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A NEW APPROACH TO RISK BASED PIPELINE INTEGRITY MANAGEMENT

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ABSTRACT

The use of risk based integrity management systems for pipelines is increasing in popularity, and now changes in legislation in the USA require operators to use risk assessment in high consequence areas. The methodologies used range from point scoring qualitative schemes to detailed quantified systems requiring structural reliability analysis, release modelling and post incident behavioural modelling.

In the UK a risk based approach to pipeline integrity management has been included in legislation since 1996, and is widely used. Experience with implementing systems and applying them to onshore and offshore pipeline systems has led to the following conclusions:

- Point scoring systems cannot replace expert knowledge
- Point scoring systems always need to be modified to suit a particular system and need updating as parameters change.
- Detailed automated systems generate a huge number of sections and range of risks. this can be confusing and cannot easily be accounted for in inspection planning.
- A clear link between risks and inspection or monitoring is needed.
- Simplicity and flexibility are critical.

This paper describes a radical new approach to using risk assessment for pipeline integrity management. This new approach focuses on identifying whether hazards are time dependant (e.g. corrosion) or random (e.g. third party damage), and then either estimating a time to failure or a probability of occurrence. These estimates can be based on experience, history, or specific detailed studies. The effect of inspection and monitoring is also considered. This methodology allows the user to manage the risks associated with their pipeline in a way that is flexible, rational, consistent, and can be readily understood by others. It also allows the reasons for decisions regarding inspections to be recorded, and new users to quickly learn the key safety issues for the pipeline.

KEYWORDS: *Pipeline, risk assessment, integrity management, inspection.*

1. INTRODUCTION

Pipeline integrity management requires the consideration of many factors that may cause the degradation of the pipeline, for example, external interference damage, external corrosion, environmental cracking, fatigue loading. Action must be taken to prevent or limit degradation, and optimise inspection and maintenance. In doing this it is important to consider the consequences of a failure.

Integrity management involves consideration of pipeline design, operation, leak detection, emergency response, training, etc.. The approach to integrity management that considers both the probability or likelihood of failure and the consequences of a failure is known risk based. When the focus of an integrity management system is inspection it is known as 'risk-based inspection' (RBI).

Recent changes in legislation in the USA[1] have led to an increased use of risk-based integrity management for pipelines. In the UK a risk based approach to pipeline integrity management has been included in legislation and widely applied since 1996[2].

Risk based integrity management includes the following basic elements:

- Data collection and integration – to facilitate a risk assessment.

- Hazard identification – hazards that may result in a rupture, leak or loss of serviceability are identified. Hazards typically include: corrosion; third party interference; ground movement; manufacturing defects; mal-operation; etc..
- Consequence evaluation – the consequences of a rupture, leak or loss of serviceability are evaluated. Consequences may include loss of life or injury; environmental damage; loss of revenue; damage to property; damage to reputation; etc..
- Section selection – the pipeline system is divided into sections where hazards, or consequences, are different from the hazards or consequences associated with other sections. For example it is common to evaluate onshore and offshore pipelines separately.
- Risk analysis – the probability of failure due to a hazard and the consequences of that failure are evaluated and multiplied together give a measure of the risk for each hazard. The risks for each hazard may then be combined to give an overall estimate of the risk level for each section.
- Risk assessment – the calculated risk is compared against an acceptable or target risk level or benchmark value to determine the high risk sections/pipelines/hazards.
- Mitigation – a plan is made to control the risks identified. This is a critical stage and must be linked clearly to the relevant hazards.
- Review and update – the process is continuous and the results of inspection and maintenance activities must be for a repeat analysis.

The risk management process is shown graphically in Figure 1.

There are a variety of different systems in use for conducting risk assessments on pipelines. The systems that are used can be placed into 3 generic methodologies:

1. Ranking
2. Point scoring
3. Quantified

In this paper these three methodologies are evaluated, and a logical methodology that can utilise the best of all three approaches is developed.

2. RANKING SYSTEMS

Risk ranking systems are simple and flexible. Credible hazards for a pipeline are identified by an expert, or team of experts. The relative probability of failure for each hazard is ranked, typically as high medium or low. For example, the probability of failure due to internal corrosion for a flow line carrying oil, with a high water cut, at high temperature, and with no corrosion inhibitor would be ranked as high compared with the probability for a gas transmission pipeline, carrying sales quality gas, which would be ranked as low. The consequences of a failure from each hazard for the pipeline are also qualitatively ranked. For example the consequences of failure of a water injection pipeline would be ranked as low compared with the consequences of failure of a gas pipeline in a densely-populated area.

The advantages of ranking systems are:

1. They are relatively easy and quick to implement and understand.
2. They are flexible and can take account of, the results of detailed studies, unusual hazards, and changes in industry practice.
3. They ensure input from experts.
4. They can be applied even where there is limited data.

Disadvantages of ranking systems include:

1. It is difficult to get consistent risk levels for different hazards; consequences; years; assessors; pipeline sections.
2. Significant issues can be missed if expert assistance is not sought.
3. Links to mitigation (e.g. inspection frequencies) are subjective.

3. POINT SCORING RISK ASSESSMENT

Point scoring systems have been developed by a number of industry experts. These involve assigning points relating to different aspects of pipeline design, operation, history and environment.

So for example, points would be assigned for good quality coating, benign ground conditions, a well-maintained cathodic protection system, etc. the accumulated score would indicate a low probability of failure due to external corrosion. Points are also assigned depending on the consequences of failure. For example points would be assigned for low population density, duplication of supply, low stress operation, well drilled emergency repair, etc.. The accumulated score would indicate low consequences of failure. The probability and consequence scores are multiplied and the resulting product of the points gives a measure of the risk.

The advantages of point scoring systems include:

1. They provide good consistency from one pipeline section to the next, and from year to year.
2. They provide good guidance on common pipeline issues.
3. They can be automated, so that all that is needed is the input of pipeline data.

