INTERNATIONAL JOURNAL OF CRITICAL INFRASTRUCTURE PROTECTION 7 (2014) 257–269

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/ijcip

Analysis of pipeline accidents in the United States from 1968 to 2009

Kyle Siler-Evans[a,*], Alex Hanson[b], Cecily Sunday[b], Nathan Leonard[b], Michele Tumminello[c,d]

[a]Department of Engineering and Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania 15213, USA
[b]Department of Mechanical Engineering and Department of Engineering and Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania 15213, USA
[c]Department of Social and Decision Sciences, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania 15213, USA
[d]Dipartimento di Scienze Economiche, Aziendali e Statistiche, Università degli Studi di Palermo, Viale delle Scienze, Edificio 13, I-90128 Palermo, Italy

ARTICLE INFO

Article history:
Received 16 January 2013
Accepted 18 September 2014
Available online 11 November 2014

Keywords:
U.S. pipeline accidents
Accident trends
Power-law distribution

ABSTRACT

Pipelines are responsible for the transportation of a significant portion of the U.S. energy supply. Unfortunately, pipeline failures are common and the consequences can be catastrophic. Drawing on data from the Pipeline and Hazardous Materials Safety Administration (PHMSA) that covers approximately 40,000 incidents from 1968 to 2009, this paper explores the trends, causes and consequences of natural gas and hazardous liquid pipeline accidents. The analysis indicates that fatalities and injuries from pipeline accidents are generally decreasing over time, while property damage and, in some cases, the numbers of incidents are increasing over time. In five of the ten cases considered in this paper, the damage from pipeline accidents – in terms of injuries, fatalities and volume of product spilled – are well characterized by a power-law distribution, indicating that catastrophic pipeline accidents are more likely than would be predicted by more common "thin-tailed" distributions. The results also indicate that relatively few accidents account for a large share of total property damage, while smaller, single-fatality and single-injury incidents account for a large share of total fatalities and injuries (43% versus 32%, respectively).

1. Introduction

Natural gas accounts for 23% of the primary energy consumption in the United States [15]. This vast supply of energy is delivered to customers through a network of transmission and distribution (T&D) pipelines that totals more than 3.8 million km (2.4 million miles) [10]. Pipelines also account for a large – and growing – share of liquid fuel transport. Hazardous liquid (HL) pipelines carry crude oil and liquid fuels such as diesel, gasoline, jet fuel and kerosene. In 2008, 282,000 km (175,000 miles) of hazardous liquid pipelines accounted for 83% of crude oil transport and 62% of petroleum transport (measured in ton-miles) [1].

Unfortunately, pipeline failures are common and the consequences can be catastrophic. For example, one million barrels of oil were spilled when a hazardous liquid pipeline ruptured in

*Corresponding author.
E-mail address: ksilerevans@cmu.edu (K. Siler-Evans).

http://dx.doi.org/10.1016/j.ijcip.2014.09.002

Kalamazoo, Michigan in July 2010. In September 2010, a transmission pipeline explosion in San Bruno, California, resulted in eight fatalities; another explosion in Allentown, Pennsylvania, in February 2011 killed five people. Accidents such as these have raised concerns about the safety of the nation's pipeline system.

This paper analyzes historic accident data from natural gas and hazardous liquid pipelines with the goal of informing future safety measures. Drawing on a database of U.S. pipeline incidents, which includes approximately 40,000 incidents from 1968 to 2009, three important hypotheses are tested:

- Pipeline accident frequency and damage are decreasing over time.
- The damage caused by pipeline accidents follows a power-law distribution.
- Relatively few pipeline accidents account for the majority of damage.

Throughout this analysis, the severity of (or damage from) pipeline incidents are measured in terms of three metrics: fatalities, injuries and monetary property damage. For hazardous liquid pipelines, the volume of product spilled is also used as a measure of accident severity.

Previous studies of pipeline accidents fall into two categories: those focused only on pipelines and those that compare risks across various energy-supply chains, which may include natural gas and hazardous liquid pipelines. Montiel, et al. [7] have performed a pipeline-specific analysis of 185 accidents in 95 countries. Their study finds an increasing trend in the number of pipeline accidents over time and identifies mechanical failure as the most common cause of natural gas pipeline accidents (43%). Hirschberg, et al. [5] conclude that approximately “21% of all natural gas accidents involving pipelines were caused by mechanical failures and 24% by impact failures.”

