Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Journal of Loss Prevention in the Process Industries 19 (2006) 433–441
Journal of Loss Prevention in the process industries
www.elsevier.com/locate/jlp

A matrix-based risk assessment approach for addressing linear hazards such as pipelines

Fred Henselwood[a,*], Gerry Phillips[b]

[a]Dendritic Consulting Ltd., 19 Mount Alberta Green SE, Calgary, Alta., Canada T2Z 3G8
[b]NOVA Chemicals Corp., 4909—49th Street, Red Deer, Alta., Canada T4N 1V1

Received 8 September 2005; accepted 31 October 2005

Abstract

Pipelines represent a linear risk source that can create unique challenges when assessing risks. In the past, risk has been managed by identifying construction requirements and setbacks based on population densities and types of land use. In the current risk assessment a matrix-based approach has been developed so as to determine the risks associated with high-vapor pressure liquids pipelines. The approach involved the development of a matrix representing each 100 m section of the reviewed pipeline along with approximately 30 risk factors that describe that section of the pipeline. Further, a receptor matrix was constructed to account for each hectare of land within 1 km of the reviewed pipeline system. This approach has allowed for the determination of risk as a function of location and separation from the pipeline and in turn has allowed for the determination of those areas where peak risks exist. In addition, this approach has ensured that the linear geometry related to pipeline risks has been accurately modeled. The resulting estimated risks have been evaluated against MIACC risk thresholds (geographic risk-based measures) and against proprietary internal corporate standards (societal risk-based measures). In this way the acceptability of the risk from the perspective of both the potentially impacted community and that of the pipeline operator can be measured. The net result is that the company has a clear picture of the risks associated with its pipeline and is better able to optimize its risk management and pipeline integrity programs.

Keywords: Risk assessment; Societal risk; Geographic risk; Failure rate analysis; Consequence analysis

1. Introduction

The Major Industrial Accident Council of Canada (MIACC, 1997) document *"Risk Assessment Guidelines for Municipalities and Industries—An Initial Screening Tool"* gives guidance as to reasonable risk thresholds for varying land uses. Further, the screening tool gives guidance as to how to estimate risk levels based on fixed facilities while stating:

> Obtaining individual risk contours for a transport corridor is not straightforward. The issue arises though the 'per unit length' frequency units that are used in transportation problems.

A second MIACC document *"Land Use Planning With Respect To Pipelines—A Guideline for Local Authorities, Developers and Pipeline Operators"* (MIACC, 1998) also avoids giving an approach as to how to address the issue of risk calculation with respect to linear risk sources such as pipelines. The document does however suggest that consultation should take place between the various parties when new development occurs based on a separation distance of 200 m. The document then goes on to suggest that this consultation distance should be expanded for high-vapor pressure liquids or sour gas pipelines. The goal of this consultation process is to help local authorities in establishing appropriate setbacks, which are not too restrictive or too conservative.

In the absence of clear guidance as to how to estimate pipeline risk organizations such as the Alberta Industrial Heartland Association (2003) have developed their own risk assessment approaches. These types of approaches

*Corresponding author. Tel.: +403 809 8837.
E-mail address: Fred@dendritic.com (F. Henselwood).

0950-4230/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jlp.2005.10.005

suffer based on limited data and do not readily reflect the operation of the reviewed pipeline systems, as the operating companies are not involved in the assessment process. As a result these types of risk assessments tend to be overly conservative and have the potential to misinform the public regarding the potential risk levels. This potential overstatement of risks can be of particular concern when pipeline risks are compared to risks related to fixed facilities where more straightforward risk assessment approaches exist.

The lack of accessible guidance with respect to conducting pipeline risk assessments creates a situation where it is critical that pipeline operators readily assess their pipeline systems in a clear manner and be in a position to share this information when needed as per the approach suggested within the MIACC guidelines. In this way local governments can be provided with appropriate information for land use planning purposes allowing for informed and balanced decision making.

Risk can be defined as the product of the likelihood of an event and its consequence. Within the current risk assessment a collection of matrices has been defined in order to allow this relatively simple risk calculation to be computed numerous times so as to give a measure of risk at both a system level and across the system. The various matrices have been defined based on geography whereby 100 m lengths or 1 ha partitions (100 m $\times$ 100 m) have been utilized. 100 m was selected as it represents a distance where factors associated with data quality, computational needs, and geometry can be best balanced. At shorter distances data quality and computational needs become an issue. At larger distances errors associated with geometry assumptions can become significant. In addition, assumptions as to the uniformity of the risk levels within the measured cell partitions can also become an issue for larger distances.

Through working with and defining the various matrices key information related to the pipeline system can be readily extracted from the risk assessment:

- Failure rate as a function of location (leak and rupture rates were calculated for each 100 m of the pipeline based on 9 different failure modes).
- Distribution of consequences following a release for each hectare of land within 1 km of the point of failure (multiple scenarios were considered and accounted for day and night conditions, varying wind directions, explosive yields…).
- Geographic risk estimates for each hectare of land within 1 km of the pipeline (this data was also utilized to give risk contours relative to the pipeline).
- Societal risk measures for each hectare of land within 1 km of the pipeline.

The net result is that the company can readily view the risk associated with its pipeline systems from a number of perspectives and is positioned to address those areas representing greatest concern. Further, through an iterative process the pipeline operator can review various risk reduction strategies so as to determine which activities yield the greatest value by balancing cost against the effectiveness of each strategy.

2. Failure rate determination

As was stated above, failure rates were calculated for each 100 m section of the reviewed pipeline with this calculation being based on the following failure models:

- Internal corrosion
- External corrosion
- Stress corrosion cracking
- Earth movement
- Over-pressure
- Valve/fitting failure
- Construction/material defect
- Third party damage
- Other/miscellaneous failures

With the exception of the stress corrosion-cracking component the various models were developed based on Alberta Energy and Utility Board (EUB) (1998) data, which was supplemented by various third party studies and other pipeline incident datasets. The stress corrosion-cracking model utilized was based on an internal company model.

As an example of the model development, the external corrosion model started with a base failure rate taken from the EUB dataset with an adjustment factor for pipeline diameter. The failure rate was then adjusted based on coating type utilizing expert judgment and data presented by the United Kingdom On-Shore Pipeline Operators' Association (UKOPA) (2000). This base failure rate was then modified in areas where pipe with heavier wall thickness existed. Modifications to the failure rate based on pipe thickness drew upon studies based on data held within the European Gas Pipeline Incident Data Group (EGIG) (2002) and the UKOPA (2000) incident datasets. Next a series of risk factors were considered and correlations were established between these risk factors (road crossings, creek crossings, power lines, slopes…) and internal inspection data held by the pipeline operator. These correlations were then built into the failure model so as to allow for the identification of those areas where external corrosion related failures were most likely to occur. The model also accounted for the time elapsed since the last internal inspection and any anomalies within the current inspection data. The net result was that a model was constructed based on approximately 15 factors that allowed for external corrosion failure rates to be estimated for each 100 m section of the pipeline. Although not directly used the "*Pipeline Risk Management Manual*" (Muhlbauer, 1999) served as an excellent reference and