Development and Experience of a Practical Approach to Risk Based Inspection: Planning Offshore Pipeline Inspection Campaigns

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Abstract

Inspection is used as part of a pipeline integrity management programme, to control the risks associated with pipeline failure. Risk based inspection (RBI) methods are commonly used to schedule pipeline inspections. However, the RBI methodologies and approaches which are applied in the pipeline industry are many and varied.

This paper presents and discusses practical application of a pipelines RBI process which provides a direct link between the inspection interval and the risk associated with a loss of containment failure from a pipeline. The RBI methodology considered applies reliability engineering methods to account for the perceived increase in risk over time, due to both degradation-related time-dependent threats and randomly occurring event-driven threats. The presented approach is flexible, allowing detailed, quantified engineering relationships and historical incident rate data to be used where available, with more subjective input from subject matter experts and engineers when required. The uncertainty associated with the assessments is accounted for explicitly, allowing different levels of analysis complexity to be accommodated within the same overall pipeline system RBI study.

The RBI approach schedules inspections such that they are completed before risk reaches a tolerability limit. This ensures that inspections are targeted appropriately to control the risk of pipeline failure. The RBI process also identifies when additional risk mitigation is required to control risk, for example this may be the case if inspection would be required at an impractical frequency, or if no suitable inspection method is available. The assessment process can be further used to investigate the effect on the assessed risk level of changes in the inspection schedule.

This paper builds upon and updates a methodology and process first developed twenty years ago. The study presents an improved development of the methodology and discusses the authors' experience of practical application and implementation of the RBI process, for large offshore pipeline systems. This practical experience includes elements such as dealing with requirements to combine inspections into optimised campaigns, as well as accounting for the time required to review, assess and act upon inspection findings. The review of experience also considers alignment of the RBI with corporate systems, procedures and risk matrix definitions. The paper concludes by identifying the key elements leading to successful development of an RBI schedule for offshore pipeline systems.

Introduction

Pipeline integrity management programmes aim to control the risk of pipeline failure by consideration of a number of factors, one of which is pipeline inspection. In the UK, a goal setting approach to pipeline integrity management is used [1] and risk based inspection (RBI) methods are commonly used to schedule pipeline inspections and offshore survey campaigns. The RBI methodologies and approaches which are applied in the pipeline industry are many and varied, from fully qualitative point scoring systems to fully quantitative detailed reliability analysis.

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Regardless of the methodology, the principle of any RBI is that inspection should be performed before risk reaches a tolerability limit. Therefore, the RBI process should provide a direct link between inspection interval and the risk associated with a pipeline failure. This is difficult to achieve using simple qualitative methodologies and semi-quantitative or fully quantitative methodologies are needed.

The RBI methodology considered in this paper applies reliability engineering methods to account for the perceived increase in risk over time, due to both degradation-related time-dependent threats and randomly occurring, event-driven threats. The method has been developed to focus on loss of containment failures rather than other functional failures of the system. The presented approach is flexible, allowing detailed, quantified engineering relationships and historical incident rate data to be used where available, with more subjective input from subject matter experts and engineers when required. The uncertainty associated with the assessments is accounted for explicitly, allowing different levels of analysis complexity to be accommodated within the same overall pipeline system RBI study.

Operator Views on Pipelines RBI

An indicative overview of opinions on pipelines RBI has been obtained from pipeline professionals working for operator organisations in the UK. A high-level questionnaire was issued, and additional feedback was also sought. Note that responses were received both from professionals who apply the RBI methodology discussed in this paper, and from those who currently use different approaches to pipelines inspection planning. The questions aimed to give an understanding of which aspects of an RBI process and its associated outcomes are considered most important. These questions are summarised in Figure 1.

The high-level findings of this questionnaire indicate that the elements of RBI with the most importance (mean > 4.5) are those that assess the current risk for all identified credible threats. The justification of inspection intervals, the linking of risk with inspection intervals, and the identification of alternative risk mitigating actions were also identified as being of interest. Note that additional comments were also raised regarding the need to accommodate the campaign-based nature of offshore and subsea inspections, and the requirement to keep assessments up-to-date with the potential for new hazards to be considered. The RBI process presented in this study has been designed with those key considerations in mind.

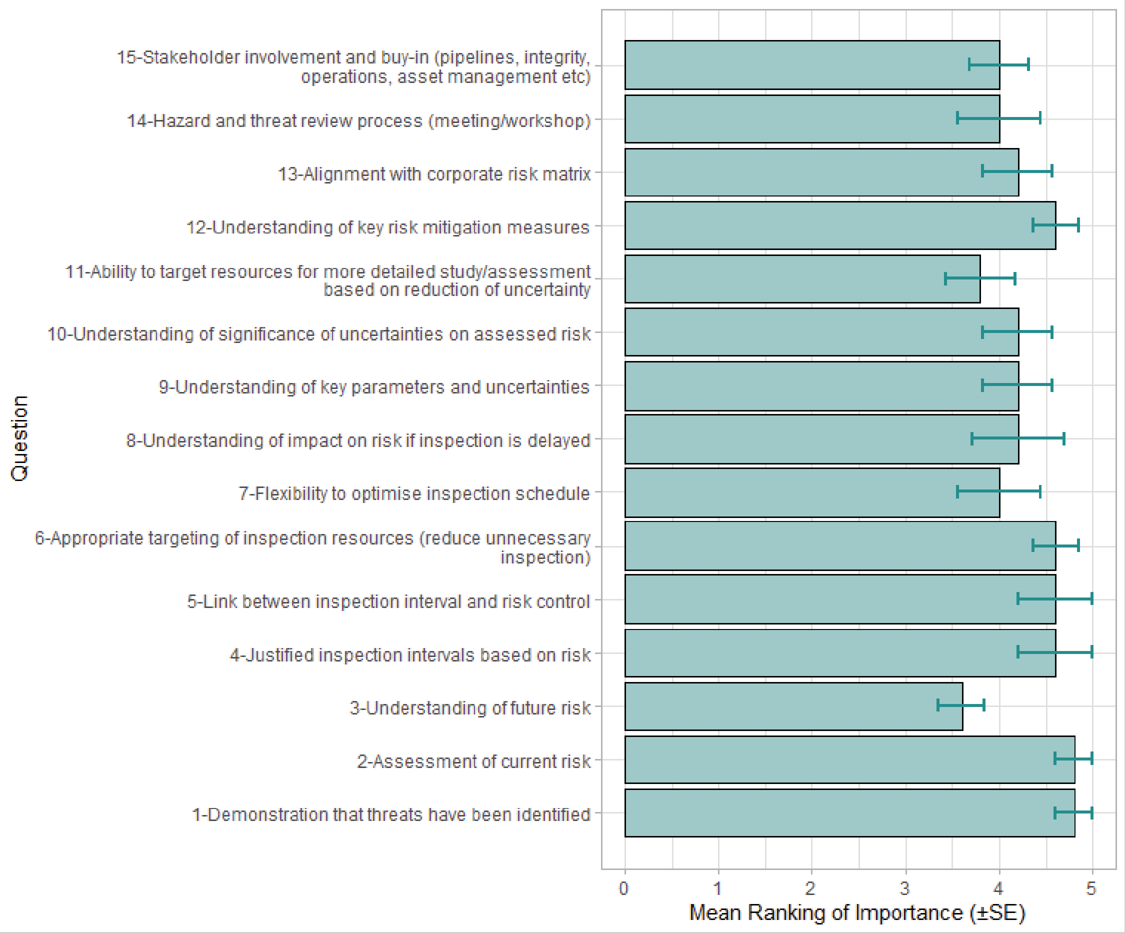

Figure 1. Summary of operator RBI questionnaire results, ranked in importance between 1 (low) and 5 (high). Posed questions are shown in **Error! Reference source not found.**

RBI Process and Methodology

The pipelines RBI process is summarised in Figure 2 and each of the steps in this process are discussed in the following sections. Note that this process is typical for any RBI.

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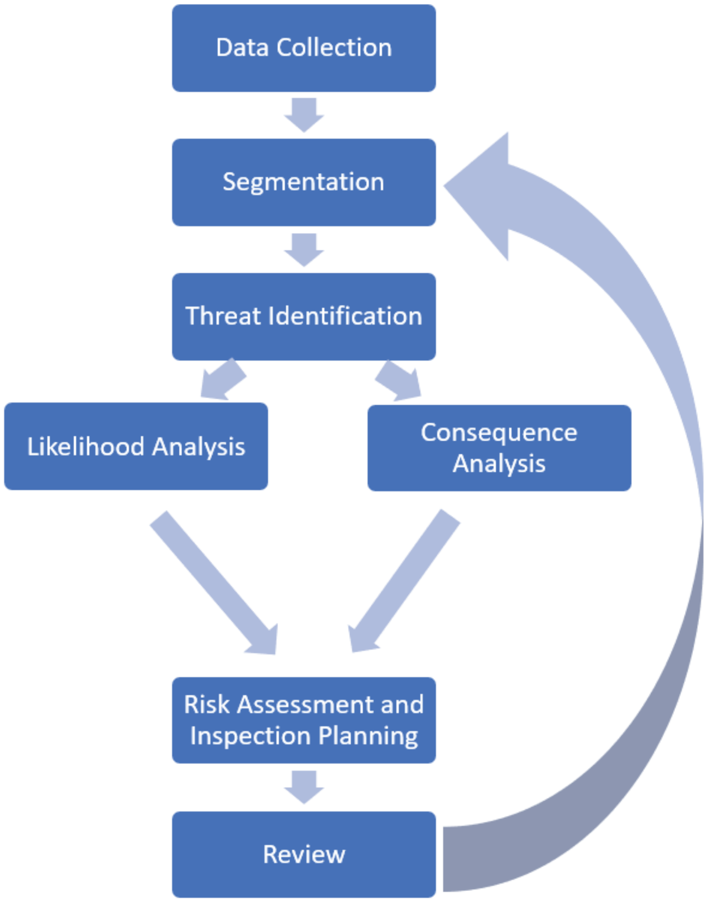

Figure 2. RBI assessment process schematic

Data Collection

The first step in any RBI process is to understand the design, operation and inspection history of a pipeline. This includes collecting data related to any repairs/failures which may have occurred. This data can be interpreted to identify credible threats to the system and to assess both the condition of the line with respect to those threats and the consequences in the event of a failure. It is important to note that the more data available which can inform an RBI assessment, the less uncertainty there is in that assessment.

