous hazard zone. The Level of Concern (LOC) is specified by the specific absorption of toxic gas that a living being emits during gas leakage.

Furthermore, ALOHA simulation can envisage flammable gas blast areas. However, ALOHA cannot generate precise results, only providing an approximate range of a devastating event. Therefore, it is essential to import the simulation file (kml) to Google Earth to represent the affected location visually.

ALOHA simulation is a step-by-step process. The coordination point of a selected location is required in the first place to initiate the simulation. In this simulation, an interactive map (showed in Result and Discussion section) defining the coordination of a hypothetical high transmission gas pipeline, which has been considered at the south side of HSIA airport near the Kurmitola Aviation Depot, Dhaka, Bangladesh. The other required values for ALOHA simulation, e.g., chemical type, transmission pipe parameters, weather information, etc., are used in subsequent steps. All the necessary data needed for the simulation are available in the following chapter. Figure 5 depicts the ALOHA simulation workflow.

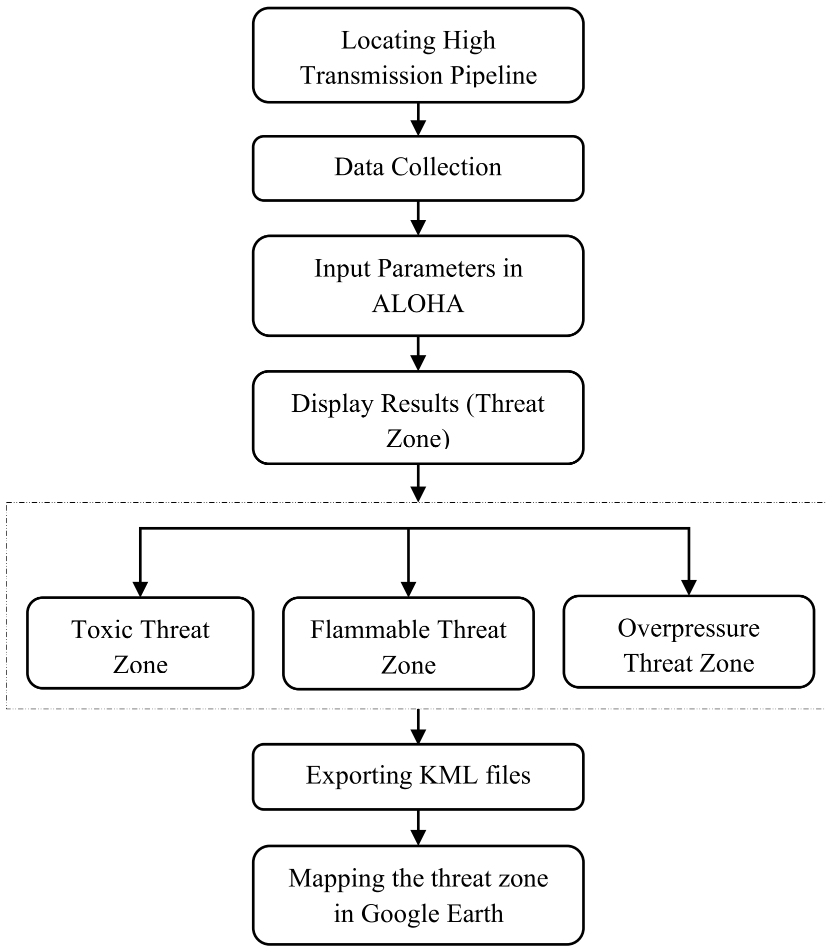

Figure 5. ALOHA simulation workflow

4. Data Collection

Most of the data for this study has been collected from government official websites or international websites. However, the coordinate selected for this study is a hypothetical one, so as some parameters of the pipeline. These assumptions were made due to the lack of availability and inaccessibility of data. Table 1 shows the data used in this work.

