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Risk Analysis For Gas Pipelines: a Sustainability Assessment Approach using Bow-Tie Analysis

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Abstract

Vast amounts of natural gas (NG) are consumed around the world everyday that are mainly transported and distributed through pipelines. Integrity of these pipelines is of primary interest to NG companies, consultants, governmental agencies, consumers and other stakeholder due to adverse consequences and heavy financial losses in case of system failure. Fault tree analysis (FTA) and event tree analysis (ETA) are two graphical techniques used to perform risk analysis, where FTA represents causes (likelihood) and ETA represents consequences of a failure event. 'Bow-tie' is an approach that integrates a fault tree (on the left side) and an event tree (on the right side) to represent causes, threat (hazards) and consequences in a common platform. The present study aims to help owners of transmission and distribution pipeline companies in risk management and decision-making to consider multi-dimensional consequences that may arise from natural gas pipeline failures.

Keywords: Natural Gas Pipeline Failures, FTA, ETA, Bow-Tie

1. Introduction

Natural gas (NG) is a widely used industrial and domestic fuel in most of the industrialized countries, with a continuously growing consumption. Due to that, piping systems have been installed to transport and distribute the gas for end industrial and domestic users. Due to the facts that Natural Gas Pipeline networks are mostly installed in urban zones, i.e. in highly populated areas, accidental gas releases can cause significant environmental damages, economical losses and injury to the population .

Although gas piping systems are mostly installed underground, they are often damaged by various activities. The leakage of NG can lead to different scenarios and outcomes. The most common consequence of NG pipeline accidents is fire (leading to jet fires, fireballs or crater fires) and to a lesser degree explosion.

2. Bow-Tie Overview.

A number of qualitative and quantitative techniques, e.g. failure mode and effect analysis (FMEA), hazard and operability study (HAZOP), fault tree analysis (FTA). event tree analysis (ETA), have been used for the risk assessment (Khan & Abbasi, 2001). FTA and ETA are two well established techniques that individually assist the risk assessment by providing qualitative analysis of hazards identification and a detail quantitative assessment of likelihood for the undcsired events. 'Bow-tie' is a common platform which couples ΙΙA and ETA by considering a common top-event named as critical event [Chevreau, Wybo, &Cauchois, 2006].

The formal definition of Bow-tie diagram, provided by CCPS, is the following: "A diagram for visualizing the types of preventive and mitigative barriers which can be used to manage risk. These barriers are drawn with the threats on the left, the unwanted event at the center, and the consequences on the right, representing the flow of the hazardous materials or energies through its barriers to its destination. The hazards or threats can be proactively addressed on the left with specific barriers (safeguards, layers of protection) to help prevent a hazardous event from occurring; barriers reacting to the event to help reduce the event's consequences are shown on the right.

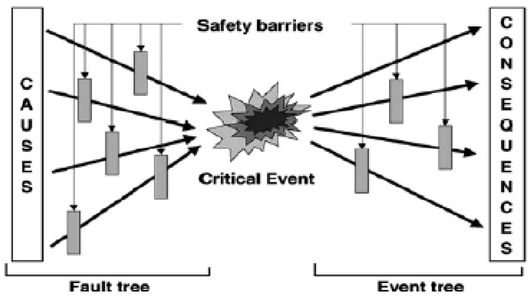

Figure 1. General Bow-Tie diagram

3. Practical Significance Of Bow-Tie Analysis In Risk Analysis For Gas Pipelines.

Hazards are intrinsically part of the NG business: this is especially true in the process industry. It is fundamental to control them for safe NG pipelines operations, from construction to decommissioning, not only for the safety of human life, but also for the environment and the business-related risks, like asset integrity, business interruptions, and reputations. In the Bow-tie method, the very first step is providing a clear definition of Hazards. To do so, the risk analyst has to define the scope of his/her activities, asking how much in depth the analysis should go.

The starting point for the definition and assessment of hazards in the NG pipelines risk assessment are data on the causes of failure and the associated hole sizes; these are drawn from industry databases and are examined below. It must be mentioned that only holes and ruptures are considered as leaks from cracks or pinholes are very unlikely to give fatalities and it should be borne in mind that the relevant datasets for pipelines are very small, so there is uncertainty in the derivations of specific frequencies.

For the NG pipelines the threats are :

- Third party interference
- Manufacturing Defects
- Internal & External corrosion
- Ground Movement
- Other (Lighning, errors etc)

Barriers are control measures put in place to prevent or mitigate an unwanted scenario. They intervention can be considered the result of the following sequence: to detect, to decide, and to act. Depending on the subjects performing these steps, it is possible to define different barrier types.

For the NG pipelines the basic barriers are :

- Pipe wall thickness
- Depth of cover (for underground pipelines)
- Other protective measures – (slabs – indicators etc)
- Preventive inspection & Maintenance

For the NG pipelines the Typical Event Trees risk assessment include variations for :

- Type of pipeline (Underground or overground)
- Failure type (Full Rupture or Leak)
- Release Direction (vertical/horizontal/angle) ,
- NG release ignition (yes/no and immediate/delayed)

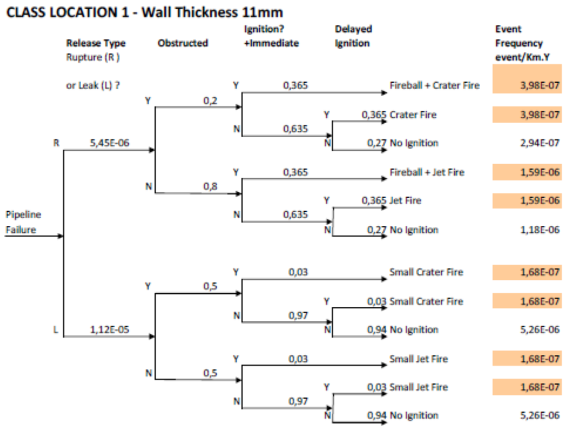

Figure 2. Basic NG risk assessment Event Tree with Probability for each outcome (wall thickness 11mm)

Leading to different outcomes (Fireball, crater fire, Jet fire, a combination of the above or simple dispersion without ignition)

Taking all the above in mind the failure mode Event Tree complete with the possible outcome probabilities is presented below (For an underground pipeline segment) in Figure 2 [Sybilla, 2017].

4. Conclusions.

NG pipeline safety engineers should answer several questions about process risks:

- "Do we understand what can go wrong?"
- "Do we know what our systems are to prevent this happening?"
- "Do we have information to assure us they are working effectively?"

Barriers are the "safety measures" or "controls". Barriers interrupt the scenario so that the threats do not result in the top event when control is lost over the hazard. Barriers can also ensure that the top event does not escalate into an actual impact (the consequences).

Barrier based approach is the founding principle of two specific assessment methods: Bow-tie (BT), used for risk assessment and management, and Barrier Failure Analysis (BFA), used for near-accident, near-misses and accident or unwanted events investigation.

The BT diagram is the core of the BT method and one of the most used diagrams within barrier-based management. With the BT diagram you can visualize a risk scenario that would be very difficult to explain otherwise. The pay-off is tremendous: risk assessments come to life. Instead of being forgotten and archived, risk assessments are actually used because they are relevant in "day-to-day" operations. Furthermore, the aggregation of various data sources allows a level of understanding and insight into risks, which is unprecedented in risk management until now.

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