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Segmentation

The risks associated with a pipeline will vary along its length because the threats, likelihood of a threat causing failure and the consequence of failure vary with changing design, environment or location. Therefore, to account for the variation in risk, each pipeline included in an RBI assessment should be segmented.

Threat Identification

All threats with the potential to cause a loss of containment should be identified. Appropriate inspection techniques for each credible threat in the pipeline system should also be determined. Suitable inspections may be considered to identify whether damage has occurred to the assets, or to protective systems, or to directly determine condition with respect to deterioration mechanisms. Threats to pipeline integrity are discussed in many industry standards and guidance documents [2] [3] [4] [5] [6].

Likelihood Analysis

The change in probability of failure over time is modelled for each credible threat in each pipeline section. The approach to the failure probability assessment depends on whether failure due to the threat would be caused by an ongoing, time-dependent mechanism or an event-driven mechanism. Three levels of analysis can be performed:

- Subjective Semi-Quantitative (SSQ): This is a subjective assessment, where engineering judgement is used to select parameters which describe the distribution of failure probability for a threat.
- Detailed Semi-Quantitative (DSQ): If sufficient information is available the subjectively selected parameters may be replaced with a more detailed semi-quantitative analysis. Some level of subjectivity is still present in the analysis.
- Detailed Fully Quantitative (DFQ): Uses comprehensive structural reliability analysis to generate threat specific failure probability distributions.

The focus of this paper is on assessment of threats using the SSQ method. DSQ and DFQ are threat and pipeline specific, however, the process of calculating an inspection interval is the same once the failure probability distribution has been determined.

Assessment of Time-Dependent Threats

Threats such as corrosion or fatigue may be ongoing, where the condition of the pipeline with respect to the threat deteriorates over time. These ongoing, time-dependent threat mechanisms are modelled assuming continuous degradation from an initial condition to a failure condition. The initial condition is based on the condition indicated at the last inspection or (if no inspection information is available) on an assumed start of life condition. The failure condition is determined according to

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a limit state for the threat, typically based on wall loss or fatigue. Models can then be used to determine the time taken to degrade from the last known condition to the failure condition.

The engineering models used require pipeline, operational and environmental data as input. These input parameters and the models themselves all have a degree of uncertainty associated with them. Because of this uncertainty, a remaining life calculated using these engineering models is not exact and a probability distribution is therefore associated with the calculated remnant life. This is illustrated in Figure 3.

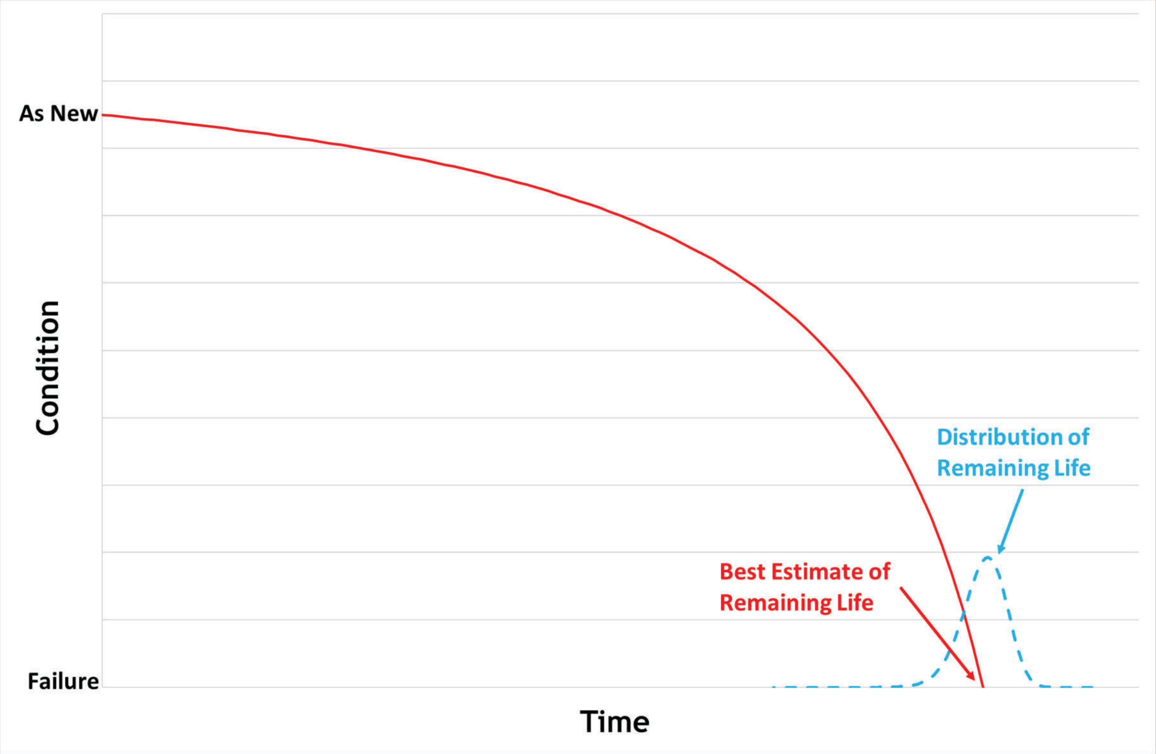

Figure 3. Uncertainty of remaining life for time-dependent threats

The probability of failure due to a threat will increase with time. Therefore, for each threat, a distribution of remaining life, defining how the probability of failure changes with time is required. The remaining life can be described using a cumulative lognormal distribution (although other distributions can be used, the lognormal is comparatively simple to generate and is an appropriate model for degradation [7]). For an SSQ assessment, two parameters are required to generate the probability of failure distribution:

- A best estimate of the remaining life.
- The level of uncertainty associated with the remnant life.

In an SSQ assessment, a best estimate of the remaining life is calculated by modelling degradation of an anomaly from the initial condition to a failure condition (as described above). For example, corroding an ILI reported metal loss anomaly to a through wall limit state. The best estimate of the remaining life then represents the mean of the lognormal distribution.

The uncertainty associated with the estimate is then selected. This uncertainty represents the probability that the actual remaining life of an anomaly is not less than 90% of the estimated remaining life. This uncertainty is interpreted to give the standard deviation of the lognormal distribution.

Once the best estimate of remaining life and the uncertainty associated with this estimate have been determined, the probability of failure of the degrading anomaly at a time, T, after the inspection can then be estimated from the cumulative lognormal function:

$$P_{fail_t} = \frac{1}{\sigma\sqrt{2\pi}} \int_0^T \frac{1}{t} e^{\frac{-(\ln(t)-\mu)^2}{2\sigma^2}} dt \qquad (1)$$

Where:

P_{fail_t} = Time-dependent failure probability at time, T, since the last inspection

μ = Mean of the lognormal distribution of remaining life

σ = Standard deviation of the lognormal distribution of remaining life

t = Time since last inspection (start of life condition)

It should be noted that the methodology for time-dependent threats described in IPC 2006-10535, calculated a probability of failure given that degradation starts at some point before the next inspection but not that it is necessarily already ongoing [8]. The time-dependent assessment presented in this paper considers that degradation is already ongoing.

Example remnant life distributions, assuming high, medium and low uncertainty are shown in Figure 4 and Figure 5. Note that for a DSQ assessment the failure probability curve may be calculated directly using probabilistic functions for distributions of key inputs.