4. They are generally accepted in the pipeline industry.

The disadvantages of point scoring systems include:

1. They can need substantial modification for each new application.
2. They can be inflexible and make it difficult to incorporate the findings of specific detailed studies.
3. They require large amounts of information, which may not be available.
4. They attempt to replace experience and expertise which can lead to significant issues being missed.
5. They can require the consideration of some issues that may not be significant for the particular system, thus wasting time and effort.
6. Automated systems that show significant changes along a pipeline can confuse inspection and maintenance planning.

4. QUANTIFIED RISK ASSESSMENT

Quantified risk assessment is a process for calculating absolute risk levels based on predicting failure frequency (failures per km per year), and the consequences of failure (the number of casualties, financial costs of a failure, etc.). Failure frequency may be predicted based on historical data, or structural reliability analysis. The consequences are predicted using fire models, oil dispersion models, loss models etc..

The advantages of these systems include:

1. Consistent comparison of risk levels for different failure modes.
2. The benefits of reducing failure frequency can be quantified.

The disadvantages of this type of system include:

1. 'Acceptable' risk levels and hence 'target' failure probabilities must be agreed.
2. Historical data may be limited and may not apply to particular pipelines
3. Good quality data is required.
4. Specialist software may be needed.
5. Generally not practical for whole pipeline systems.
6. The effects of inspection and maintenance on failure frequency can be difficult to quantify.

5. COMBINATION RISK ASSESSMENT

The three generic approaches outlined above each have advantages and disadvantages. An alternative is to combine the different methods in a rational manner, and ensure that mitigation activities such as inspection are appropriate.

The combined system is a qualitative risk ranking system that provides flexibility and ensures expert input, and which is calibrated against quantified risk levels to provide credibility and consistency. The aim of the combined system is to set inspection intervals that give an acceptable probability of failure.

Any risk management system must consider pipeline design; operation; and inspection and remedial actions, since these are the factors that control risk. The combined system directly links risk mitigation activities to the relevant hazards or consequences.

This combined risk assessment is now illustrated by applying it to two different types of pipeline hazard:

1. Time dependant hazards (e.g. corrosion)
2. Random hazards (e.g. external interference)

6. APPLICATION OF THE NEW APPROACH TO TIME DEPENDENT FAILURE

6.1 Traditional Approach to Inspection

Time dependent failures are where the condition of the pipeline degrades over time. Inspection is used to monitor this degradation. If the condition of the pipeline is known precisely, and if the rate of degradation can be accurately predicted, then it is possible to select an inspection frequency that will always allow timely remedial action to be taken so that all failures can be prevented.

This approach is both simplistic and subjective as there is significant uncertainty about the pipeline condition and degradation rate. In cases where high degradation rates are expected, extremely frequent inspection may be required to prevent failures using this method. Such inspections may not be practical or cost effective. Inspection for time dependent failure modes will always be aimed at monitoring degradation, but the uncertainties mean that some probability of failure must be accepted, and whether or not this is tolerable should depend on the risk presented by the hazard.

6.2 Traditional Approach to Defining Inspection Frequency

Inspections aimed at monitoring degradation can be used to prevent failures due to time dependent failure modes. Figure 2 illustrates the degradation of pipeline condition over time for a time dependent failure example.

The required inspection interval (T_{insp}) that will allow failures to be avoided is dependent on the time taken to degrade to failure (the remaining life,), and on the time required to take action to prevent failure (the action time, T_a), after the damage has been detected.

The remaining life (T_{rem}) will depend on the degradation rate. For example an onshore pipeline that is 10mm thick subject to external pitting corrosion at a typical rate of 0.1 mm per year will have a remaining life of approximately 100 years.

The action time (T_a) will depend on the hazard, and the pipeline design. For example for internal corrosion of an offshore pipeline the action required to prevent failure might be pipeline replacement, this could take 2 to 3 years, for external corrosion pitting of an onshore pipeline it may be possible to carry out a repair within a few days of detecting the damage.

$T_{insp} = (T_{rem} - T_a)$ **Equation 1**

Note that T_{rem} is the remaining life from the the point at which some degradation of the pipeline can be measured to failure.

This method does not account for the probability that the pipeline starts to degrade. It works on the basis that if degradation should start, then an inspection will always be carried out sometime between the start of degradation and the point at which there is only time T_a left before failure.

However, in reality this method cannot guarantee that all failures are prevented because it does not take any account of the uncertainty associated with the prediction of T_{rem}. A more realistic illustration of the degradation of a Time Dependent failure is shown in Figure 3. This illustrates how T_{rem} might be expected to follow a statistical distribution.

Basing the calculation of T_{insp} on the minimum expected value of T_{rem} should ensure that there are no failures. However, if there is significant uncertainty over the degradation rate this will lead to the minimum value of T_{rem} being extremely small. The calculated required T_{insp} would then also be small, possibly requiring inspection at impractical intervals, with no indication given of the level of risk represented by inspection at a longer interval.

An alternative is to calculate the required value of T_{insp} to give an acceptable probability of failure, given what is known about the likely values of T_{rem}.

6.3 New Approach: Time Dependant Failure

The aim of the method is to maintain an acceptable and consistent probability of failure. The probability of failure depends on the inspection interval. So the method aims to find the inspection interval that gives an acceptable failure probability, and the acceptable failure probability depends on the acceptable risk level, which in turn depends on the consequences of failure.

6.3.1 Calculation of Failure Probability

The probability of failure of a section of pipeline, P_{fail}, due to a particular time dependent failure mode is calculated for any given value of T_{insp} as

$$P_{fail} = \int_{all\,T_{rem}} p(T_{rem}) P_{IF}\, d(T_{rem}) \qquad \textbf{Equation 2}$$

Where

$p(T_{rem})$ is the Probability Density Function (pdf) of T_{rem} (the probability that T_{rem} has any given value), and

P_{IF} is the probability that inspection is too late to allow failure to be prevented, for any given value of T_{rem} and the chosen value of T_{insp}.

Note that P_{fail} is the probability of failure before the next inspection, given that degradation starts before the next inspection. It is therefore a conservative calculation of failure probability given that there is a finite chance that the degradation will not have initiated.

