Pipeline Risk Assessment

Risk assessment on any facility is most efficiently done by first dividing the facility into components with unchanging risk characteristics. For a cross-country pipeline, this involves collecting data on all portions of the pipeline and its surroundings and then using this data to 'dynamically segment' the pipeline into segments of varying length. Risk algorithms are applied to each of the segments, producing risk estimates that truly reflect changing risks along the pipeline.

The risk estimating algorithms are conceptually very straightforward. However, as with any assessment of a complex mechanical system installed in a varying, natural environment, there are many details to consider. This is illustrated by an example risk assessment on a hypothetical pipeline. .

Varying levels of analyses rigor are available to risk assessors. For example, a resistance estimate might be modeled as simply being related to stress level and pipe characteristics or, for more robust analyses, could include sophisticated finite element analyses. In this example, a certain amount of detail is omitted in order to better demonstrate the higher level principles.

To illustrate key concepts, one time-independent failure mechanism (third party damage) and one time-dependent failure mechanism (external corrosion) are assessed. All other failure mechanisms will follow one of these two forms. Estimates from all failure mechanisms can be combined in various ways to meet the needs of the subsequent risk management processes.

Example:

A 120 mile pipeline is to have a risk assessment performed. For the assessment, failure is defined as loss of integrity leading to loss of pipeline product. Consequences are measured as potential harm to public health, property, and the environment and are expressed in units of dollars loss-ie, all consequences are monetized.

Verifiable measurement units for the assessment are as follows:

MEASUREMENT	UNITS
Risk	***$/year***
Probability of Failure (PoF)	***failures/mile-year***
Consequence of Failure (CoF)	***$/failure***
Time to Failure (TTF)	***years***
Exposure	***events/mile-year***
Mitigation	***%***
Resistance	***%***

Data is collected and includes Subject Matter Expert (SME) estimates where actual data is unavailable. The integrated data shows changes in risk along the pipeline route—6,530 segments are created by the changing data with an average length of 87 ft. This relatively short average length shows that a risk profile with adequate discrimination has been generated.

A level of conservatism is defined as P90 for all inputs that are not based on actual measurements. This is conservative—a bias towards overestimation of actual risks. P90 means that risk is underestimated once out of every 10 inputs, ie, there will be a negative surprise only 10% of the time. The risk assessors have chosen this level of conservatism to account for plausible (albeit extreme) conditions and to ensure that risks are not underestimated.

For assessing PoF from time-independent failure mechanisms—those that do not worsen over time, such as third party damage and human error-- the summary equation is as follows:

PoF_time-independent = exposure x (1 - mitigation) x (1 - resistance)

As an example for applying this to PoF due to time-independent third-party damage, the following inputs are identified (by SME's) for a certain portion of the subject pipeline.

- Exposure (unmitigated 'attack') is estimated to be three (3) third-party damage events per mile-year. This means that, over this mile of pipeline, excavators will be operating 3 times per year and, in the absence of mitigation, will cause damage to the pipeline three times per year
- Using a mitigation (defense) effectiveness analysis, SME's estimate that 1 in 50 of these exposures will not be successfully prevented by existing mitigation measures. This results in an overall mitigation effectiveness estimate of 98% mitigated.
- SME's perform a resistance analysis to estimate that, of the exposures that are not mitigated, 1 in 4 will cause immediate failure, not just damage. This estimate includes the possible presence of weaknesses due to threat interaction and/or manufacturing and construction issues. So, the pipeline in this area is judged to have a 75% resistance to failure (survivability) from this mechanism, given the failure of mitigations.

Assuming that frequencies and probabilities are practically interchangeable, these inputs result in the following assessment:

PoF_third-party damage
= (3 damage events per mile-year) x (1 - 98% mitigated) x (1 - 75% resistive)

= 1.5% (0.015) per mile-year
(a failure every 67 years along this mile of pipeline)

Note that a useful intermediate calculation, 'probability of damage' (but not failure), emerges from this assessment and can be verified by future inspections.