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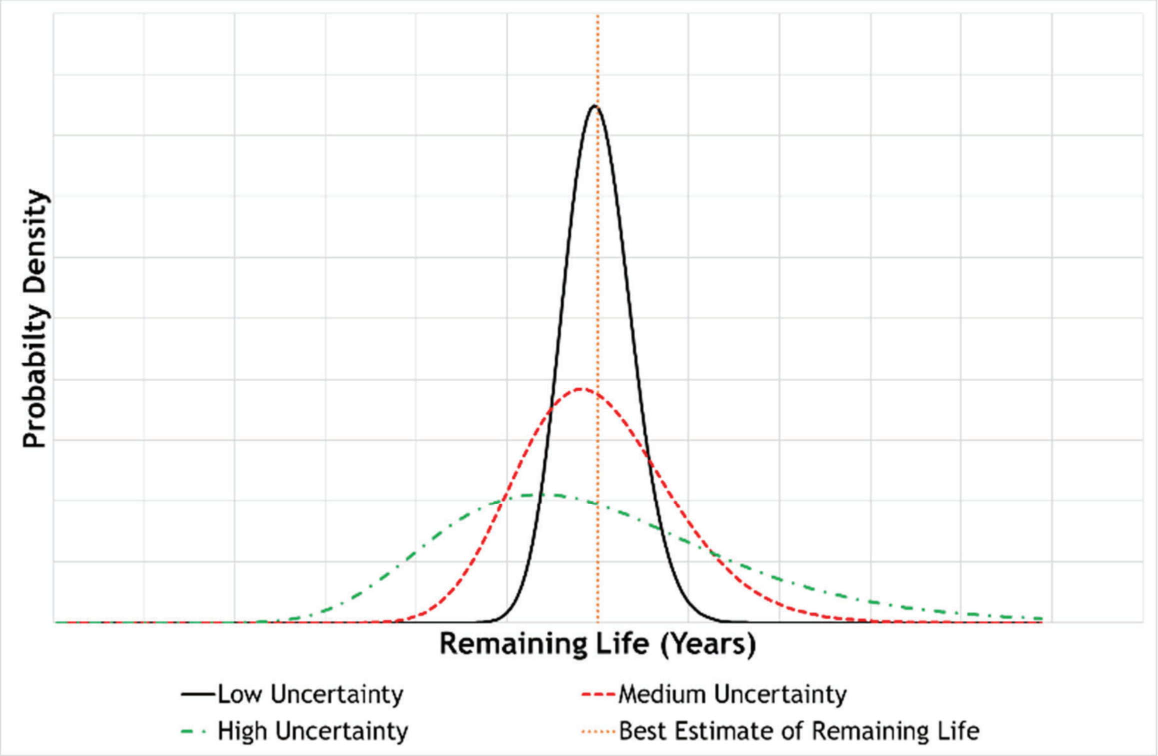

Figure 4. Failure probability for time-dependent threats – subjective uncertainty (SSQ)

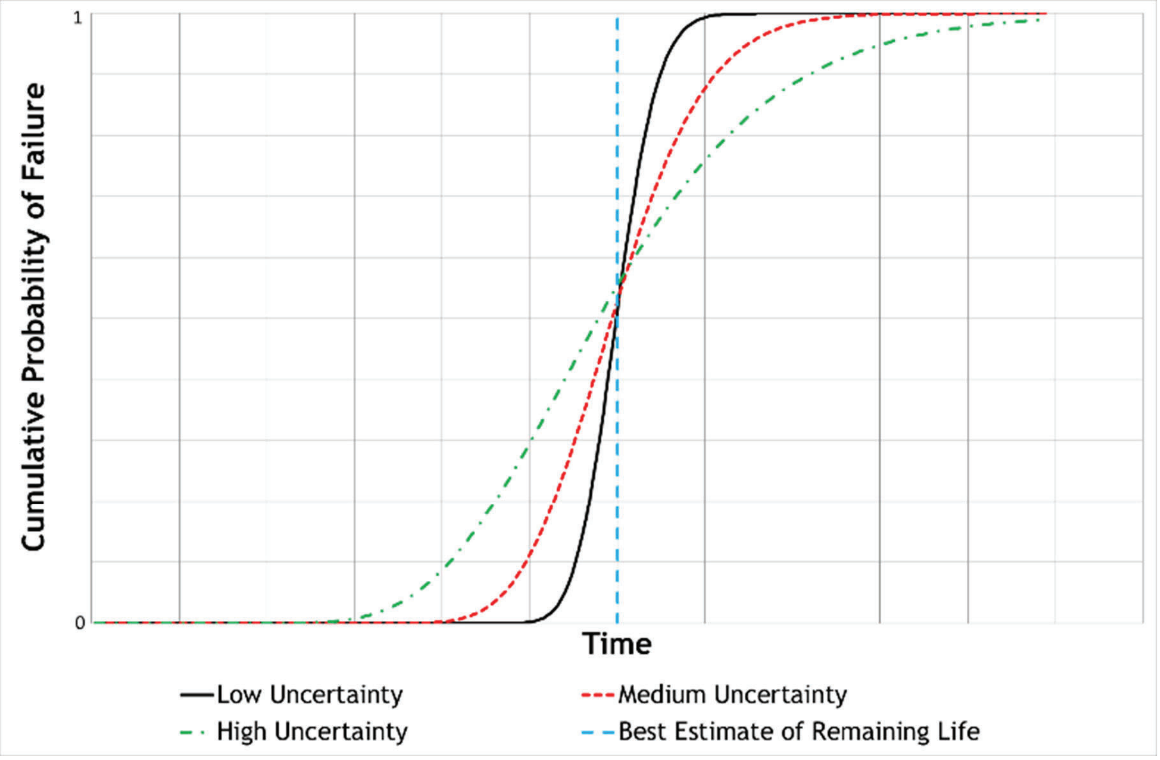

Figure 5. Cumulative failure probability for time-dependent threats - subjective uncertainty (SSQ)

Assessment of Event-Driven Threats

Many threats are associated with initiating events rather than continuous degradation. To model these event-driven threats the following is considered:

- The probability that an initiating event occurs.
- The conditional probability of failure given occurrence of the event.

The probability of failure associated with an event-driven threat is given by multiplication of these two probabilities.

The initiating event could cause immediate failure (for example a major third-party interaction could result in pipeline rupture). However, there is the potential for an event to result in damage to the pipeline which does not fail immediately but which degrades in service and later fails in operation (for example, due to fatigue). It is also possible the pipeline itself is not damaged by the initiating event but that the event allows initiation of a degradation mechanism, for example failure of cathodic protection and pipeline coatings may allow initiation of external corrosion.

The SSQ assessment approach considers a constant annual chance of the initiating event occurring, and is modelled using a cumulative exponential distribution, where λ is the event occurrence rate and t is the time since the last inspection. The probability of at least one event occurring in time t is given as:

$$P(Event) = 1 - e^{-\lambda t} \qquad (2)$$

For the SSQ approach, the event rates are selected subjectively and typical order of magnitude rates from 10^{-1} to 10^{6} are assigned, with reference to representative industry data and operational experience. However, the analysis process allows the event occurrence rate to take any value, such that asset or location specific data can be used as part of a DSQ or DFQ analysis. An example exponential distribution is shown in Figure 6.

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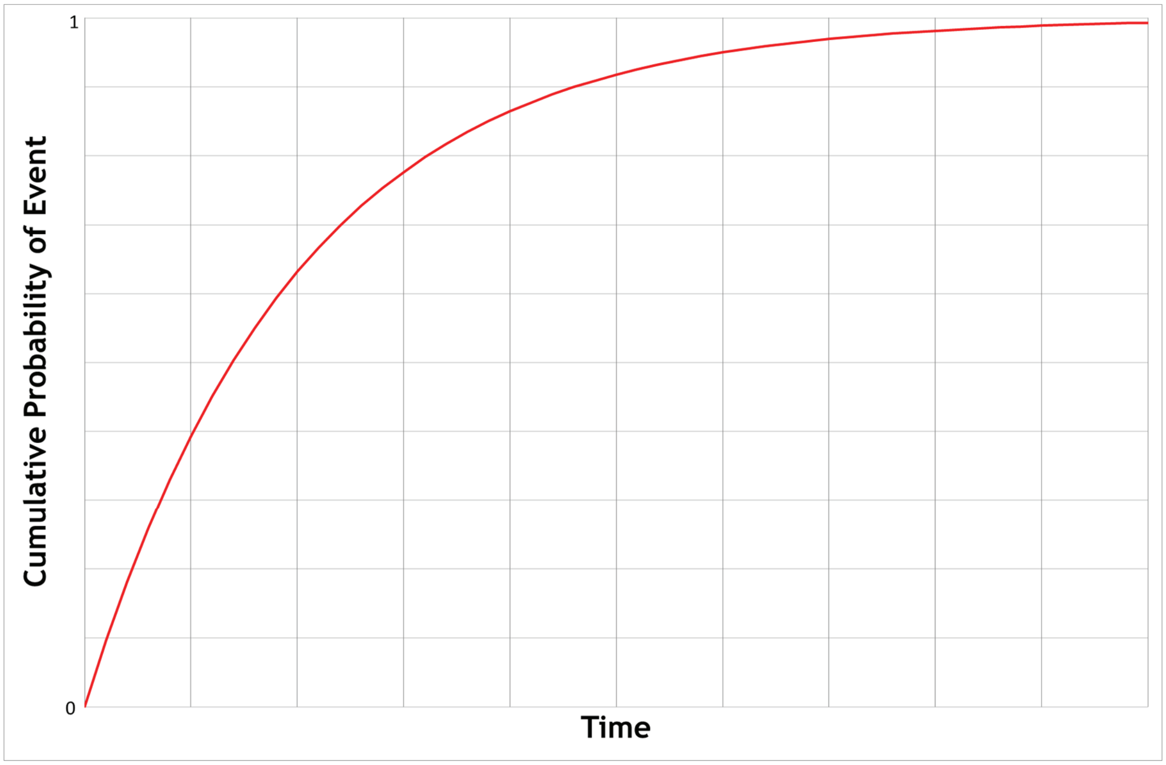

Figure 6. Event occurrence probability (for event-driven threats)

The conditional probability of failure given occurrence of the initiating event is determined in a similar way to the distribution of remaining life for time-dependent failures. Such that the probability of degrading to failure in time T, given that an event has occurred, $P(D)$ is given by:

$$P(D) = \frac{1}{\sigma\sqrt{2\pi}}\int_0^T \frac{P(IF)}{t} e^{\frac{-(\ln(t)-\mu)^2}{2\sigma^2}} dt \tag{3}$$

Where $P(IF)$ is the probability that inspection at time T would be too late to prevent failure:

$$P(IF) = \begin{matrix} 1 & if\ t \le t_a \\ \frac{T-(t-t_a)}{T} & if\ T > (t - t_a) \\ 0 & if\ T \le (t - t_a) \end{matrix} \tag{4}$$

Where t_a is the action time. This represents an additional time period included in the calculation to allow for analysis of inspection results and any required remediation in the event that damage is reported.