6.3.2 Calculation of Remnant Life Probability

The distribution of T_{rem} must be defined to effectively use this method. In most cases statistical parameters describing the pdf will not be available. A semi-quantitative method is therefore proposed using a Best Estimate value for T_{rem}, and a level of confidence in this Best Estimate by use of a High, Medium or Low confidence rank.

The Best Estimate value is then used to represent the expected value of T_{rem} in a lognormal distribution, and the confidence rank is used to infer the expected value of $\ln(T_{rem})$ and the value of the variance of $\ln(T_{rem})$ as required to define the lognormal distribution. The lognormal distribution has the benefit that the pdf is zero at zero $T_{rem,}$ and the distribution does not include negative values of T_{rem}. This represents the practical case where the time to failure cannot be negative.

In this proposed method, the confidence rank is used to define the confidence that the actual value of T_{rem} is not less than 0.9 times the Best Estimate of T_{rem}. This is illustrated by Figure 4.

Table 6-1 gives the probabilities proposed for the definition of High, Medium and Low confidence, and Figure 5 illustrates the pdfs derived using these confidence ranks. Note that by defining the confidence rank probabilities relative to a proportion of the mean (rather than an absolute value or a difference), the shape and position of the pdfs relative to the origin remain unchanged with changing values of the Best Estimate of T_{rem}.

Confidence Rank	**Probability that actual value of remaining life (T_{rem}) is not less than 0.9 times the Best Estimate of T_{rem}**
High	95%
Medium	75%
Low	60%

Table 6-1 Proposed Definitions for Confidence Ranks

6.3.3 Probability that Inspection is Too Late to Prevent Failure

For each combination of T_{rem} and T_{insp} there is a probability that the inspection will be too late to prevent failure.

One inspection is performed in each time interval of T_{insp}. The condition of the pipeline at the time of inspection depends on when the degradation started relative to the time of

inspection. If the remaining life at the time of the inspection is less than the action time (T_a) then the pipeline may fail before it can be repaired, if the remaining life is greater than the action time (T_a) then failure can be prevented.
The density distribution of the time of inspection relative to the start of degradation takes a rectangular form as shown in Figure 5. Inspection is as likely to be at one time relative to the start of degradation as at another (given that degradation starts).

The probability that inspection is too late to prevent failure, P_{IF}, is then given by the shaded area of the pdf in Figure 6. The calculation of P_{IF} is defined by Equation 3.

$$P_{IF} = 1 \text{ if } T_{rem} \leq T_a$$

$$= \left[\frac{T_{insp} - (T_{rem} - T_a)}{T_{insp}}\right] \text{if } T_{insp} > (T_{rem} - T_a)$$

$$= 0 \text{ if } T_{insp} \leq (T_{rem} - T_a) \qquad \textbf{Equation 3}$$

6.3.4 Calculation of T_{insp} for Target Failure Probabilities

Equation 2 can be used to find the value of T_{insp} required to give a specific failure probability, P_{fail}. This requires an iterative, numerical solution.

For a risk based system, the required values of P_{fail} would be expected to vary with the different consequence ranks. Table 6-2 lists the proposed target failure probabilities (and associated survival probabilities) for five consequence ranks ranging from 1 – low (e.g. no safety implications, low cost) to 5 – high (e.g. significant safety implications). Note that the calculated and target failure probabilities are interpreted as failure probabilities per km.

Consequence Rank, C	Proposed Target Failure Probability per km yr	Proposed Target Survival Probability
1	10.00%	90.00%
2	1.00%	99.00%
3	0.1%	99.90%
4	0.01%	99.99%
5	0.001%	99.999%

Table 6-2 Proposed Target Failure and Survival Probabilities

6.4 Calculated Failure Probability as a Qualitative Probability Rank

The principle of the combined method is to provide a qualitative tool allowing simple comparison between the risks presented by each failure mode, in each pipeline section. Therefore the calculated values of P_{fail} are converted into qualitative probability ranks as defined in Table 6-3.

Probability Rank, P	Proposed Range of Calculated P_{fail}
1	P_{fail} <= 0.1%
2	0.1% < P_{fail} <= 1%
3	1% < P_{fail} <= 10%
4	10% < P_{fail} <= 50%
5	P_{fail} > 50%

Table 6-3Proposed Conversion of Calculated P_{fail} to Probability Ranks

The target failure probabilities listed in Table 6-2 would convert to probability ranks as shown in Table 6-4. This table also shows the calculated qualitative risk rank.

Consequence Rank, C	Proposed Target Failure Probability as Probability Rank, P	Implied Target Risk Rank (C x P)
1	3	3
2	2	4
3	1	3
4	1	4
5	1	5

Table 6-4 Target Probabilities Converted to Probability Rank

6.5 New Approach: Application to Random Failure

Inspections aimed at finding damage, can be used to control the risk due to failure modes initiated by random events that fail with time, but it can do nothing to control the risk due to random events that would result in immediate failure of the pipeline. In these cases, risk can only be reduced by changing the design (for example installing additional pipeline protection), or by operational measures (for example, more patrols).

In the case where the damage does not fail immediately inspection can be used to limit the probability that damage will fail. The probability that damage has occurred increases over time until the pipeline is inspected. Once the pipeline is inspected the condition of the pipeline is revealed and the probability of that hidden damage has occurred is returned to zero, either because it is shown that no damaging event has occurred, or because remedial action is taken to repair the damage; this is illustrated in Figure 7.

A shorter inspection interval will reduce the probability that undetected damage has occurred, as shown in Figure 8.

6.5.1 Failure Criteria

Once a damaging event has occurred, the pipeline may fail due to a degradation of the pipeline condition at the damaged site, by mechanisms such as corrosion or fatigue. Alternatively, subsequent events at the location which has already been damaged (and weakened), may cause failure. In this methodology it is proposed that events are considered coincident if they occur in the same 5 m length of pipeline.

