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Avoiding pitfalls in assembling an equipment failure rate database for risk assessments

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Abstract

As companies move progressively toward quantifying the risks of releases of hazardous materials, there becomes a greater need for developing the data necessary to populate the risk analysis. Sophisticated mathematical models have been developed to predict the consequences of a hazardous material release. But the effort devoted to the frequency side of the "risk equation" has been very disorganized by comparison, with inconsistent or non-existent definitions of "failure", mixing of incompatible data, application of data from one industry to a completely different industry, and a host of other problems. Nonetheless, through judicious assembly and analysis of a variety of data sources, a useful failure rate database can be developed. Many seminal sources of data are described, with an emphasis on loss of containment failure rates. Pitfalls in interpreting failure rate data are also illustrated.

Keywords: Risk assessment; QRA; Failure rate; Database; Chemical

1. Introduction

Risk analysis, by definition, requires evaluation of both the consequences of a potential negative event, and the frequency of that event occurring. Researchers in the process industry and academia have devoted many years to developing models of the manner in which chemicals may be released and dispersed, and the consequences that result.

Risk analysts have paid less attention to the equally important frequency side of the risk equation. Historically, equipment reliability has been the realm of reliability gurus in companies, each of whom generally has collected information in a specific equipment niche such as compressors. Frequently, this storehouse of knowledge is maintained solely by this individual and is permanently lost when that person retires.

But what is the value of sophisticated consequence models to the risk analyst, when the frequency side of the risk equation may be in error by an order of magnitude or more? One might do just as well using a risk matrix approach to risk analysis. The following sections describe the basis and development of an equipment failure rate database, with an emphasis on loss of containment failures.

2. Motivation for having a company database

There are several reasons why a company might want to establish an in-house database, including:

- to make risk analyses more accurate;
- to make analyses consistent from one project to the next;
- to demonstrate consistency with/conformance to industry standards.

These seem self-evident. But suffice to say that people who have been doing risk analyses for a long period of time can cite horror stories of how one office did the analysis one way, the other did it using a number 10 times higher, and so forth. When these problems become public, they are very difficult to explain away.

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3. Scope of a database

When developing a database, some thought should be given to the scope of the database. Considerations might include:

Equipment types—Should my database include process-containing equipment only, or also these: instrumentation, pipelines, vehicles, loading equipment? And should it consider human reliability?

Risk types—Is the scope of this review restricted to acute risk to personnel resulting from loss of containment, or is there a broader portfolio of issues to consider: on-stream efficiency, emissions, etc., that might require a wider view of failures?

Failure mode types—Leaks only, or also other critical/non-critical failures? As a safety risk analyst, I will be interested in loss of containment. But other events (e.g., failure of check valve to prevent backflow, failure of a remote isolation valve to close on demand, failure of operator to respond correctly to an alarm) may be just as important in assessing process risks.

Data modification methods—Data may be available for “typical” situations. But how does an analyst account for atypical applications? Or how does one give credit for extraordinary design measures? A “users” database might consider ways of modifying data to make the analysis more accurate and useful.

Outcome probabilities—Given a release, there may be several types of outcomes. In the case of a flammable material release, there may be a jet fire and/or pool fire, vapor cloud explosion, or BLEVE. It may be useful to develop standardized data for determining the likelihood of each outcome.

Risk acceptability concepts—At the end of the day, the results of a risk analysis will need to be compared to some measure of what is acceptable and what is not. It may be useful to develop sources for addressing this concept, to provide guidance to upper management on how to manage risks that cannot be reduced to zero, and to lower management who make the day-to-day decisions on capital projects and other risk control efforts.

4. Existing sources of data

The good news is that there are many sources of information available in the literature. The bad news is that most of this information was developed for industries other than the