In the SSQ assessment of event-driven threats, the event conditional remaining life is selected based on historical failure data, subject matter experts or calculated using engineering models. There is assumed to be high uncertainty in the assessment of remaining life due to deterioration after an initiating event. This is because there is uncertainty over the nature and relative severity of the event as well as the inherent uncertainty in the remaining life prediction.

If more detailed information is available from which to derive threat specific remaining life distributions, then DSQ or DFQ assessments of event-driven threats can be performed.

Example remnant life distributions, assuming best estimates of remaining lives from 5-75 years are shown in Figure 7 and Figure 8.

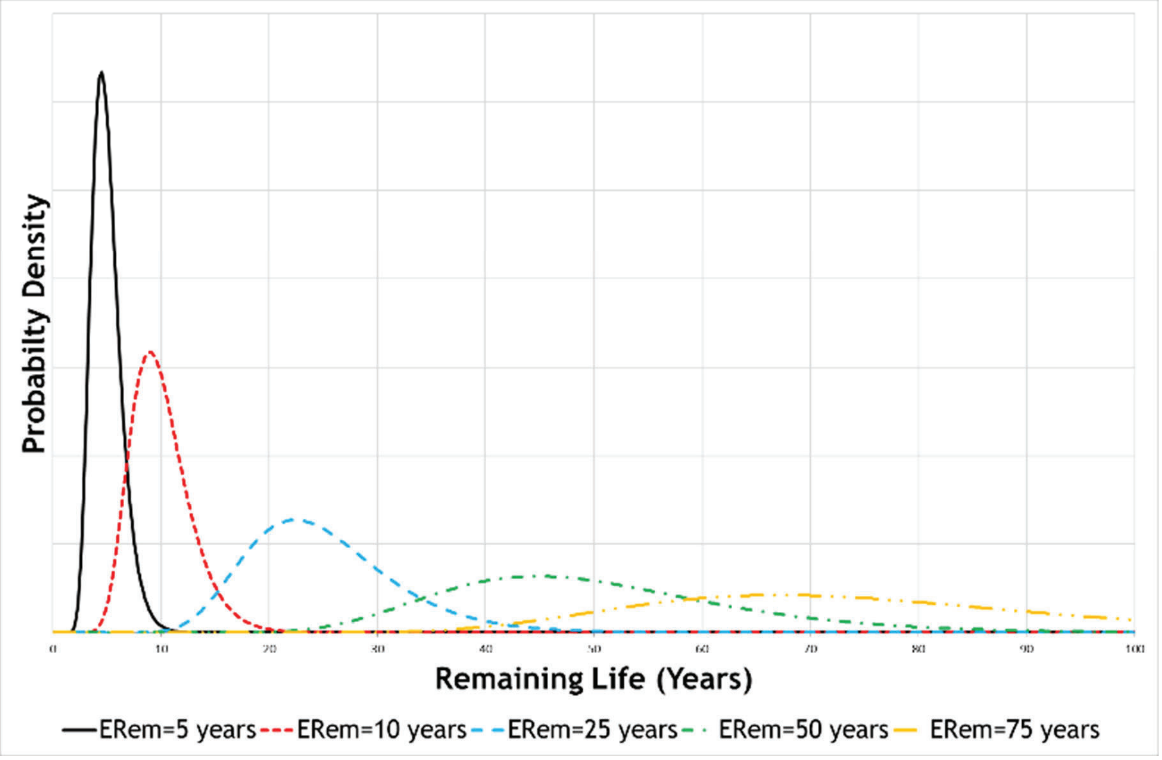

Figure 7. Probability of failure given an initiating event (for event driven threats)

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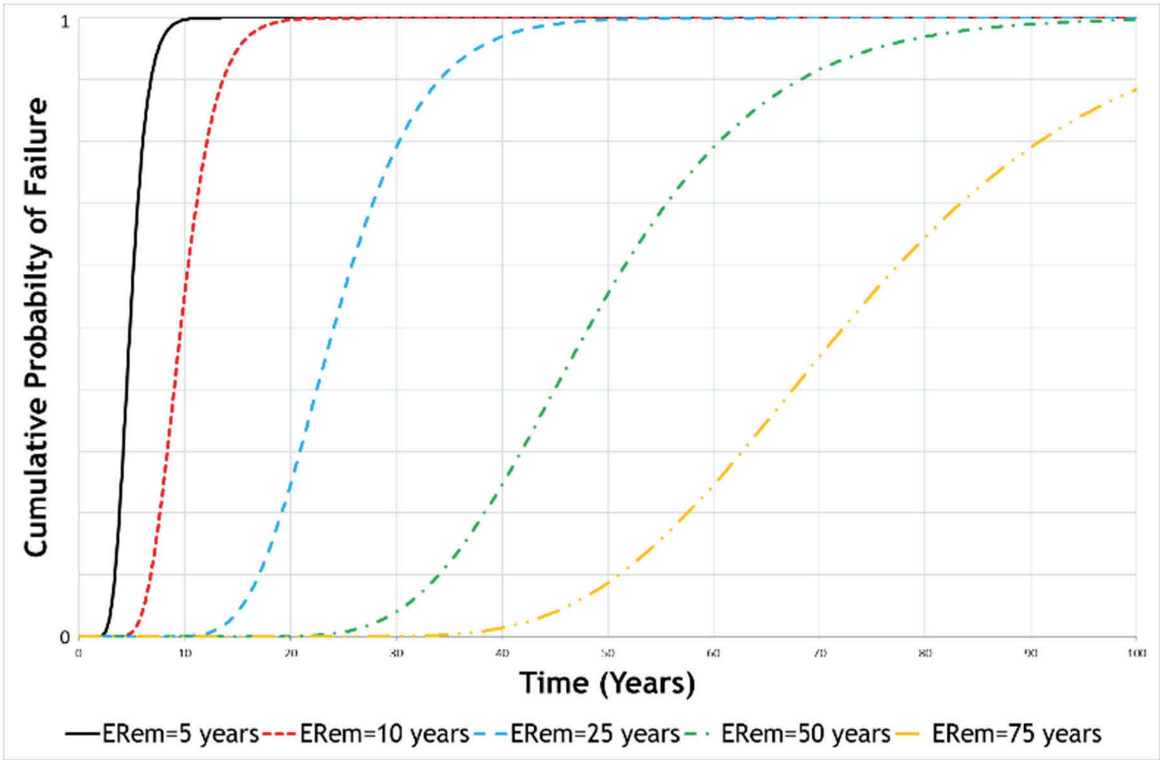

Figure 8. Cumulative probability of failure given an initiating event (for event-driven threats)

The overall probability of failure with time for event-driven threats is then found as the product of the event occurrence probability and the conditional probability of failure given the event:

$$P_{fail_{ev}} = \sum_{n=1}^{\infty} P(D) \frac{(\lambda T)^n}{n!} e^{-\lambda T} \qquad (5)$$

Where the event occurrence probability in Equation 5 represents the probability that n events occur in a time period, described using a homogeneous Poisson point process. In general, the probability that multiple events occur in a time period will have a negligible effect on the probability of failure, where $n = 1$ will dominate the result. However, the chance that multiple events will occur will be greater for higher event occurrence rates and longer time intervals. For these cases, multiple events may be credible.

The overall probability of failure curve for event-driven threats is presented in Figure 9.