For each pipeline section, the overall probability of failure per km (P_{fail}), due to a particular Randomly Initiated hazard, within the inspection interval T_{insp}, is given by

$$P_{fail} = 1 - (1 - P_5)^{1000/5} \qquad \textbf{Equation 4}$$

Where P_5 the probability of failure within the inspection interval T_{insp} for each 5 m section, given by

$$P_5 = P(1) \times P(D \mid 1) + P(>1) \qquad \textbf{Equation 5}$$

where

P(1) is the probability of one damaging event occurring in 5 m within time T_{insp},

P(D|1) is the probability that the damage degrades to failure within time T_{insp}, given that one damaging event has occurred[1], and

P(>1) is the probability that more than one event occurs in 5 m (i.e. that multiple coincident events occur and the pipeline failures).

6.5.2 Random Event Probability and Incident Rates

The damaging pipeline incidents are modelled as events which occur randomly at a constant average rate. Each event can then be described as a Homogeneous Poisson Process, where *P(n)*, the probability of *n* events occurring in time T_{insp}, in 5 m of pipeline (as used in Equation 3.3) is given by[1,4]

$$P(n) = \frac{(\lambda T_{insp})^n}{n!} \exp(-\lambda T_{insp}) \qquad \textbf{Equation 6}$$

Where λ is the incident rate, which is constant and is expressed as incidents per 5 m per year. λT_{insp} is then the expected number of incidents in time T_{insp} in a 5 m section.

It follows that *P(1)* and *P(>1)* in Equation 5 are given as

[1] Note that *P(1) x P(D|1)* is then the probability that one event occurs and that this event degrades to failure.

$$P(1) = \lambda T_{insp} \exp(-\lambda T_{insp}) \qquad \textbf{Equation 7}$$

$$P(>1) = 1 - (P(1) + P(0)) = 1 - (1 + \lambda T_{insp}) \exp(-\lambda T_{insp}) \qquad \textbf{Equation 8}$$

Calculation of the probability of events occurring in a given time period therefore requires knowledge of the incident rates for each failure mode modelled, in each section of pipeline assessed. To avoid the need for detailed numerical calculation, and to allow a simplified lookup process, a qualitative description of the incident rate from a low incident rate of 1, to a high rate of 5 is used. Table 6-5 gives the proposed rates and as an example an indication of typical pipeline incidents in the UK North Sea to which these relate. Note that it is important to consider that these are the incident rates for events causing damage.

Incident Rate Rank	**Incident Rate (per km year)**	**Examples of Typical North Sea Incident and Location**[5]
1	1.0E-06	Dropped object incidents requiring repair.
2	1.0E-04	Ship impact incidents requiring repair. Trawl interaction incidents requiring repair. Anchor incidents requiring repair.
3	1.0E-03	Incidents requiring repair on risers of diameter less than 10 inches. Incidents requiring repair in subsea well safety zones.
4	1.0E-02	Incidents requiring repair on flexible risers.
5	1.0E-01	No applicable data.

Table 6-5 Incident Rate Rank Definitions

6.5.3 Probability of Degradation of Damage

The probability of damage degrading to failure within time T_{insp}, given that an incident has occurred, *P(D|1),* is calculated using the methodology proposed for Time Dependent failures, as

$$P(D \mid 1) = \int_{all\,T_{rem}} p(T_{rem}) P_{IF} \, d(T_{rem}) \qquad \textbf{Equation 9}$$

where

T_{rem} is the remaining life after the pipeline has been damaged,

$p(T_{rem})$ is the Probability Density Function (pdf) of T_{rem} (the probability that T_{rem} has any given value), and

P_{IF} is the probability that inspection is too late to allow failure to be prevented, for any given value of T_{rem} and the chosen value of T_{insp}.

The probability that at least one out of *n* incidents degrades to failure in time T_{insp}, $P(D|n)$, is then given by

$$P(D \mid n) = 1 - (1 - P(D \mid 1))^n \qquad \textbf{Equation 10}$$

For time dependent failures, a best estimate for remaining life is required, together with a qualitative assessment of the confidence in that estimate. That level of detail is excessive for Randomly Initiated failures. Instead incidents are classified as likely to give damage of High, Medium, or Low severity. These Incident Severity Ranks are used to define the best estimate of T_{rem} which is taken as the mean of a lognormal distribution. The spread of the distribution is defined according to the definition of Medium Confidence in the methodology for Time Dependent failures, where there is a 75% confidence that the actual remaining life after an incident will not be less than 0.9 times the best estimate of remaining life.

The proposed definitions for the best estimate of remaining life for High, Medium, and Low severity incidents are defined in Table 6-6 and the pdfs are illustrated in Figure 9. The severity of an incident will depend on the nature of the incident as well as on the design of the pipeline and the level of protection provided.

Incident Severity Rank	Best Estimate Remaining Life (years)
High	3
Medium	10
Low	50

Table 6-6 Proposed Incident Severity Rank Definition

7. EXAMPLE

As an example, consider the risk associated with failure due to anchor impact on two 18” diameter parallel sub-sea crude oil pipelines, both with a consequence rank of 3 (significant environmental and lost production cost, limited safety issues). The incident rate rank, which is the same for both as they run parallel, is 3 (the pipelines are in an area with significant oilfield development activity). The severity rank for one pipeline is Medium since it is pressure cycled and any damage caused would degrade due to fatigue, and for the second section, which is not cycled, it is Low.

Calculations of the required inspection interval T_{insp} have been performed for each combination of Incident Rate Rank and Incident Severity Rank, for Consequence Rank 3, assuming that coincident events will cause failure. These results are shown in Figure 10. Note that it is assumed that inspections are scheduled on a yearly basis, and the calculated values of T_{insp} have been rounded down to the nearest year.

From Figure 10, the first section would require inspection every 8 years for anchor impact, and the second would require inspection every 40 years.

8. IMPLEMENTATION AND FUTURE DEVELOPMENTS

The methodology described here is still in development. It is being implemented for the operator of a network of onshore and offshore pipelines in the UK. It is expected that fine tuning of the links between qualitative rankings, target probabilities and failure rates will be required to suit different applications. It is also anticipated that the impact of maintenance and monitoring (for example inhibitor injection reliability) could be incorporated, to give a more rounded assessment.