Table 1. Simulation Data and Sources

Input Name	**Value**	**Data Source**
Location	Nikunja	Google Map
Elevation	9 m	https://en-gb.topographic-map.com/maps/lpj4/Dhaka/
Latitude	23°50'10.1"N	Google Earth
Longitude	90°24'52.6"E	Google Earth
Country Name	Bangladesh	N/A
Local Standard Time	GMT +6	https://www.timeanddate.com/worldclock/
Building Type	Sheltered surrounding	N/A
Chemical Type	Methane	N/A
Wind Speed	3.5 knots (max or min)	http://live.bmd.gov.bd/
Wind Degree	SSE	Hypothetical
Ground Roughness	Open country	N/A
Types of Cloud Cover	Partly clouded	http://live.bmd.gov.bd/
Air Temperature	25	http://live.bmd.gov.bd/
Stability Class	B	ALOHA
Humidity	65%	http://live.bmd.gov.bd/
Date & Time	Use internal clock	N/A
Source	Natural gas pipeline	N/A
Input Pipe Diameter	20 Inch	(Lu et al., 2018)
Input Pipe Length	10826.8 ft	(Ahmed, 2020)
Type of Pipe	Rough pipe	(Ahmed, 2020)
Input Pipe Pressure	1000 psi	(Lu et al., 2018)
Input Pipe Temperature	Ambient	ALOHA

5. Results and Discussion

The ALOHA software analyzed the probable hazardous threat area to understand the possible failure consequences. So, it will indicate and help to compute the potential structural damage and other associated background factors.

5.1 Toxic Threat Zone

The threat zone is generally categorized in three different zones in ALOHA to indicate threat levels and illustrated in red, orange, and yellow colors. Figure 6(a) shows the toxic threat zone for this simulation. Point (0, 0) acts as an origin point of the incident. From the origin point of the incident to the primary downwind direction, approximately 110 yards are reflected as the worst LOC (level of concern). LOC defines the exposure level in the surrounding atmosphere; hence, marked in red. Any human being who is exposed to this zone may have a breathing problem attributable to gas toxicity. The toxic levels decrease as much as 65 concentrations in the other two zones compared to the red zone. The orange zone is measured in approximately 140 yards and the yellow zone is measured in roughly 290 yards. The affected area of the toxic threat area simulation is visualized in Google Earth as well and shown in Figure 6(b).

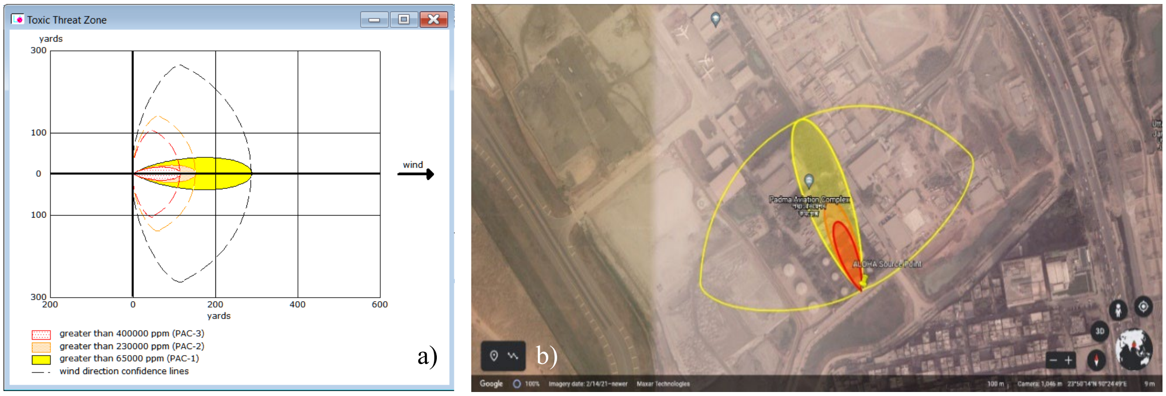

Figure 6. Toxic Threat Zone: a) ALOHA simulation b) Mapped in Google Earth

The figure above shows that the toxic (Red /Orange/ Yellow) zone crosses the Kurmitola Aviation Depot, which is very close to the third terminal; therefore, associated passengers and staff will be affected by the toxic air and pollution from the explosion. The most affected zone (red zone) is the region of the Kurmitola Aviation Depot.