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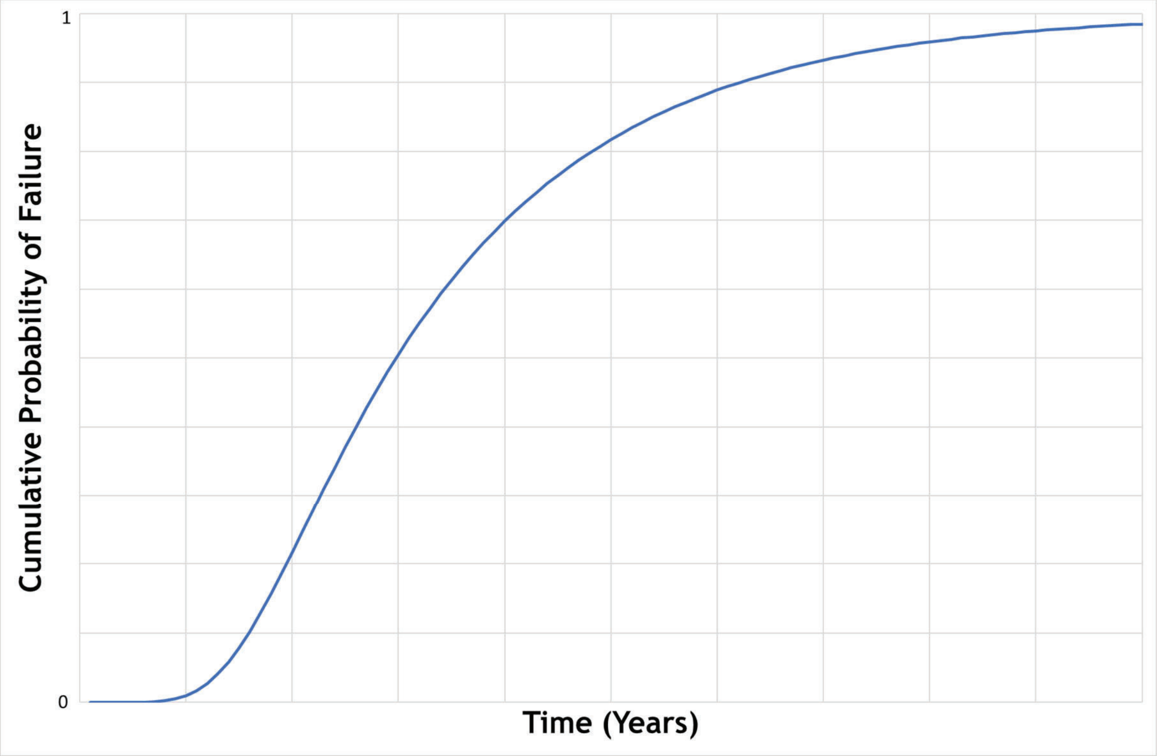

Figure 9. Failure probability over time for event-driven threats

Assessment of Consequences

Risk is a function of probability and consequence, where higher risk results from a combination of both high probability and consequences of an event. Given this, the failure consequences of a loss of containment event can be used to define a tolerable failure probability at a limiting, acceptable level of risk.

This methodology assesses failure consequences using generic failure consequence ranks. These ranks represent tolerable failure limits, defined in orders of magnitude. See Table 1 for an example. Note that industry guidance for tolerable failure probability limits are broadly consistent, but are often asset specific, see for example [9], [10], [11], [12], [13], [14].

Consequence Rank	Tolerable Failure Probability Limit
5	$<10^{-5}$
4	$<10^{-4}$
3	$<10^{-3}$
2	$<10^{-2}$
1	$<10^{-1}$

Table 1. Example tolerable failure probability limits

Typically, operators will already have qualitative consequence rank definitions, as part of their corporate management strategy, for safety, environmental and business consequence fields. Safety

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and environmental consequence rank definitions (and tolerable failure probability limits) will be in line with regulatory requirements and are broadly similar between operators. Whereas business rank definitions will be operator specific. Often, the defined consequence ranks are presented against defined probability ranks and shown on a risk matrix.

Inspection Scheduling and Risk Assessment

Inspection reduces uncertainty in assessment of the integrity of a pipeline (which is modelled using the distributions of failure probability for each threat with time, as described earlier). The consequences define the tolerable failure probability limit and hence the time at which a given failure distribution curve passes this limit. This is illustrated in Figure 10. Note that an additional allowance is included for the time required to review the results of an inspection as well as to plan and execute any required interventions. This allowance (the action time) typically ranges between 6 months for above ground onshore pipeline sections and 2 years for subsea sections, where intervention may require significant levels of planning.

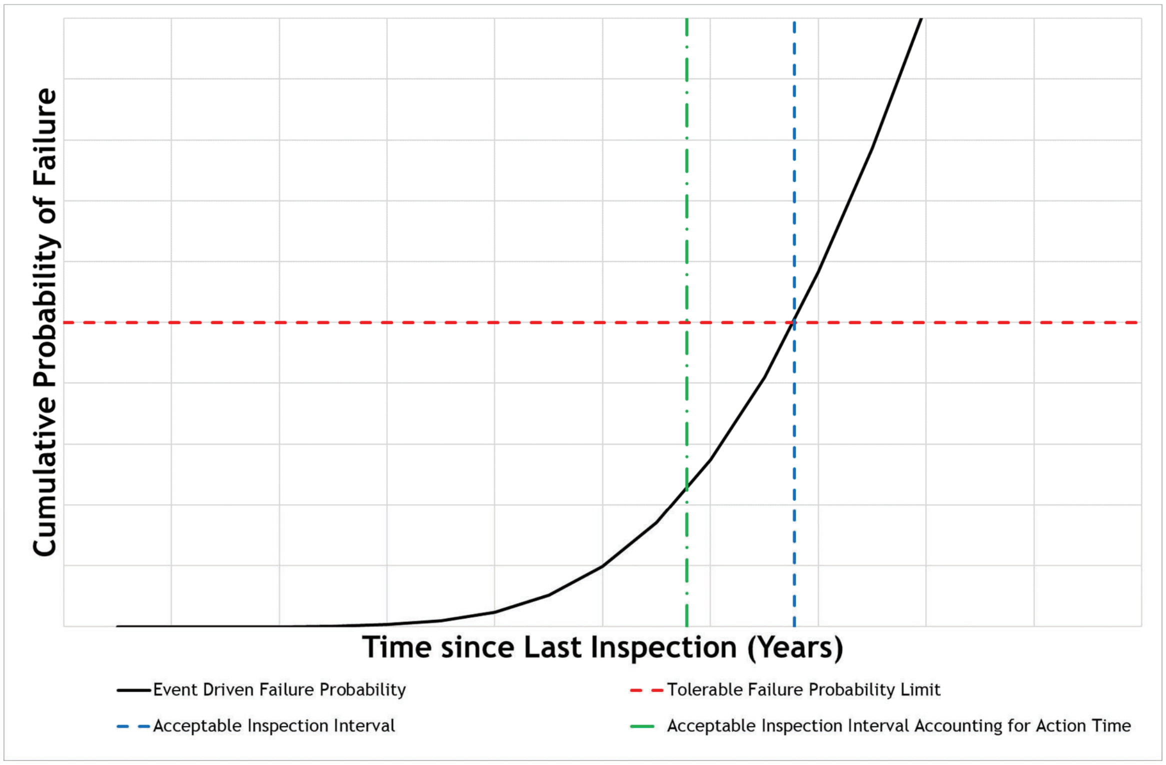

Figure 10. Inspection interval based on failure probability

For an event-driven threat, inspection will identify whether damage has occurred and if damage has occurred, engineering analysis of the data can indicate whether the condition will degrade. If any damage has been identified then it can be assessed and repaired, as required. Whether or not damage is present, after the inspection is completed the probability of failure will therefore reset the failure distribution curve to zero. This is illustrated in Figure 11, for a constant event occurrence rate.

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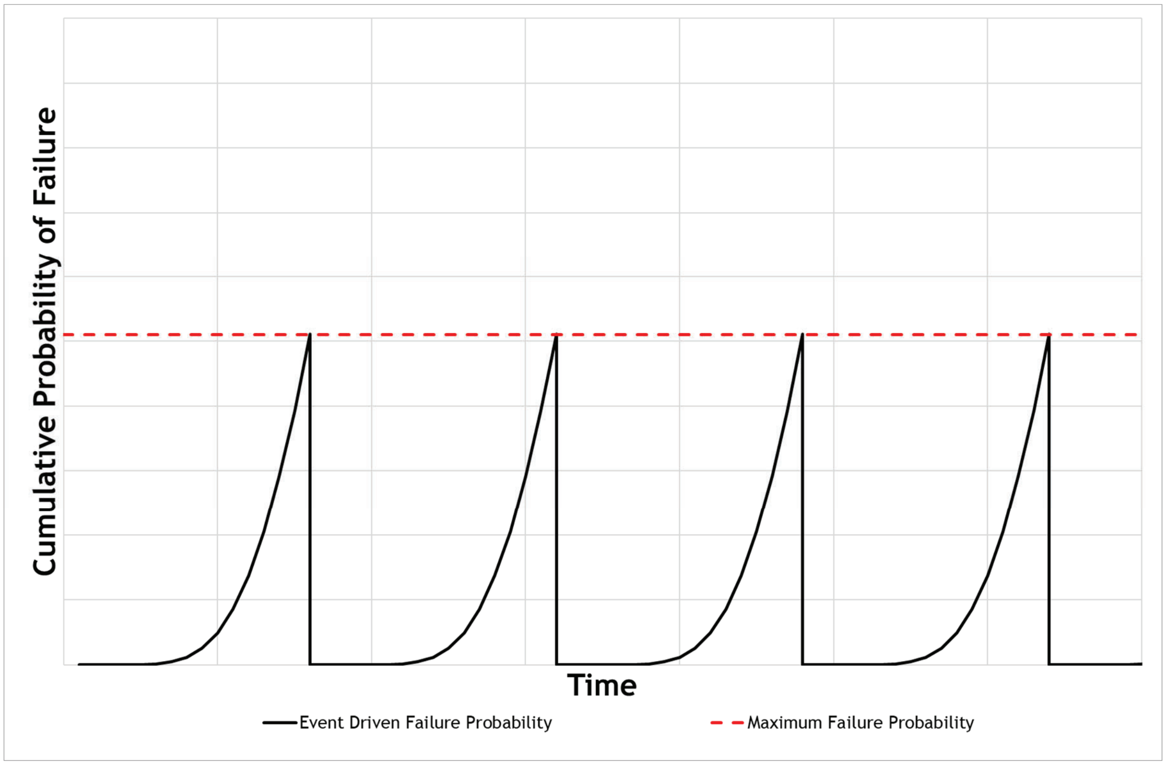

Figure 11. Event-driven threat – effect of inspection on failure probability

For a time-dependent hazard, an inspection reduces uncertainty in the level of deterioration. Immediately after the inspection, the failure probability can therefore also be reset to zero, and the failure probability curve can be reassessed. However, where deterioration due to the time-dependent hazard is on-going, the failure probability curve will become progressively steeper after each inspection, and failure may eventually be expected unless remedial action is taken. This is illustrated in Figure 12.

