Measuring failure potential: exposure, mitigation and resistance

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In several previous columns we have noted the need for a very specific approach to measuring failure probability (PoF). Three factors must be independently measured in order to fully understand PoF. Let's explore those factors a bit deeper here.

Regardless of the definition of 'failure' being used, failure only occurs when there is a failure mechanism, preventive measures are insufficient, and there is insufficient resistance to the failure mechanism. All three must occur before failure occurs. This is the genesis of the proper way to measure PoF.

Failure measurement aspects

We also recognise that there is more than one potential failure mechanism that can lead to failure. These two basic concepts lead to one of the most important elements of pipeline risk assessment[1].

All plausible failure mechanisms must be included in the assessment of PoF. Each failure mechanism must have each of the following three aspects measured or estimated in verifiable and commonly used measurement units:

- Exposure (attack)—the type and unmitigated aggressiveness of every force or process that may precipitate failure
- Mitigation (defence)—the type and effectiveness of every mitigation measure designed to block or reduce an exposure
- Resistance—a measure or estimate of the ability to absorb damage without failure, once damage is occurring.

For each time-dependent failure mechanism, a theoretical remaining life estimate must be produced and expressed in a time unit.

Measuring exposure independently generates knowledge of the 'area of opportunity' or the aggressiveness of the attacking mechanism. The separate estimate of mitigation effectiveness then shows how much of that exposure should be prevented from reaching the component being assessed. Finally, the resistance estimate shows how often the component will fail, if contact with the exposure occurs. In risk management, where decision-makers contemplate possible additional mitigation measures, additional resistance, or even a relocation of the component (often the only way to change the exposure), this knowledge of the three key factors will be critical.

PoF estimates

Units of measurement are transparent and intuitive. In one common application of the exposure, mitigation, and resistance triad, units are as follows. Each exposure is measured in one of two ways—either in units of 'events per time and distance', i.e. events/mile-year, events/km-year, or in units of degradation – metal loss or crack growth rates, i.e. mpy, mm per year, etc. An 'event' is an occurrence that, in the absence of mitigation and resistance, will result in a failure. To estimate exposure, we envision the component completely unprotected and highly vulnerable to failure (think 'tin can' wall thickness). So, an excavator working over a buried pipeline is an event. This is counted as an event regardless of type of excavator, excavator reach, depth of burial, use of one-call, signs/markers, etc.


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Mitigation and resistance are each measured in units of per cent representing 'fraction of damage or failure scenarios avoided'. A mitigation effectiveness of 90 per cent means that 9 out of the next 10 exposures will not result in damage. Resistance of 60 per cent means that 40 per cent of the next damage scenarios will result in failure, 60 per cent will not.

For assessing PoF from time-independent failure mechanisms – those that appear random and do not worsen over time – the top level equation can be as simple as:

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

With the above units of measurement, PoF values emerge in intuitive and common units of 'events per time and distance', i.e. events/mile-year, events/km-year, etc.

As an example of applying this to failure potential from third-party excavations, the following inputs are identified for a hypothetical pipeline segment:

- Exposure (unmitigated) is estimated to be three excavation events per mile-year.
- Using a mitigation effectiveness analysis, it is estimated that one in 50 of these exposures will not be successfully kept away from the pipeline by the existing mitigation measures. This results in an overall mitigation effectiveness estimate of 98 per cent.
- Of the exposures that result in contact with the pipe, despite mitigations, the analysis estimates that one in four will result in 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 be 75 per cent resistive to failure from these excavation events, once contact occurs.

These inputs result in the following assessment:

(3 excavation events per mile-year) x (1 – 98 per cent mitigated) x (1 – 75 per cent resistive) = 0.015 failures per mile-year[2]

This suggests an excavation-related failure about every 67 years along this mile of pipeline.

This is a very important estimate. It provides context for decision-makers. When subsequently coupled with consequence potential, it paints a valuable picture of this aspect of risk.

Note that a useful intermediate calculation, probability of damage (but not failure) also emerges from this assessment:

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

This suggests excavation-related damage occurring about once every 17 years.

This damage estimate can be verified by future inspections. The frequency of new top-side dents or gouges, as detected by an in-line inspection, may yield an actual damage rate from excavation activity. Differences between the actual and the estimate can be explored. For example, if the estimate was too high, was the exposure overestimated, the mitigation underestimated, or both? This is a valuable learning opportunity.

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

For assessment of PoF for time-dependent failure mechanisms – those involving degradation of materials – the previous algorithms are slightly modified to yield a time-to-failure (TTF) value as an intermediate calculation in route to PoF.

PoF_time-dependent = f (TTF)

TTF = resistance / [exposure x (1 - mitigation)]

As an example, it has been determined that, at certain locations along a pipeline, soil corrosivity creates a 5 mpy external corrosion exposure (unmitigated). Examination of coating and cathodic protection effectiveness leads to assignation of a mitigation effectiveness of 90 per cent (this is not a trivial estimate, and will be detailed in a later column). Recent inspections, adjusted for uncertainty, result in a pipe wall thickness estimate of 0.220 inches (resistance). This includes allowances for possible weaknesses or susceptibilities, modelled as equivalent to a thinning of the pipe wall[3] (this also can be a complex calculation, and captures 'threat interaction' as noted in a previous column).

Use of these inputs in the PoF assessment is shown below:

TTF = 220 mils / [5 mpy x (1 - 90 per cent)] = 440 years

Next, a relationship between TTF and PoF for the future period of interest is chosen. For example, a simple and conservative relationship yields the following:

PoF = 1 / TTF = [5 mpy x (1 - 90 per cent)] / 220 mils = 0.11 per cent PoF

In this example, an estimate for PoF from the two failure mechanisms examined – excavator damage and external corrosion – can be approximated by 1.5 per cent + 0.1 per cent = 1.6 per cent per mile-year. If risk-management processes deem this to be an actionable level of risk, then the exposure-mitigation-resistance details lead the way to risk-reduction opportunities.

A reliable, comprehensive understanding

This exposure-mitigation-resistance analysis is one aspect that differentiates a modern pipeline risk assessment from classical quantative risk assessment (QRA). Classical QRA uses past failure rates without the exposure-mitigation-resistance breakdown. Without this insight, the past failure rates typically used in such assessments have questionable relevance to future failure potential. Classical QRA also typically produces future failure estimates that likewise do not have the exposure-mitigation-resistance influences identified. That leads to incomplete understanding, which makes risk management problematic. Ideally, historical event rate information will be coupled with the exposure-mitigation-resistance analysis to yield the best PoF estimates.

The exposure-mitigation-resistance analysis is an indispensable step towards a full understanding of PoF. Without it, understanding is incomplete. Full understanding leads to the best risk-management practice – optimised resource allocation – which benefits all stakeholders.

[1] *http://www.dnvusa.com/industry/oil_gas/segments/Pipelines/Services/RiskSolutions.asp*

[2] *[Exposure vents/mile-yr] x [damage events/exposure event] x [failures/damage events] = failures/mile-yr*

FUTURE COLUMN TOPICS

- "The Perfect Storm" chain of events
- How do I handle non-pipe assets?
- Getting info from SMEs – facilitation!
- PL RA – is it helping me?
- Monetisation of risks – a controversial common denominator
- How safe is "safe enough"?
- The troubles with weightings
- Consequences of failure—ID the scenarios