Table 1
Some sources of equipment reliability data

Subject type	Reference	Comments
General sources [these should be consulted for all equipment types]	WASH-1400 [1]	>30-year-old data used for assessing nuclear plants. But still a cited, seminal work
	Lees [2]	The process risk analysis “bible”. Relatively up-to-date, but still cites much older material by necessity
	CCPS [3]	An initial effort at a chemical process industry database. Unfortunately, it was not progressed, and has limited data as a result
	IEEE-500 [4]	Contains data on a variety of systems, for a variety of failure modes. But nuclear-based
	OREDA [5]	Covers equipment types of interest; offshore industry-based
	E&P Forum [6]	A compendium of onshore, offshore, shipping, and other failure rates
Additional equipment-specific sources		
Pressure vessels	Smith and Warwick [7]	The most widely quoted source. Unfortunately, the data are limited, and include pressure vessel applications that may or may not be of interest to general process industry analysts
Atmospheric storage tanks	API [8]	The API Atmospheric Storage Tank committee is developing risk-based protocols for managing ASTs. This includes failure rates
Compressors	Bloch and Geitner [9]	Includes a number of reliability modifiers that can be used to customize an analysis. Emphasis is on on-stream reliability, as opposed to leaks
Cross-country pipelines	DOT [10]	Largest database of US pipeline data
	California Fire Marshal [11]	Provides detailed analysis of variables affecting leak rates
	Muhlbauer [12]	Not data, but a useful reference work describing the many factors that can influence pipeline leak rates
	CONCAWE [13]	European pipeline data source
Truck transporters	DOT [14]	Information is available on the web from the Bureau of Transportation Statistics
	FEMA [15]	Provides a risk assessment protocol, with numbers, for shipping hazardous materials
Human error	NUREG [16,17]	The primary works in this area, but focused on the nuclear industry
	CCPS [18]	Good subject overview

chemical process industry, the data are frequently an order of magnitude apart from each other, the information is dated, the definitions of "failure" are not consistent—the list of shortcomings goes on and on.

But until something better comes along, this is all we have. Table 1 lists references that can be used as the foundation of a database.

5. Combining data sources

So now we have a number of data sources. And there may also be data available from the operating companies themselves. How to combine this information into a single 'best estimate' for a specific application?

Among the issues that need to be addressed to answer this question are the following:

- different scope (e.g., do piping failures include or exclude flanges);
- different definitions of "failures" from one source to the next (e.g., "leak" versus "pinhole leak" versus "1/4-in. leak");
- relevance of the data source to the application at hand (e.g., nuclear versus onshore versus offshore);
- significance of the data (i.e., based on experience from just a few operating years, or a few million operating years).

The user of the data will generally have to make judgment calls on how much to weight the value of each source.

But there are statistical methods that can be brought to bear as well. One method for combining sources is based on a statistical approach known as "Bayes' Theorem" [19]. Using this approach, or similar statistical methods, requires knowledge of the number of incidents in each constituent data source as well as the standard deviation of that source (or model built from it).

The advantage of this approach is that it avoids the problem of combining the data sets conventionally by simply adding them together—that is, the volume of one set of data will typically swamp the other. The Bayes' approach is especially useful at incorporating plant operating data into an a priori failure rate estimate that was based on general industry data.

6. 'Customizing' data for an analysis

In some cases, there are public data available from which correlations can be developed to assess the impact of different design and operating variables. These can be extremely powerful in providing an accurate failure rate estimate for a specific situation. However, there are some hazards associated with developing these correlations, or depending on others. Two cases are considered below.

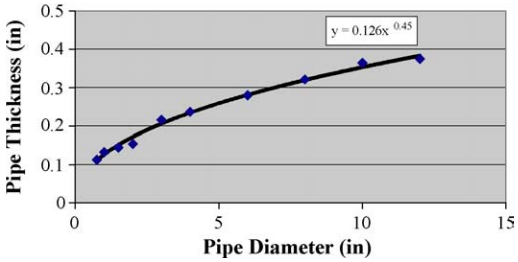

Fig. 1. Relationship between pipe diameter and thickness (standard).

6.1. Case 1: effect of thickness or diameter (or both?) on process piping leak rates

In 1981, Thomas [20] developed correlations for piping and pressure vessel failure rates that are still widely cited. He proposed that the total leak failure rate from a pipe is directly proportional to the pipe diameter, as the surface area available for leakage increases proportionately with the diameter.

This appears to be inconsistent with other sources of data, which suggest that failure rates are roughly *inversely* proportional to diameter. However, process pipe thickness typically increases significantly with increasing pipe diameter, and so this needs to be accounted for to make apples-to-apples comparisons.

Note the relationship between diameter and thickness for standard pipe classes given in Fig. 1.

This is roughly a situation where the thickness is proportional to the square root of the diameter, or D is proportional to the square of the thickness. The Thomas model for thickness (see below) suggests that failure rates are inversely proportional to the thickness squared. This in turns suggests that the failure rates are more accurately described as being *inversely* proportional to pipe diameter, as suggested in other sources, if thickness and diameter are not treated independently. Note that the curve above applies only to piping up to 12 in. diameter; for larger diameter piping the thinnest 'standard' pipe thickness remains the same (0.375 in.).

Thomas provides other data that suggest that *all else being equal*, failure rates are inversely proportional to the square of the pipe thickness—that is, a pipe that is twice as thick as a reference pipe has 1/4 the failure rate of the reference. This is useful information when considering:

- adjusting generic failure rates to account for higher than normal pipe schedule provided by the site;
- cost–benefit analysis of risk mitigation measures.