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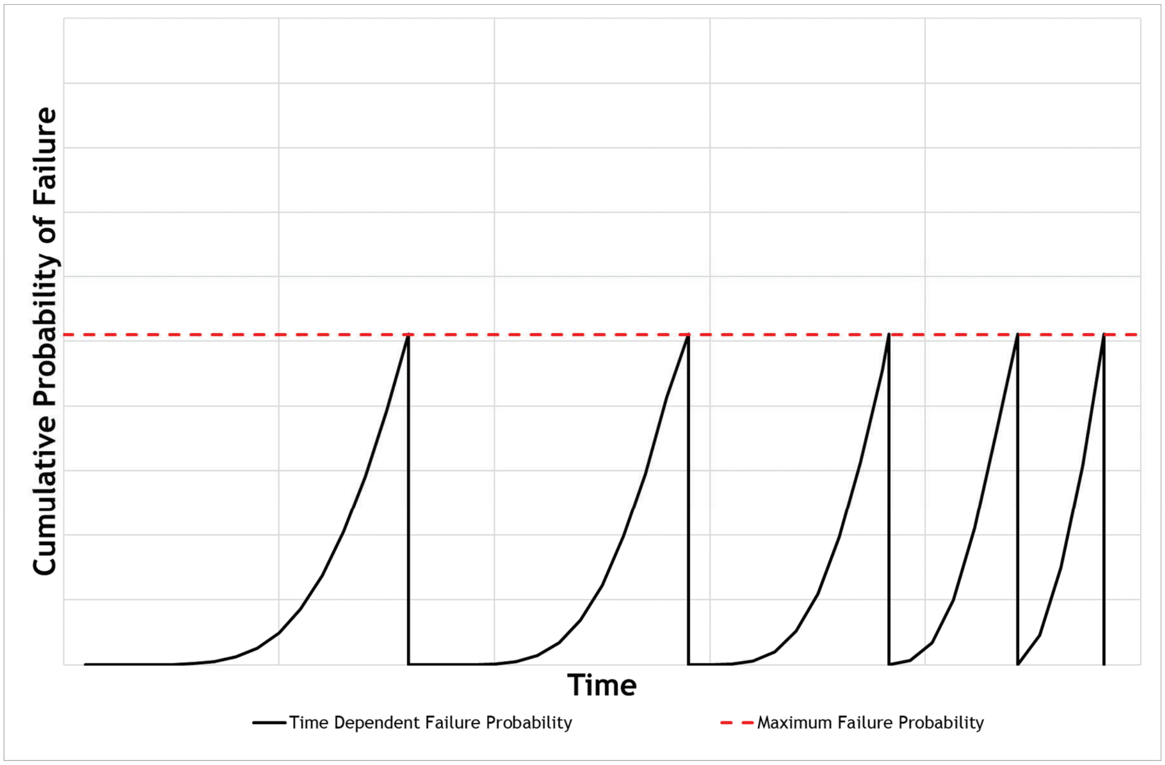


Figure 12. Time-dependent threat – effect of inspection on failure probability

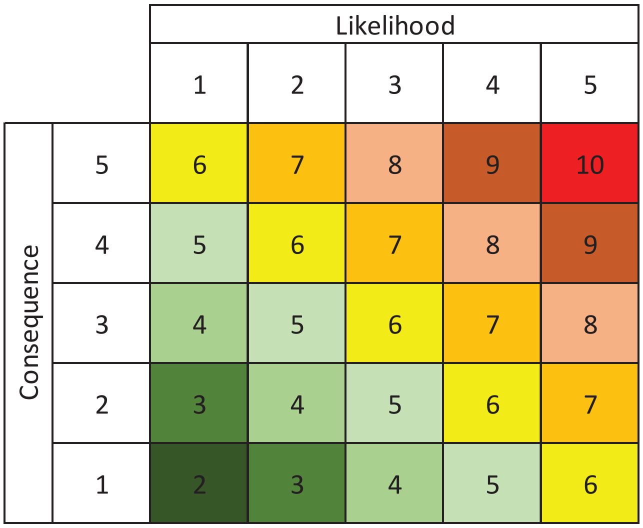
Risk Matrix

As discussed, failure probabilities and consequences are often represented as qualitative ranks. The presented RBI methodology can be used to calculate the failure probability of a threat at any point in time. These calculated failure probabilities can be aligned to ranks which represent orders of magnitude. For example see Table 2.

Probability Rank	Failure Probability
1	$<10^{-5}$
2	$10^{-5} \leq P < 10^{-4}$
3	$10^{-4} \leq P < 10^{-3}$
4	$10^{-3} \leq P < 10^{-2}$
5	$10^{-2} \leq P < 10^{-1}$

Table 2. Example probability of failure ranks

Combining the probability of failure order of magnitude ranks with those defined for consequences (see Table 1), the risk levels can be presented on a risk matrix, where risk is the product of consequence and probability [3], [15]. Given that the ranks represent orders of magnitude, the qualitative rank effectively represents power index of that order of magnitude. Therefore, the qualitative risk rank is represented by a summation of the probability and consequence rank. For example, a probability rank of 2 is a factor of 10^2 greater than a relative reference at 1, whilst a probability rank at 4 is 10^4 times bigger than the same reference. Similarly, a consequence rank of 3 is 10^3 times bigger than a reference consequence level, whilst a rank of 1 represents a factor of 10^1 on the same reference. For risk as a product of probability and consequence, P2 x C3 = 10^2 x 10^3 = 10^5 and P4 x C1 = 10^4 x 10^1 = 10^5. Both represent the same order of magnitude risk, which can be interpreted as a qualitative risk rank of 5. See the example risk matrix in Figure 13 where the order of magnitude risk ranks are shown for each position on the matrix. The constant levels of risk lie on the diagonals as indicated by the colour-coding on the matrix.



		Likelihood				
		1	2	3	4	5
Consequence	5	6	7	8	9	10
	4	5	6	7	8	9
	3	4	5	6	7	8
	2	3	4	5	6	7
	1	2	3	4	5	6

Figure 13. Example risk matrix

Operators will already have pre-existing risk matrices and consequence/probability of failure rank definitions, which can be aligned with the examples described above.

Discussion

The main advantage of using the semi-quantitative RBI approach described in this paper over a fully qualitative methodology is the greater understanding of the link between probability of failure and risk with inspection. This is discussed further in the following sections.

Inspection Schedule Optimisation

Using the approach described in this paper, operators will be able to see a clear link between the change in failure probability and risk associated with changing inspection intervals. More frequent inspection will reduce the maximum failure probability and less frequent inspection will increase it. For example, see the failure probability distribution presented in Figure 14.