(3 damage events per mile-year) x (1 - 98% mitigated)
= 0.06 damage events/mile-year

(damage occurring about once every 17 years).

This same approach is used for other time-independent failure mechanisms and for all portions of the pipeline.

In assessing PoF due to time-dependent failure mechanisms—corrosion and cracking, the previous algorithms are slightly modified:

PoF_time-dependent = ƒ (Time-to-Failure, TTF)
TTF = resistance / [exposure x (1 - mitigation)]

To continue the example, SME's have determined that, at certain locations along the 120 mile pipeline, soil corrosivity leads to 5 mpy external corrosion exposure (if left unmitigated). Analyses of coating and CP effectiveness leads SME's to assign a mitigation effectiveness of 90%.

Recent inspections, adjusted for uncertainty and considering possible era-of-manufacture weaknesses, result in an effective pipe wall thickness estimate of 0.220" (remaining resistance). Use of these inputs in the PoF assessment for the next year is shown below:

TTF = 220 mils / [5 mpy x (1 - 90%)] = 440 years
PoF = 1 / TTF = [5 mpy x (1 - 90%)] / 220 mils = 0.11% PoF

So, the combined PoF from these two threats is estimated to be 0.015 + 0.0011 = 0.016 failures/mile-year. This 1.6% failure probability can now be used with estimates of consequence potential to arrive at overall risk estimates generated by these two threats.

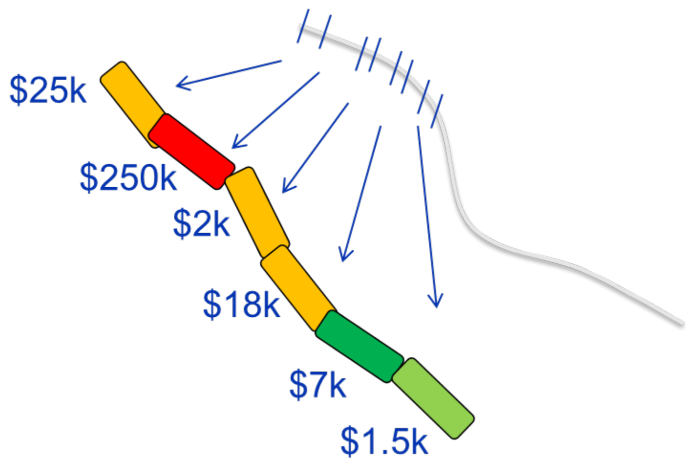
SME's have analyzed potential scenarios and determined the range of possible consequences generated by a failure. After assignment of probabilities to each scenario, a point estimate representing the distribution of all future scenarios yields the value of $18,500 per failure. This can be thought of as a probability-adjusted 'average' consequence per failure.

Risk assessors similarly calculate all risk elements for each of the 6,530 segments. To estimate PoF for any portion of the 120 mile pipeline, a probabilistic summation is used to ensure that length effects and the probabilistic nature of estimates are appropriately considered. To estimate total risk, an expected loss calculation for the full 120 miles yields $25,200 of risk exposure from this pipeline per year of operation. The average is $210/mile-year.

Risk Management

The risk estimates generated in this way are extremely useful to decision makers. Such estimates can become part of the budget setting and valuation processes. In this example, the company first uses these values to compare to, among other benchmarks, a US national average for similar pipelines of $350/mile-year. The comparison needs to consider the P90 level of conservatism employed. Often, a P90 or higher level of conservatism is appropriate for determining risk management on specific pipeline segments, but will not compare favorably to historical incident data since those generally reflect P50 estimates.

Understanding how each pipeline segment contributes to the overall risk sets the stage for efficient risk management.



Changing Risk Along a Segmented Pipeline

For risk management at specific locations, cost / benefits of various risk mitigation measures can be compared by running 'what if' scenarios using the same equations with anticipated mitigation effectiveness arising from the proposed action(s).

These estimates can also be used to establish 'safe enough' limits by following pre-determined risk acceptability criteria such as those proposed in CSA Z662 Annex 0.