The key issue in risk assessments in any risk-based integrity management system is that the selected or calculated failure probability scores, and failure consequence scores, must be fully justified, and the justification should be recorded to ensure consistency in future updating.

9. CONCLUSIONS

The methodology described here is the result of many years experience in the development and application of risk-based inspection and integrity management systems for pipelines. It attempts to retain the best aspects of flexibility and simplicity that a risk ranking scheme provides, while providing a much higher level of consistency, and clear justifiable links to inspection frequency and mitigation actions.

9.1 Acknowledgements

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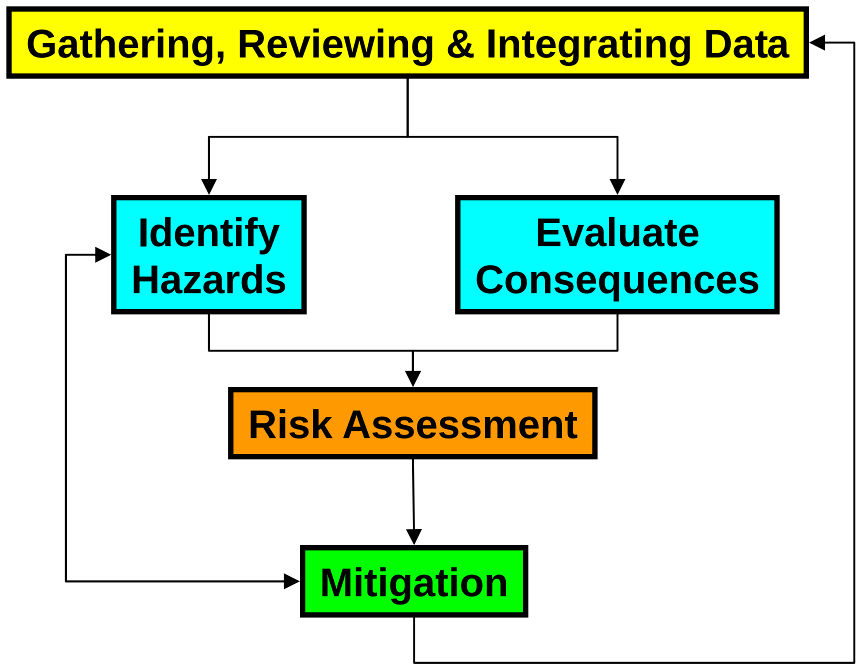