5.2 Flammable Threat Zone

The flammable threat zone is generally the concentration of flammable vapor cloud, which indicates the possible explosion range. Figure 7(a) shows the flammable threat zone for this simulation. Here, a flammable Level of Concern (LOC) is considered as a fraction of each Lower Explosive Limits (LEL). While choosing the flammable LOC for the red threat zone, ALOHA generates 60% of the LEL by default. An amount greater than 30,000 parts per million (ppm) flammable chemical vapors, in this scenario, Methane exists in the air of the red zone. Therefore, the red threat zone area is more vulnerable in the case of any mechanical sparks caused as an ignition source.

On the other hand, flammable chemical vapor concentration is lesser in the yellow threat zone. The LOC for the yellow threat zone is 10% of the LEL. No orange threat zone is illustrated for this simulation because ALOHA can't generate an orange threat zone for Methane Gas. Figure 7(a) also shows that the explosion range in the red zone spans approximately 0.3 miles in the primary downwind direction and 0.6 miles in the yellow zone. Figure 7(b) shows the flammable threat zone simulation mapped in Google Earth.

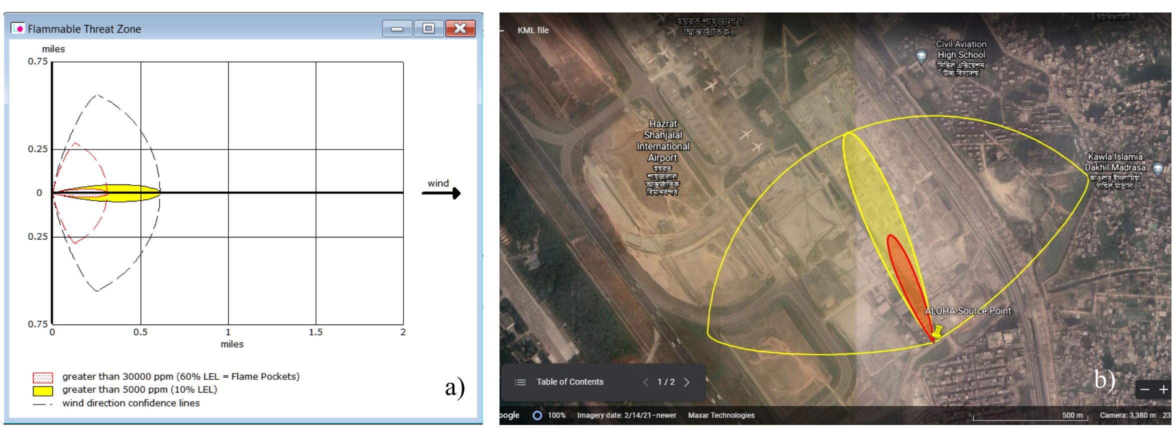

Figure 7. Flammable Threat Zone: a) ALOHA simulation b) Mapped in Google Earth

From the figure 7(b), it can be observed that the red zone covers the Kurmitola Aviation Depot and the construction site of the Third Terminal, that means these two areas are extremely vulnerable to a secondary explosion; the yellow zone reaches the Arirang Aviation Limited, the third terminal, the aircraft bay, and other valuable infrastructures of the airport. Aircrafts in the terminals and aircraft bays are mostly likely to cause another explosion due to the presence of the aircraft fuel. This explosion will damage the major infrastructure of the airport; subsequently, it will lead to a heavy casualty of human life.

5.3 Overpressure Threat Zone

The Level of Concern (LOC) for the overpressure threat zone is also categorized in three zones and displayed in red, orange, and yellow similar to the toxic and flammable threat zone. The pressure range varies from red to yellow threat zone. The selected overpressure LOC for the red threat zone is 8.0 psi (destruction of buildings), the orange threat zone is 3.5 psi (serious injury likely), and the yellow threat zone is 1.0 psi (shatters glass). Figure 8(a) shows the overpressure threat zones. Aftermaths of a gas pipeline explosion result in a sudden blast or pressure wave attributable to overpressure. The pressure wave is actually generated from the energy released at the time of the initial explosion. Because pressure waves are traveling approximately at the speed of sound, damage can be vary depending on the explosion rates. This higher initial explosion results in an enormous damaging pressure wave. The pressure wave can be far more threatening to human livelihood in comparison with the toxic cloud and fire. Pressure waves can cause shattering of glass, building or structure debris, etc. From the source of the blast, this pressure wave spread out to the specific affected region. Therefore, it can badly damage any structure and its surroundings, often resulting in injuries or killing a valuable life. The overpressure threat area simulation is mapped in Google Earth. Figure 8(b) shows the affected region.

