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PIPELINE RISK ASSESSMENT

The Essential Elements

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An initiative through collaboration of

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GUIDELINES FOR PIPELINE RISK ASSESSMENT

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Understanding Pipeline Risk

Although pipelines continue to be the safest way to transport fluids over long distances, accidents still threaten the public and/or environment, exposing the industry to scrutiny. Concerns about managing these risks are reflected in PHMSA's recent public meetings and in the Advanced Notice of Proposed Rule Making (ANPRM) of January, 2011.

One of PHMSA's primary aims is to establish better risk assessment leading to improved integrity management and increased public safety.

Essential Elements of Pipeline Risk Assessment

In collaboration, DNV and W. Kent Muhlbauer introduce an important set of guidelines to address aspects of pipeline risk assessment not well developed in existing industry standards – guidelines that optimize the risk assessment efforts of both operators and regulators.

DNV is a global leader in integrity and risk management while Mr. Muhlbauer is a leading authority on pipeline risk management. This joint effort provides an immediately useful set of common sense tactics to make risk assessment more meaningful, defensible, and acceptable to regulators. We have oriented these guidelines to directly satisfy PHMSA's stated goal of *smarter risk assessment.*

Our guidelines offer a formalized process with logical, structured approaches to efficiently integrate all available information into a robust risk assessment. The guidelines are intentionally concise yet flexible, allowing tailored solutions to situation-specific concerns. At the same time, an appropriate level of standardization is incorporated to manage expectations of regulators as well as those regulated.

These initial guidelines establish a basic risk assessment framework from which to build. Discussion beyond the essentials presented here will be available in subsequent guidance documents.

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Smarter Risk Assessment

- Measures risk in verifiable units
- Calculates failure probabilities grounded in engineering principles
- Fully characterizes consequence of failure
- Profiles risk along a pipeline
- Integrates *all* pipeline knowledge
- Promotes accurate decision making
- Controls the bias
- Ensures proper aggregation

Intended Outcomes

- Efficient and transparent risk modeling
- Accurate, verifiable, and complete results
- Improved understanding of actual risk
- Risk-based input to guide integrity decision making - true risk management
- Optimized resource allocation leading to higher levels of public safety
- Appropriate level of standardization facilitating smoother regulatory audits
- Expectations of regulators, the public, and management fulfilled

PIPELINE RISK ASSESSMENT - THE ESSENTIAL ELEMENTS

This document sets forth essential elements for a pipeline risk assessment. Their utilization ensures that meaningful risk estimates are produced. Furthermore, adoption of these minimum elements facilitates efficient and consistent regulatory oversight and helps manage expectations of all stakeholders.

The essential elements are intentionally a very short list, providing a foundation from which to build a comprehensive (or modify an existing) risk assessment program. They supplement existing industry guidance documents on risk assessment and therefore do not repeat the important issues addressed there.

Application of these elements is easy and intuitive, as is shown in a sample case starting on Page 5. These essential elements and other aspects of pipeline risk assessment will be fully detailed in subsequent guidance documents.

1. Measure in Verifiable Units

The risk assessment must include a definition of 'failure' and produce *verifiable* estimates of failure potential. Therefore, the risk assessment must produce a measure of probability of failure (PoF) and a measure of potential consequence.

Both must be expressed in verifiable and commonly used measurement units, free from intermediate schemes (such as scoring or point assignments). Failure probability, which can also be expressed as a frequency, must capture effects of length and time, leading to risk estimates such as 'leaks per mile per year' or 'costs/km-year', etc.

2. Ground Probability of Failure in Sound Engineering Principles

All plausible failure mechanisms must be included in the assessment of PoF. Every failure mechanism must have the following three elements independently measured:

> ***Exposure*** (attack) - The type and unmitigated aggressiveness of the force or process that may precipitate failure. Example measurement units are 'events per mile-year' or 'mils per year metal loss'.
>
> ***Mitigation*** (defense) - The type and effectiveness of every mitigation measure designed to block or reduce an exposure. The benefit from each independent mitigation measure, coupled with the combined effect of all mitigations, is to be estimated.
>
> ***Resistance*** (survivability) - The inherent ability of a pipeline to sustain forces and deformations in the event of mitigation failure. Resistance characteristics are to be evaluated separately to determine the probability of 'damage without failure' vs. 'damage resulting in failure'.

For each time-dependent failure mechanism, a theoretical remaining life estimate must be produced and expressed as a function of time.

3. Fully Characterize Consequence of Failure

The risk assessment must identify and acknowledge the full range of possible consequence scenarios associated with failure, including 'most probable' and 'worst case' scenarios.