However, the analysis must be sure to only give credit where credit is due. If a plant has thicker piping because the service is extremely high pressure, or extremely corrosive, the net effect of the increased thickness may simply be to compensate for this severe service. In this case, the increased thickness may only serve to bring the failure frequency back to something close to generic.

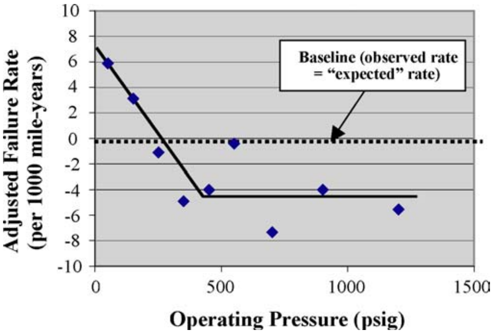

Fig. 2. Effect of pressure on expected pipeline leak rates, after adjusting for temperature and age. *Note*: This is shown in the form of the actual (non-compensated) rate minus the rate that would be expected for the average age and temperature in the data subset for a given operating pressure. Thus, the rates are presented as the deviations above and below a baseline of 0, where there is no pressure influence.

6.2. *Case 2: effect of operating pressure on cross-country pipeline failure rates*

Raw data (not shown) from hazardous liquid pipelines in California show no particular influence of operating pressure on leak rates. But they do show a strong dependence on age and the temperature of the material being transported. If one compensates for the influence of age and temperature, the data show that there may in fact be an effect of operating pressure on failure rates (Fig. 2).

The plot suggests that pipelines operating at higher pressure have lower failure rates for a given age and temperature. This might be explained by increased pipe wall thickness, greater care given to higher pressure lines, or something else. But should this be accounted for in a model without knowing the underlying explanation for the effect? And there is a visceral hesitancy to give credit for operating at more severe conditions.

7. Leak data for sample equipment types

Some leak frequency data are provided in Fig. 3. These are presented in ranges of values found in the literature, since it is not the purpose of this paper to judge the validity of a particular data source to the reader's situation. If nothing else, these data illustrate the variability that one encounters in this area, and the need for developing consistent standards for data use.

8. The future

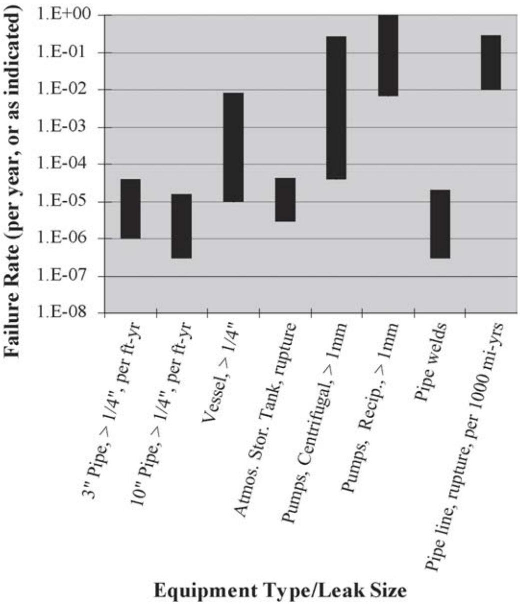

Fig. 3. Variability in equipment leak frequency data.

With improvements in communications and technology, the ability to collect and analyze data is improving. Process industry efforts are proceeding along in fits and starts, and too slowly. In large part, this is because the continuing downsizing of staffing and corporate functions has reduced the amount of discretionary time available to engineers to undertake these kinds of 'pet projects'. The onus is now on these specialists to make an economic case to management to justify the time and cost associated with data collection activities.

One case in point is the effort by the Center for Chemical Process Safety to develop a "Process Equipment Reliability Database". This effort is laudable, and should ultimately lead to highly rigorous data that will unquestionably be the industry standard. But again, this effort suffers in large part from lack of funds and industry participation due to mergers, downsizing, etc. And so the effort is coming to fruition much more slowly than many people would like.

9. Conclusions

In spite of the many shortcomings of published data, it is possible to assemble a failure rate database in which we can have reasonable confidence. But it is much easier to develop a database which is either inaccurate or is documented in a way that it can be applied incorrectly to analyze a particular operating situation. The chemical process industry will do well to develop and publish data that are defined and accurate, and to give their specialists the statistical knowledge necessary to apply these data properly to analyzing specific situations they encounter.

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