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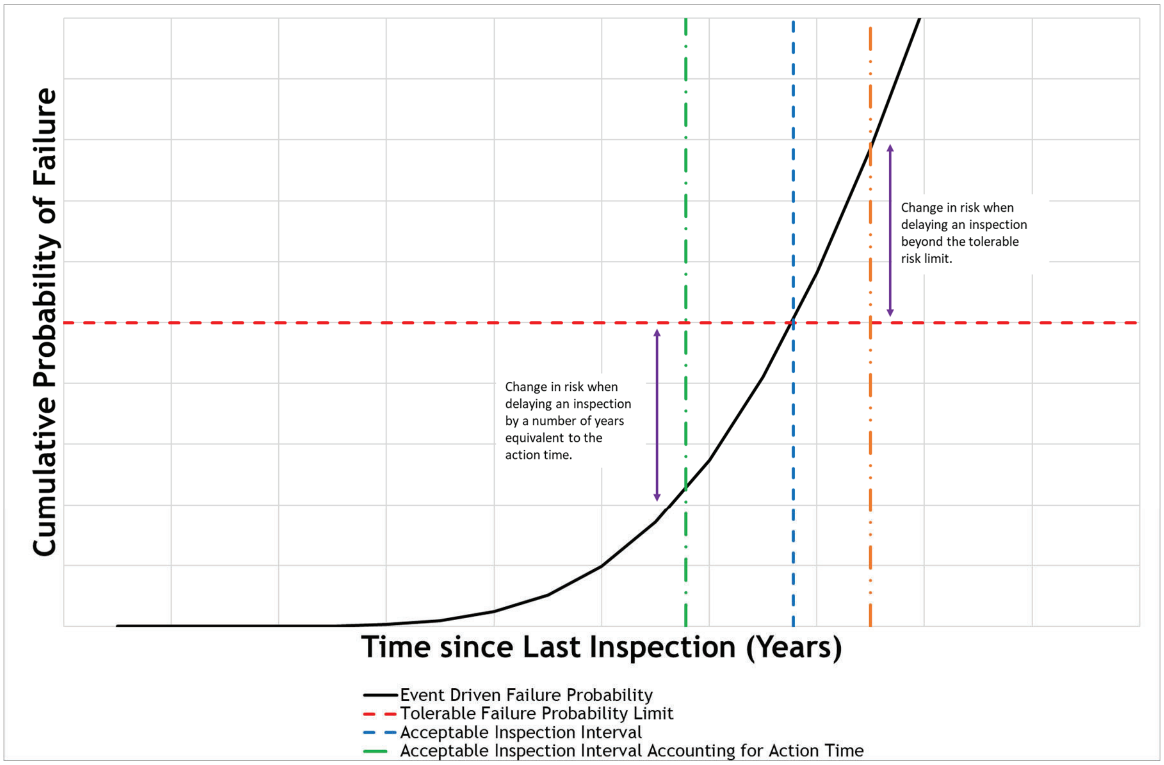

Figure 14. Example cumulative failure probability distribution

The green line represents the RBI-scheduled inspection date, including action time. As described previously, this action time is included to allow for analysis of inspection results and to perform any repairs, if required. Therefore, the failure probability at this time is below the tolerable limit but will increase to the tolerable limit as the action time is used. This is represented by the blue line on the figure. If inspection is performed after this later date, the failure probability will have increased above the tolerable limits. For example, represented by the orange line on the chart. Using the approach described in this paper, the failure probability at any time along the curve presented in Figure 14, can be calculated. This provides a direct link between the inspection interval and risk, allowing the operator to fully understand the impact on risk from delaying or performing more frequent inspection. For this example, the operator could justify a deferral of inspection up to the blue line (as long as they could manage the reduced action time) but delay past the blue line would result in the assessed risk being above the tolerable limit.

Understanding the changes in failure probability with differing inspection intervals can be useful for inspection schedule optimisation, i.e. the alignment of inspection intervals between sections and pipelines. For example, Figure 15 presents failure probability curves for two pipelines. As shown, the inspection date for pipeline 1 could be delayed and aligned with the inspection date for pipeline 2. This results in an increased risk for pipeline 1, however, if the delayed inspection is within the action time for the pipeline, risks are still within acceptable limits but the operator needs to be prepared to act quickly on the results of the inspection, if required. Also note that inspection can, potentially, be delayed beyond the acceptable limit if the most significant failure consequences are business/financial. In this case the operator can chose to accept a higher risk for a more optimised inspection schedule for a group of assets. This choice can be subjective or cost benefit analysis can be used to fully implement an optimised inspection plan for the operator's assets.

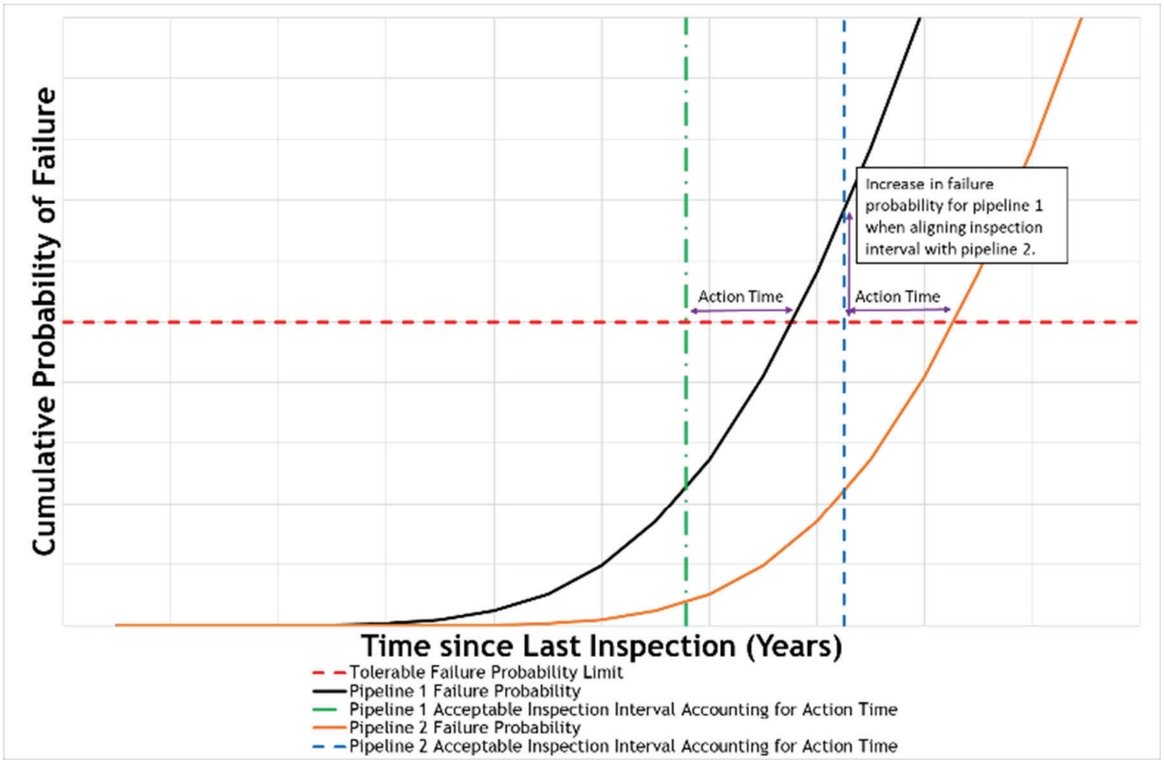

Figure 15. Comparative failure probability curves for two pipelines

As discussed, the methodology presented here allows for a significant level of flexibility and understanding of risk when managing the inspection schedule of pipelines. In contrast, a fully qualitative methodology is more subjective, assigning frequent prescriptive inspection intervals to high risk lines. There is a limited link between the risk and the assigned inspection interval and the impact on risk of less or more frequent inspections is largely unknown. There is therefore no clear rationale for making decisions about optimising or deferring inspections.

Effect of Uncertainty on Inspection Intervals

For any threat, the more data that is available to complete an assessment, the less uncertainty there is in that assessment. For example, in general there is less uncertainty in an assessment of internal corrosion on a line that has recently been subject to ILI compared to an unpiggable pipeline. The uncertainty in these assessments on the failure probability is represented by the standard deviation of the distribution (see Figure 4), where higher uncertainty results in a broader distribution. Figure 16 compares failure probability curves with high and low uncertainty.

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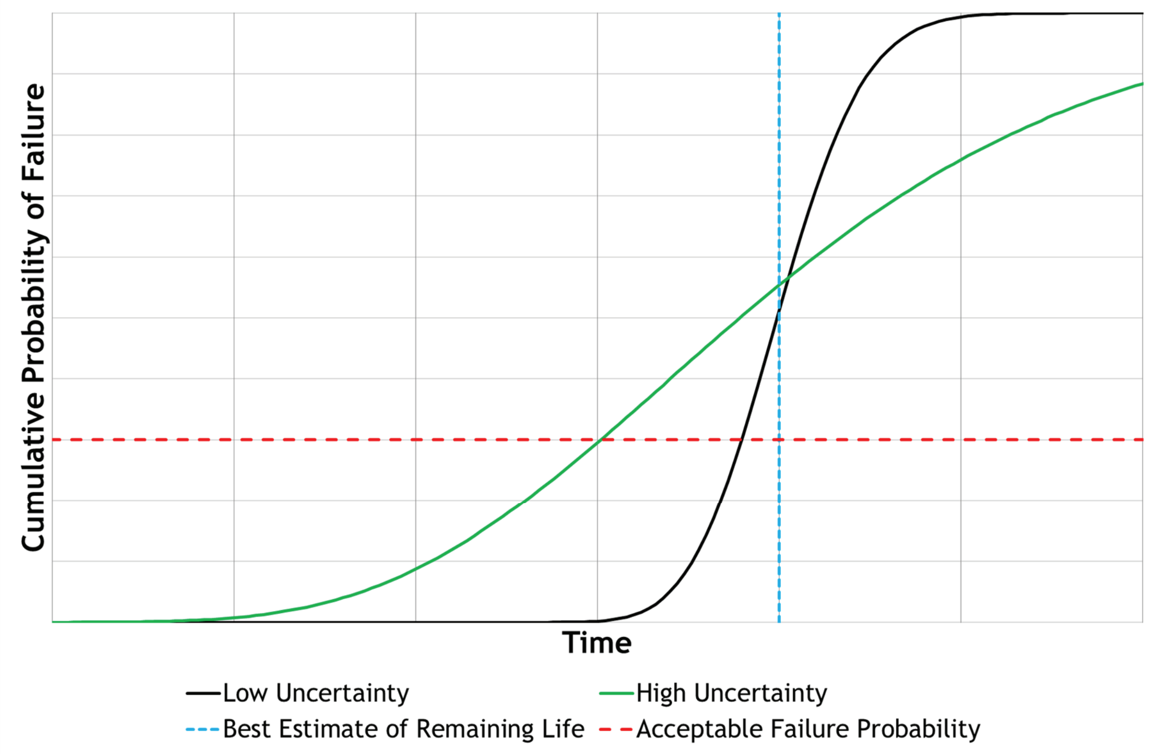

Figure 16. Comparative failure probability curves for high and low uncertainty

As shown, assessments with high uncertainty would recommend inspection is performed sooner to maintain acceptable risks than those with low uncertainty, because the failure probability limit is predicted to be reached more quickly. However, the curve for high uncertainty is shallower than that for low uncertainty. Therefore, the high uncertainty assessment is more tolerant to delayed inspections, i.e. the risk increases more slowly with time.