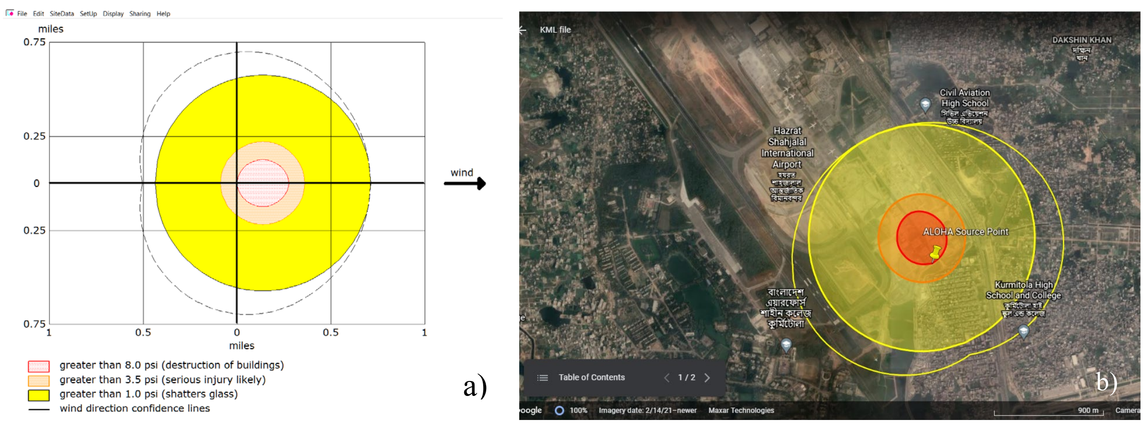

Figure 8: Overpressure threat zone: a) ALOHA simulation b) Mapped in Google Earth

Figure 8(b) indicates that the worst overpressure Level of Concern (red zone) engulfs the Kurmitola Aviation Depot, Padma Aviation Complex, and Arirang Aviation Complex of the airport, which will definitely cause a secondary explosion because of the fuel tanks of the depot that contains jet fuel. It will lead to a great catastrophe, and the casualty will most likely increase. In these scenarios, after the explosion, earthquakes can follow; craters can form.

The orange zone will affect the local habitats of Nikunja Area, and parts of the third terminal will also be affected. The radius of the yellow overpressure zone is significantly higher. It engulfs the entire third terminal, part of the VVIP terminal, a significant portion of the southern taxiway, and nearly touches the airport's southern runway. Furthermore, the effect of this explosion can be felt in the residential areas nearby, including the Civil Aviation High Schools. The main roads that connect the city with the airport will also be affected.

5.4 Source Strength

Gas flows with certain pressure through the transmission pipeline. This pipeline is connected with a source storage tank or reservoir; the length and the input pressure of the pipeline influence the duration of the ALOHA release rate. Mainly the leakage sources strength changes continuously over the period of the natural gas release time. Figure 9 displays the graphical representations of the gas release rate over time. The input pipe pressure is 1000 psi, and the input pipe length is 10826.8 ft in this case.