Two recent studies are specific to U.S. pipelines. Restrepo, et al. [12] have conducted a regression analysis of hazardous liquid pipeline incidents from 2002 to 2005; their results reveal that the cause of an accident is a strong predictor of the resulting monetary damage. Their study also identifies corrosion as the most common cause of hazardous liquid pipeline accidents. Simonoff, et al. [13] have developed a predictive model to estimate the magnitude of damage from transmission pipeline incidents based on their causes. Their study also presents several accident scenarios that are intended to inform risk management efforts.

Several studies compare the accident risks from various energy supply chains, including natural gas. Sovacool [14] observes that, in the energy sector, natural gas systems fail most frequently, accounting for 33% of all accidents. However, Sovacool notes that natural gas accidents account for only 9% of the total property damage and 0.39% of the total fatalities. Studies conducted by the Paul Scherrer Institute [5] reveal that the world-wide fatality rates from natural gas accidents, when normalized by energy production, are roughly one-fifth that of oil or coal.

The findings discussed above are not fully applicable to the U.S. pipeline system. With the exception of the work by Restrepo, et al. [12] and Simonoff, et al. [13], the studies are based on international databases, many of which do not disaggregate data between OECD (Organization for Economic Cooperation and Development) and non-OECD countries. In addition, Felder [4] indicates that “a fundamental problem with investigating energy accidents is [the] incompleteness [of data sets].” For example, Sovacool [14] identifies only 279 severe accidents from 1907 to 2007, 91 of which involved pipeline systems. Hirschberg, et al. [5] use the Energy-Related Severe Accident Database from 1945 to 1996, which contains only 159 natural gas accidents.

This paper provides a detailed analysis of pipeline accidents and, to our knowledge, is the first to fit a distribution to pipeline damage. The analysis is limited to U.S. pipeline systems and draws on a database containing approximately 40,000 incidents from 1968 to 2009.

2. Data collection and filtering methods

The analysis presented in this paper is based on data collected by the Pipeline and Hazardous Materials Safety Administration (PHMSA) [9]. The database covers approximately 40,000 pipeline incidents from 1968 to 2009. Detailed information provided about each incident includes fatalities, injuries, monetary property damage, accident location, accident cause and pipeline material.

In the case of gas transmission and distribution pipelines, the reporting requirement includes incidents: (i) with more than $50,000 in property damage, including damage to the operator and other entities, but excluding the value of lost gas; (ii) with one or more fatalities; (iii) with one or more injuries that result in hospitalization; (iv) involving a shutdown of a liquefied natural gas (LNG) facility; or (v) judged by operators to be significant, even if the incidents do not satisfy the other four criteria.

Unfortunately, the definition of an “incident” has changed over time, leading to inconsistencies in the data. Before 1984, only incidents that resulted in fires were reported. A dramatic drop in incident reports occurred after this criterion was eliminated. For consistency, the transmission and distribution pipeline data were filtered to include only the incidents that met the first three criteria listed above. The fourth criterion pertaining to liquefied natural gas facilities is outside the scope of this analysis. The fifth criterion was also excluded because operator judgment is unlikely to have been consistently applied and may, therefore, bias the results.

In the case of hazardous liquid pipelines, the reporting requirements have remained unchanged since 2002. Incidents are reported if they result in (i) more than $50,000 in property damage, including the value of lost product, cleanup costs and damage to the operator and other entities; (ii) one or more fatalities; (iii) one or more injuries that result in hospitalization; (iv) an explosion or fire; or (v) the loss of five gallons or, in some cases, five barrels of hazardous liquids.

Before 2002, there were numerous changes in the reporting criteria. For example, the threshold for property damage was increased from $5,000 to $50,000 in 1994. In 2002, the threshold for the volume of hazardous liquid spills was reduced from 50 barrels to five gallons (or in some cases five barrels). For consistency, the first four criteria listed above