Figure 1 The risk management process

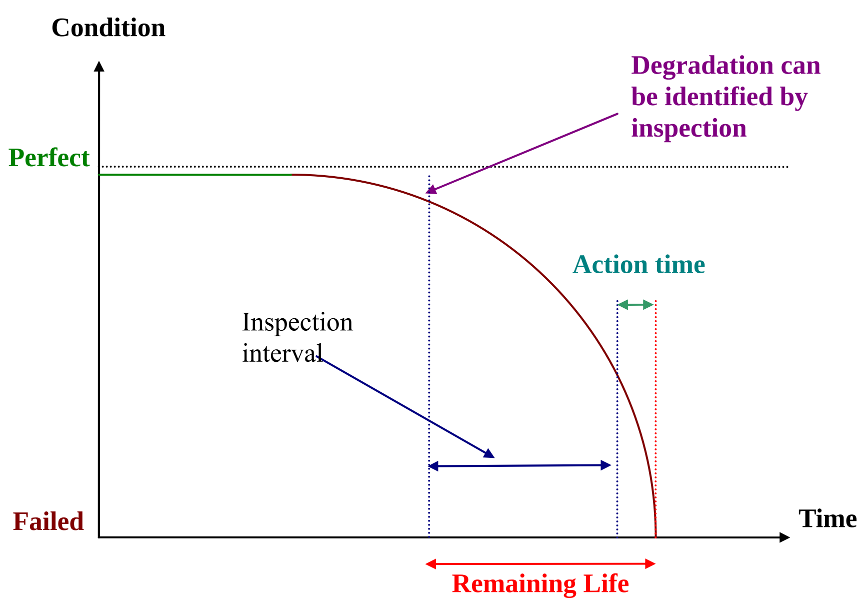

Figure 2 Prevention of time dependent failures by inspection

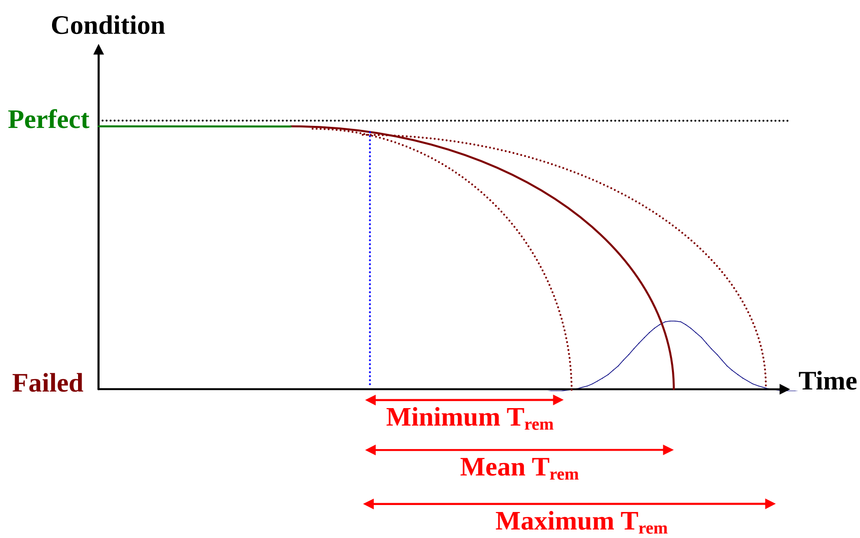

Figure 3 Illustration of Distribution of T_{rem}

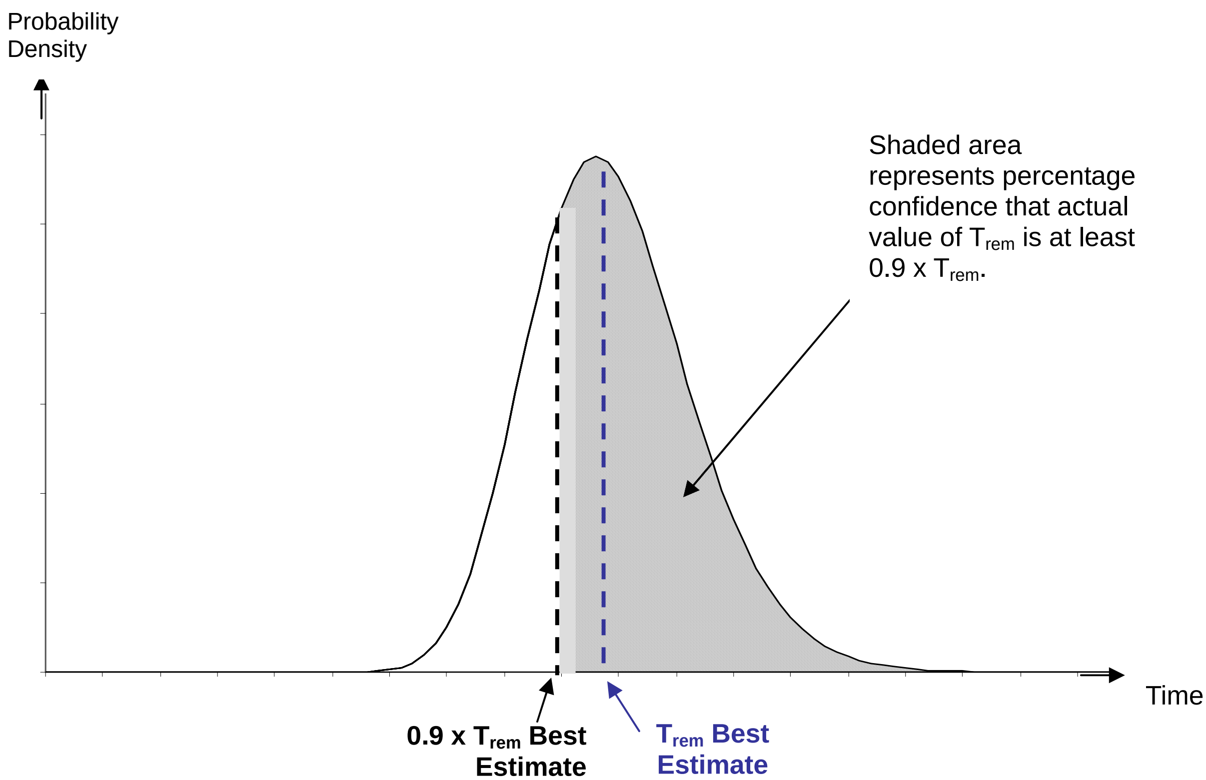

Figure 4 Illustration of Confidence Rank Definition