PIPELINE RISK ASSESSMENT - THE ESSENTIAL ELEMENTS (continued)

4. Profile the Risk Reality

The risk assessment must produce a continuous profile of changing risks along the entire pipeline, recognizing the changing characteristics of the pipe and its surroundings. The risk assessment must be performed at all points along the pipeline.

5. Integrate Pipeline Knowledge

The assessment must include complete, appropriate, and transparent use of all available information. Appropriateness is evident when the risk assessment uses all information in substantially the same way that a subject matter expert (SME) uses information to improve his understanding of risk.

6. Incorporate Sufficient Granularity

For analysis purposes, the risk assessment must divide the pipeline into segments where risks are unchanging (i.e. all risk variables are essentially unchanging within each segment). Due to factors such as hydraulic profile and varying natural environments, most pipelines will necessitate the identification of at least five to ten segments per mile with some pipelines requiring thousands per mile. Compromises involving the use of averages or extremes (i.e. maximums, minimums) to characterize a segment can significantly weaken the analyses and are to be avoided.

7. Control the Bias

The risk assessment must state the level of conservatism employed in all of its components—inputs, defaults (applied in the absence of information), algorithms, and results. The assessment must be free of inappropriate bias that tends to force incorrect conclusions for some segments. For example, the use of weightings based on historical failure frequencies may misrepresent lower frequency albeit important threats.

8. Unmask Aggregation

A proper process for aggregation of the risks from multiple pipeline segments must be included. For a variety of purposes, summarization of the risks presented by multiple segments is desirable (e.g. 'from trap to trap'). Such summaries must avoid simple statistics (i.e. averages, maximums, etc.) or weighted statistics (length-weighted averages, etc.) that may mask the real risks presented by the collection of segments. Use of such summarization strategies often leads to incorrect conclusions and is to be avoided.

An *Essential Elements* 'Sample Case' can be found starting on Page 5.

Expectations for pipeline risk assessment go beyond many pipeline operators' current methodologies. The DNV / Muhlbauer team stands ready to improve existing risk assessment programs or to help establish new, comprehensive programs.

DNV is recognized by pipeline operators and regulators alike for its credibility, reliability and technical expertise. Our near-150 year heritage as an *independent foundation* has garnered a reputation as a trusted 3rd party.

DNV acquired its North American pipeline business unit, (previously *CC Technologies*) in 2005. Our research scientists and engineering subject matter experts (SME's) are backed by industry-leading laboratories for materials / technology testing and verification, failure analysis, degradation, mechanical integrity and risk management.

DNV has been formidably involved in the post-failure response and/or forensic investigation of virtually every major US pipeline failure over the past quarter century.

W. Kent Muhlbauer is an internationally recognized authority on pipeline risk management and is highly sought after as an author, lecturer and consultant. He acts as advisor to private industry, governmental agencies and academia worldwide.

Mr. Muhlbauer has extensive background in pipeline design, operations and maintenance, having held technical and management positions in a pipeline operating company for many years prior to becoming a risk management consultant.

Mr. Muhlbauer's published works, including Pipeline Risk Management Manual now in its 3rd edition, are largely considered by the pipeline industry as 'go to' sources for pipeline risk management.

This collaboration looks forward to continuing support of this critical issue and all other technical aspects of pipelining worldwide.

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Sample Case:
Pipeline Risk Assessment

The following example illustrates the application of the *Essential Elements* in a pipeline risk assessment. The *Elements* are inherently flexible allowing for alternative, yet effective, approaches while the methodology establishes a desirable level of rigor for assessing risk. All risk calculations are efficiently performed in a variety of software environments - no specialized software is required.

Scenario: 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.

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 or mpy***
Mitigation	***%***
Resistance	***%***

Minimum data (as defined, for example, in ASME B31.8S) are collected and include Subject Matter Expert (SME) estimates where measurement data are unavailable. The collected data show changes in risk along the pipeline route—6,530 segments are created by the changing data with an average length of 87 ft. This ensures that a risk profile with adequate discrimination is generated.

The level of conservatism used is defined as P90 for all inputs that are not based on actual measurements. This means that an underestimation of actual risk will arise only once for every ten inputs (i.e. the input will only underestimate the true value 10% of the time and overestimate actual risk 90% of the time). The risk assessors have chosen this level of conservatism to account for plausible (albeit extreme) conditions and ensure that risks are not underestimated.