To demonstrate this further, consider a comparison of two time-dependent assessments, both using a calculated remaining life of 15 years. The first assessment assigns low uncertainty to this remaining life and the second assigns high uncertainty. This would result in two failure probability distribution curves similar to those shown in Figure 16. Assuming a consequence rank of 4 for both assessments, inspection intervals of 13 and 6 years would be predicted for the low and high uncertainty assessments, respectively. Note that, for the purposes of this example, no account of action time has been taken here and the calculated risk at inspection would be equivalent to the tolerable risk limit. In this case, this is equal to a probability rank of 2 (see Table 2). Delaying inspection by one year would increase the probability of failure. This increase is greater for the low uncertainty assessment resulting in a probability of failure rank of 4. For the high uncertainty assessment, the probability of failure rank would increase to 3. This is illustrated on the risk matrix in Figure 17.

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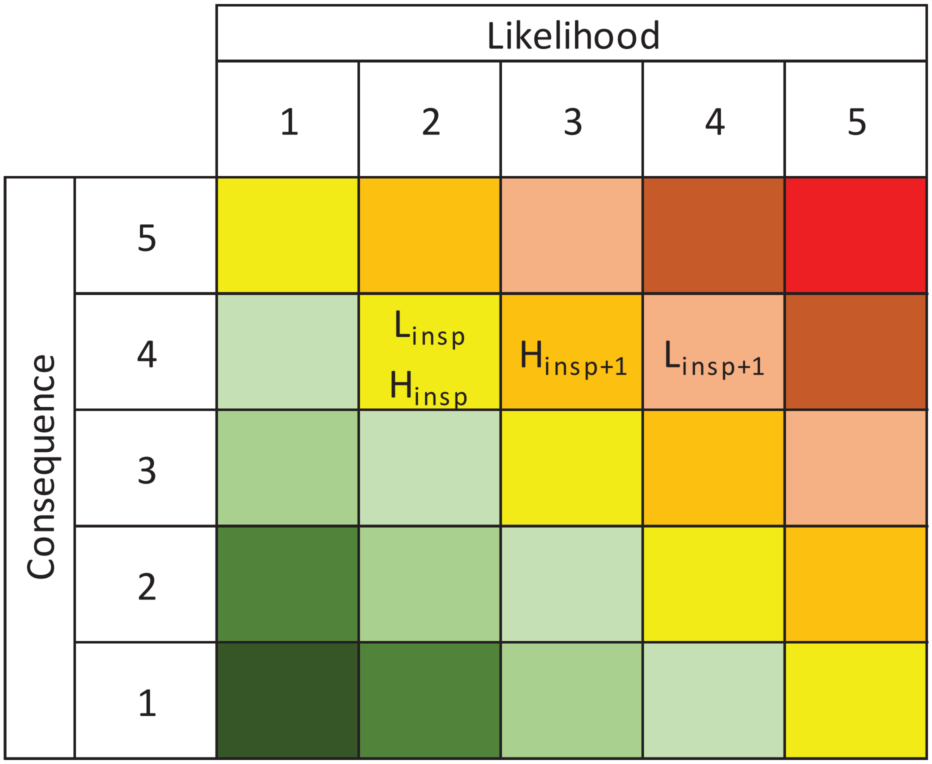

Figure 17. Comparison of change in risk due to delayed inspection for high and low uncertainty

Note that many assessments with greater uncertainty are associated with limited inspection data. For example, assessment of internal corrosion of unpiggable pipelines. In these cases, the operator would like to understand the risk associated with these lines up to the cessation of production date. Typically, there will be some data from corrosion control measures and local inspection, however, there is still significant uncertainty in the assessment without ILI data. The RBI assessment can indicate whether risk is predicted to remain tolerable for the required remaining life. If the risk limit is predicted to be exceeded, then the RBI also provides a timescale for reducing uncertainty in the integrity of the line. For example, such a reduction in uncertainty may be achieved by further, detailed assessment (DFQ), possibly combined with a program of local inspection, see [16] [17]. Alternatively, the operator may have to implement tighter operational corrosion control and monitoring, or potentially consider a downrating or early retirement of the line.

Conclusion

This paper presents and discusses the key elements for practical application of an effective RBI process. A structured RBI approach ensures that credible threats are identified and that risks are understood. The major advantage of the RBI approach presented is that it provides a direct link between the inspection interval and the risk associated with a loss of containment failure from a pipeline. The suggested RBI approach also accounts explicitly for the time required to take action following an inspection, allowing for assessment of results and remediation, as necessary.

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The paper discusses that the presented methodology allows for inspection schedule optimisation, aligning inspection intervals between pipeline assets, by understanding the risk associated with more or less frequent inspection of each asset. This allows the campaign-based nature of offshore and subsea inspections to be accommodated. In addition, the methodology can be used to identify threats where inspection may not be practicable or adequate to control risk. The paper discusses that in these cases managing uncertainty may be critical to allow for continued operation over the required lifetime of an asset.

The results of the RBI assessment can be aligned with and presented on corporate risk matrices, to provide a simple representation of the risk in the pipeline system and to communicate this to management.

References

1 The Health and Safety Executive. A Guide to the Pipeline Safety Regulations 1996, 2012.

2 BSI Standards Publication. Pipeline Systems. Part 4. Steel pipelines on land and subsea pipeline - Code of practice for integrity management, 2012.

3 Det Norske Veritas. Integrity Management of Submarine Pipeline Systems DNVGL-RP-F116, May 2017.

4 API Standard 1160 First Edition. Managing System Integrity for Hazardous Liquid Pipelines, November 2001.

5 American Society of Mechanical Engineers, ASME B31.8S-2014: Managing System Integrity of Gas Pipelines, ASME Code for Pressure Piping B31, Supplement to ASME B31.8, 2014.

6 Energy Institute, Guidelines for The Management of Integrity of Subsea Facilities, April 2009.

7 O'Connor, P.D.T.; *Practical Reliability Engineering*, Wiley, Third Edition 1991.

8 Palmer-Jones, R. Turner, S. and Hopkins, P.; A New Approach to Risk-based Inspection, IPC2006-10535, 6th International Pipeline Conference (IPC), Calgary, Canada, September 2006.

9 American Society of Mechanical Engineers, *Criteria for Reliability-Based Design and Assessment for ASME B31.8 Code STP-PT-048*, 2012.

10 Nessim, M., Zhou, Wenxing., Zhou, J., Rothwell, B., McLamb, M., Target Reliability Levels for Design and Assessment of Onshore Natural Gas Pipelines, IPC04-0321, International Pipeline Conference (IPC), Calgary, Canada, October 2004.

11 Det Norske Veritas. Submarine Pipeline Systems Standard DNVGL-ST-F101, October 2017.

12 Sotberg, T., Moan, T., Bruschi, R., Jiao G., Mork, K.J.;. The Superb Project: Recommended Target Safety Levels for Limit State Based Design of Offshore Pipelines, OMAE 1997.

13 BSI Standards Publication. Pipeline systems. Part 3: Steel pipelines on land – guide to application of pipeline risk assessment to proposed developments in the vicinty of major accident hazard pipelines containing flammables. Supplement to PD 8010-1:2004. PD 8010-3, 2009+A1:2013.

14 BSI Standards Publication. Petroleum and natural gas industries - Pipeline transportation systems - Reliability based limit state methods. EN ISO 16708:2006, April 2006.

15 API Recommended Practice 580 First Edition. Risk-based Inspection, May 2002.

https://doi.org/10.52202/078572-0008

16 Turner, S. and Gray, F.; Interpretation of Local Inspection Date for Unpiggable Pipeline - Understanding the Meaning of Nothing. Pipeline Pigging and Integrity Management Conference, February 2020.

17 Taylor, K., Turner, S., Goodfellow, G.; A Case Study on The Application of Structural Reliability Analysis to Assess Integrity for Internal Corrosion of Unpiggable Pipelines, IPC2016-64341, 11th International Pipeline Conference (IPC), Calgary, Canada, September 2016.

https://doi.org/10.52202/078572-0008

https://doi.org/10.52202/078572-0008