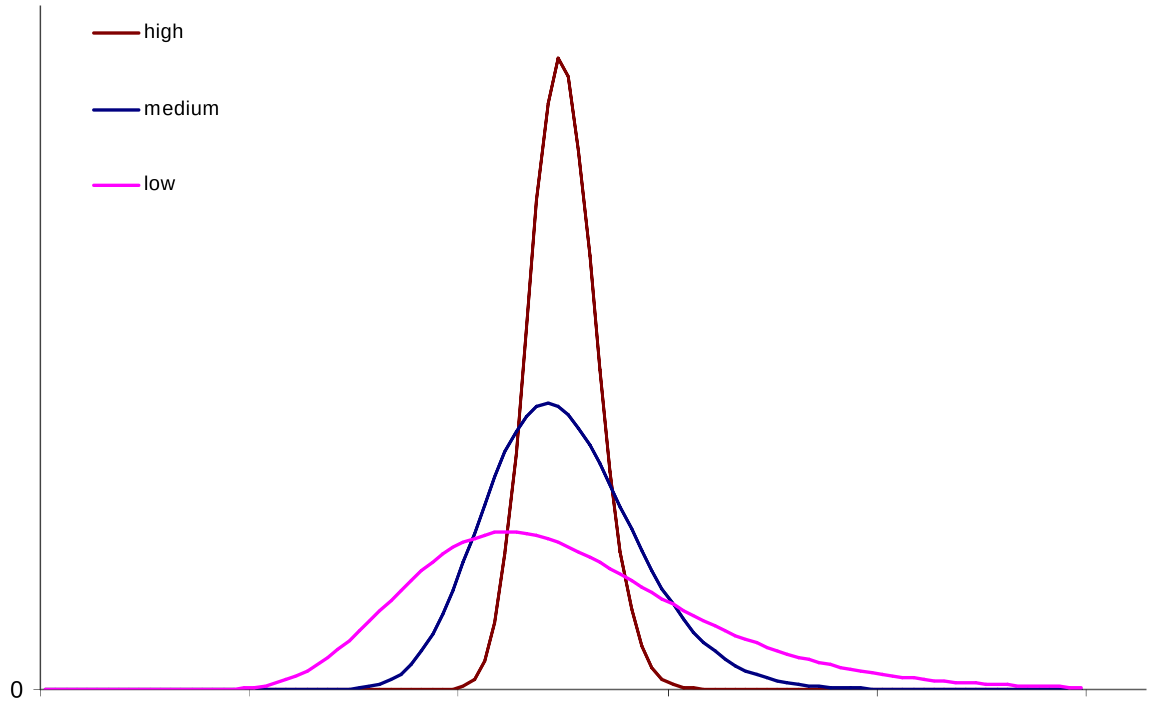

Figure 5 Probability Density Functions for High, Medium and Low Confidence

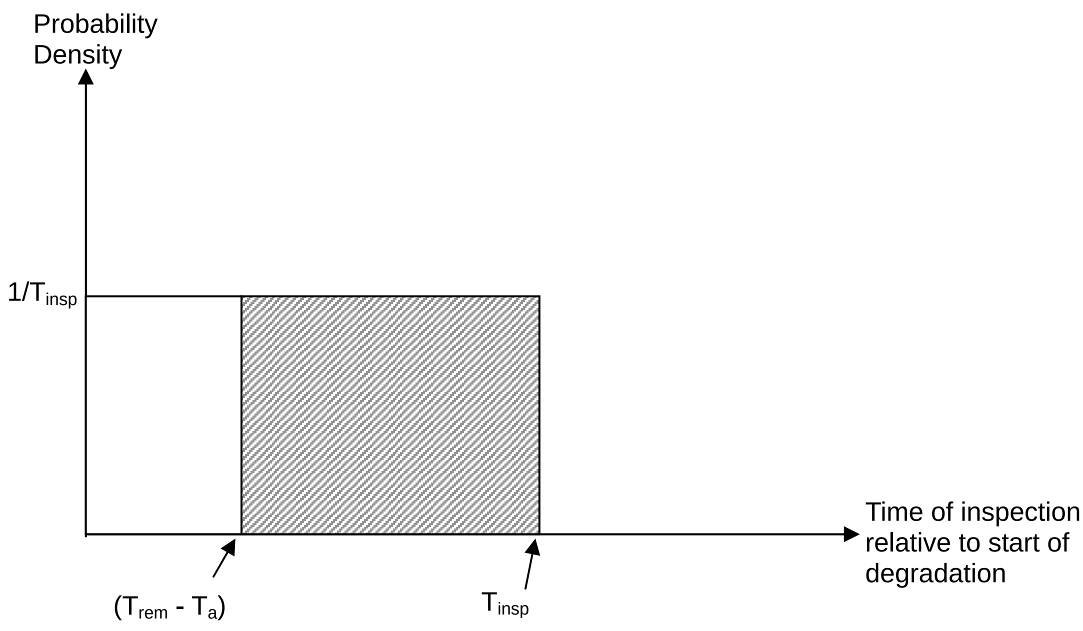

Figure 6 Illustration of Calculation of P_{IF}

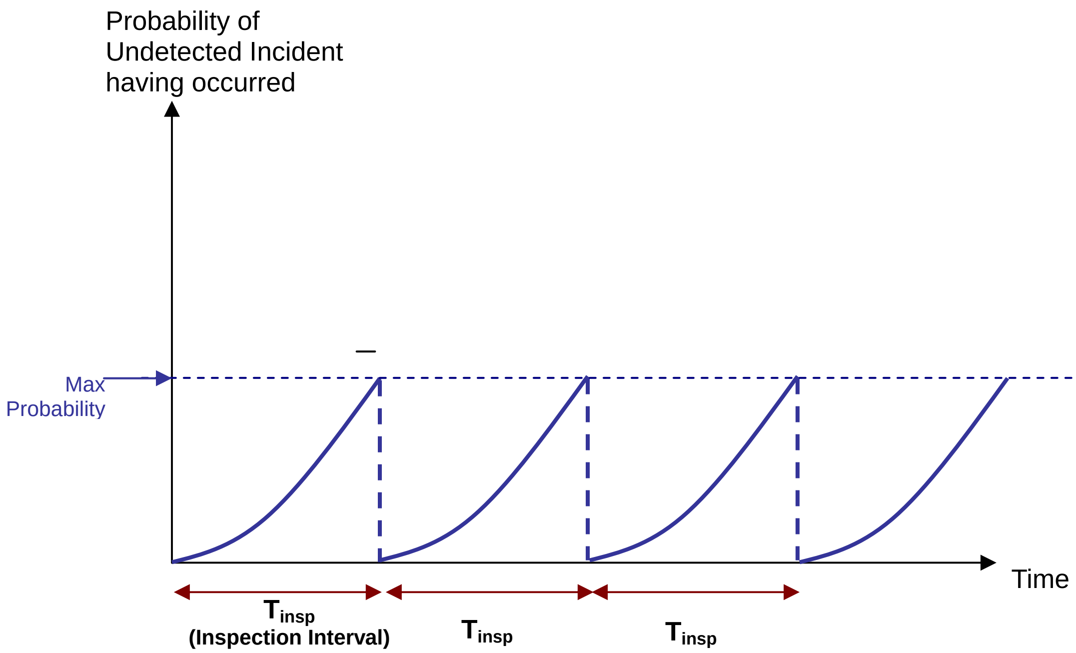

Figure 7 Illustration of Inspection to Control the Probability of Undetected Damage Having Occurred