For assessing probability of failure (PoF) from time-independent failure mechanisms, the top level equation selected by risk assessors is as follows:

$$\mathbf{PoF_{time\text{-}independent} = exposure \times (1 - mitigation) \times (1 - resistance)}$$

'Failure' and 'Consequences' clearly defined

Measuring in verifiable units keeps process honest:

- **Understandable terms**
- **Calibrated to reality**
- **Meaningful, applicable results**

Full data integration

Sufficient resolution

Bias Control: Clearly defined level of conservatism

Grounding in sound engineering principles:

- **Provides a firm basis in science**
- **Helps provide a rational, defensible assessment**

This equation is applied to every time-independent threat at every point along the pipeline. As an example for applying this to PoF due to third-party damage, the following inputs are identified (by SME's) for certain portions of the subject pipeline. Here, by independently measuring the attacks, defenses and survivability, the analysis promotes a full understanding of the PoF:

Gain full understanding of PoF: Measure the attacks, defenses, and survivability – independently

Produce useful estimates even when data is scarce

Verifiable units of measure, even for estimates

- Exposure (unmitigated 'attack') is estimated to be three (3) third-party damage events per mile-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.
- Of the exposures that result in contact with the pipe, SME's perform an analysis to estimate that 1 in 4 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 have a 75% resistance to failure (survivability) from this mechanism, once contact occurs.

These inputs result in the following assessment:

$$\textbf{PoF}_{\textbf{third-party damage}} = \textbf{(3 damage events per mile-year) x (1 - 98\% mitigated) x (1 - 75\% resistive) =}$$

$$\textbf{1.5\% (0.015) per mile-year (a failure every 67 years at this location)}$$

Note that a useful intermediate calculation, probability of damage (damage short of failure), emerges from this assessment and can be verified by future inspections.

$$\textbf{Probability of Damage}_{\textbf{third-party}} = \textbf{(3 damage events per mile-year) x (1 - 98\% mitigated) =}$$

$$\textbf{0.06 damage events/mile-year (damage occurring about once every 17 years)}$$

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

$$\textbf{PoF}_{\textbf{time-dependent}} = \textbf{ƒ (TTF}_{\textbf{time-dependent}}\textbf{)}$$

$$\textbf{TTF}_{\textbf{time-dependent}} = \textbf{resistance / [exposure x (1 - mitigation)]}$$

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 unmitigated). Examination of coating and CP effectiveness leads SME's to estimate a mitigation effectiveness of 90% at this sample location. Pipe strength obtained from inspections, pressure tests, and manufacture/construction considerations, adjusted for uncertainty, result in an effective pipe wall thickness estimate of 0.220" (remaining resistance).

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

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

PoF = 1 / TTF[1] = [5 mpy x (1 - 90%)] / 220 mils = 0.23% PoF

As with the time-independent PoF estimates, these equations are applied for each time-dependent threat (i.e. corrosion and cracking) at all locations along the 120 mile pipeline.

Risk assessment uses data as would an SME

Proper aggregation of risk estimates

Risk estimates in verifiable units

Generate a risk profile to visualize changing risks along the pipeline

Critical input for defining strategic focus:

- **Maintenance**
- **Operational**
- **Regulatory**
- **Risk-informed decisions**

Next, potential consequences are assessed. Fully characterizing consequence of failure provides the opportunity for the operator to consider consequence control as an element of risk management. Using quantifiable measures of consequence ensures the results are robust and forces consistency in selecting prevention and mitigation measures.

In this case, SME's have analyzed potential consequences and determined the range of possible consequences generated by various failure scenarios. This company has decided to monetize all potential consequences in their risk assessments. After assignment of probabilities to each scenario, a point estimate representing the distribution of all future scenarios yields the value of $11,500 per failure at this sample location.

At this location, the above methodologies are applied and total risks are estimated to be 0.008 failures[2]/year x $11,500/failure = $92/year.

Risk assessors repeat the sample calculations shown above for every threat on each of the 6,530 segments comprising this pipeline. To estimate PoF for any portion of the 120 mile pipeline—i.e. aggregation for 'trap to trap' PoF—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 a value of $25,100/year with per mile values ranging from $42/mile-year to $1,208/mile-year for specific portions of the system.

The company uses these values to compare to, among other benchmarks, a US national average of $350/mile-year for similar pipelines.

This sample case illustrates the intended application of The Essential Elements of Pipeline Risk Assessment, first published in *Pipeline & Gas Journal* (May, 2012) and found in the preceding pages. The *Essential Elements* can also be found at http://www.dnvusa.com/news_events/news/2012/PipelineRiskAssessnebt.asp.

[1] PoF as 1 / TTF is one of many possible relationships relating PoF to TTF.

[2] The aggregate of all failure mechanisms potentially causing failure on this pipeline segment