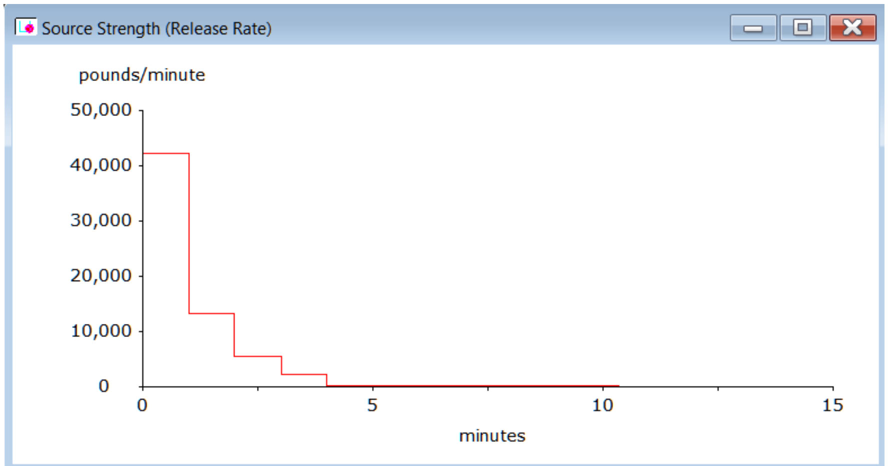

Figure 9: Source strength (release rate)

6. Conclusion

Natural Gas Transmission Pipeline failure consequence model has been constructed using ALOHA simulation software. Three different threat zones, i.e., overpressure threat zone, toxic threat zone, flammable threat zone, and the aftermath of the explosion, have been investigated in this paper. The ultimate aim of this study is to reduce potential failure risks and prepare for probable hazards. ALOHA simulation software can be very efficient for attaining this goal. Despite this significant failure and consequence analysis for natural gas high transmission pipelines, there are certain limitations to the current research.

ALOHA prerequisites a high transmission pipeline for simulating a natural gas explosion and hazardous scenario. In this study, a high transmission line is assumed to be existed near the Kurmitola Aviation Depot. The lack of availability and inaccessibility of data from the respective organizations enforced this assumption. Nevertheless, due to the demographic nature of Dhaka city, a small pipeline explosion can turn into a causal sequence resembling a high transmission pipeline disaster.

Despite the fact that the ALOHA simulation software is a powerful tool for reducing human deaths, financial losses, and other disasters, very few studies are available on the subject, specifically focusing on airport infrastructure. With sufficient data, additional tools and algorithms, and other data analyses methods, a better and realistic outcome can be retrieved in future research. This study can also be beneficial in other relevant industries to classify the potential risks and consequences. Airport authorities, researchers, policymakers, stakeholders, and local gas companies can be benefited from this study, and many disasters can be prevented by taking appropriate measures.

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Biographies

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Shahrukh Khan, a recent graduate from Beihang University, Beijing, China, earned his Manufacturing Engineering of Aerospace Vehicle degree in August 2020. He has worked as a researcher at Aircraft Manufacturing Lab and HTFP-Hydro Lab at Beihang University for three years. He has contributed to six scientific journals and three conference papers so far. While pursuing his MEng. degree, he has completed his thesis on "An Investigation into the Key Techniques of Forming Lightweight Material Based on Hydroforming." During that time, he undertook three projects that included Hydroforming Technics, Hybrid Material Manufacturing, and Tensile test. Recently, he has taught "Finite Element Methods and Abaqus CAE" at Yogyakarta State University, Indonesia, as a guest lecturer (online). He pursued his BEng. in "Aircraft Manufacturing Engineering" degree from Shenyang Aerospace University in 2016. During that time, he has completed his thesis on "New Technique of Repairing keyhole Friction Stir Additive Manufacturing." Furthermore, He was elected as the head of academics of the student union at that university. He received five rewards throughout his student life for his academic brilliance.

Sumaiya Rahman has completed her Bachelor degree from University of Asia Pacific in Civil Engineering in 2011. After her Bachelor, she started working in Engineering and Planning Consultants Ltd. Then she worked in Greater Dhaka Sustainable Urban Transport Project under LGED as Quality Control Engineer. Currently, she is working as Office Engineer in Feasibility Study and Detail Design for Construction of Large Bridges on Upazila, Union & Village Road Project under LGED.

Md Asifuzzaman Khan has completed Bachelor of Aeronautical Engineering (Aircraft Manufacturing) from Shenyang Aerospace University, P.R. China. During his academic period, he was involved in research activities and completed his graduation thesis on "Comparative study of coated and uncoated tools in drilling CFRP/Al stacks" under the supervision of prof. Gong-Dong Wang. He also worked as a Trainee Engineer in the department of System Maintenance at Saudi Arabian Airlines, Dhaka station.