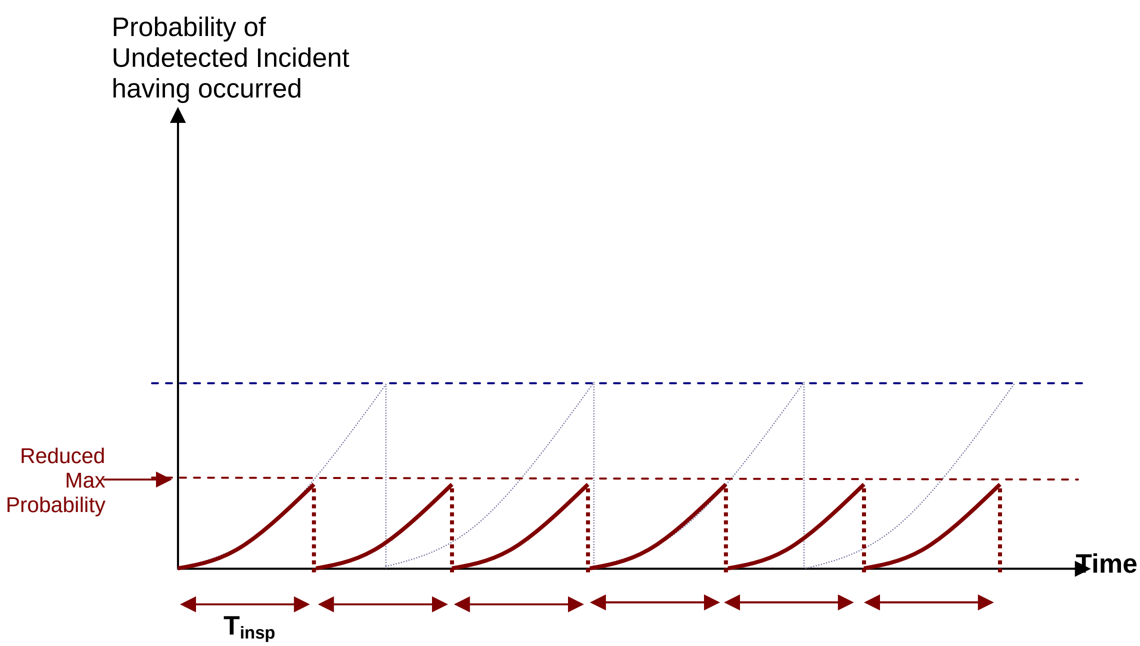

Figure 8 Illustration of Effect of More Frequent Inspection on the Probability of Undetected Damage Having Occurred

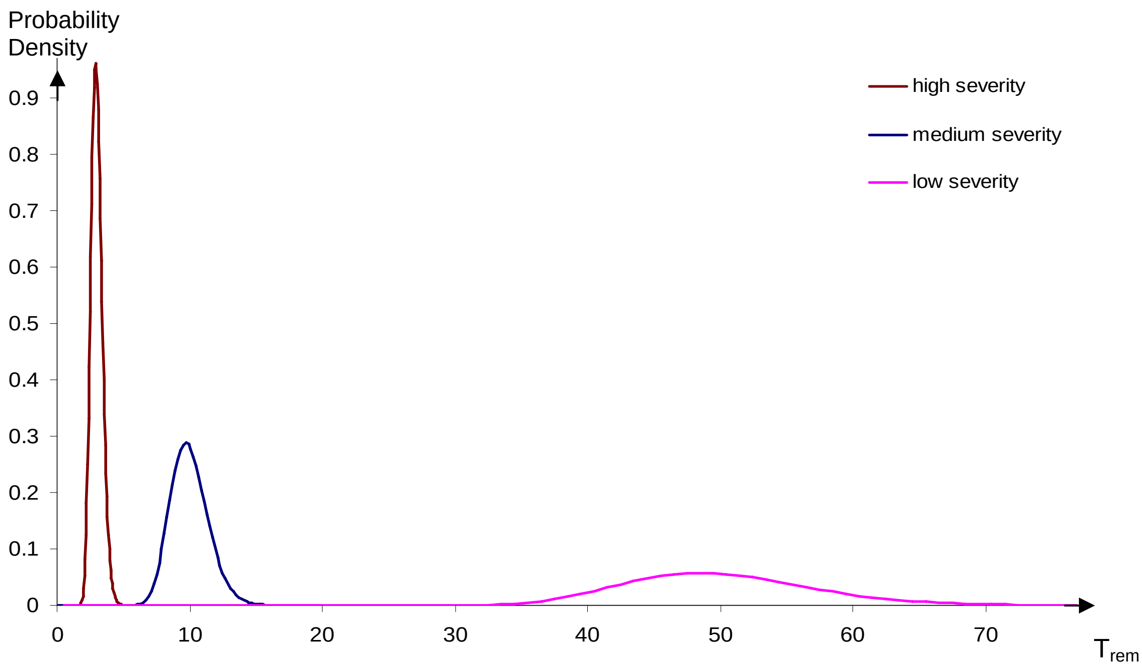

Figure 9 Illustration of Incident Severity Rank Probability Distributions.

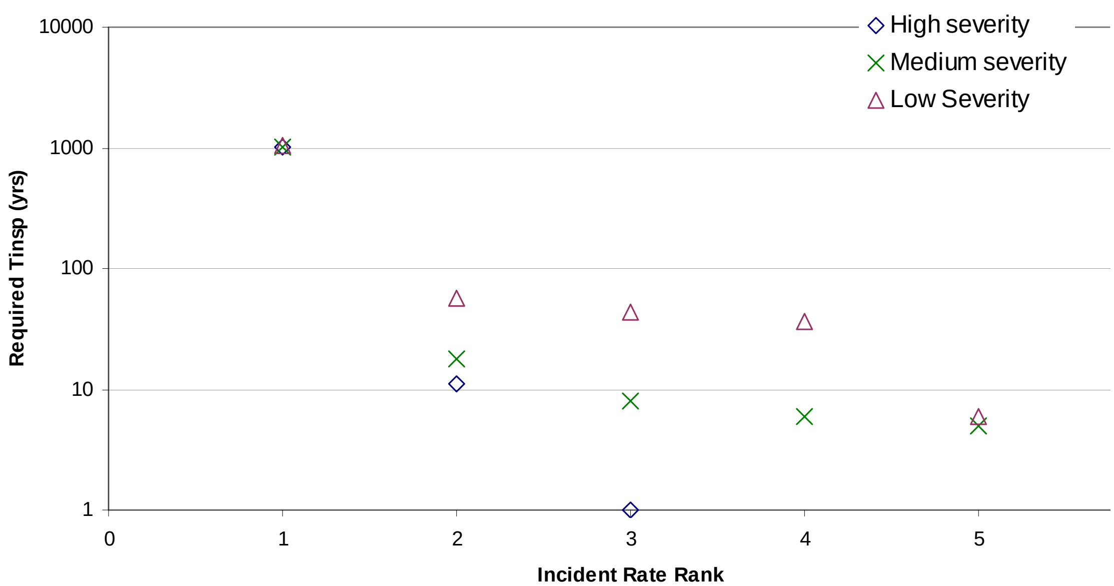

Figure 10 Variation of Required T_{insp} with Incident Rate Rank and Severity Rank, for Consequence Rank 3.