Implementation of Statistical Analysis of Inspection Data to Improve Integrity Management Process

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Integrity Management

- The main objective is to **identify and implement actions** to avoid failure by leaks or rupture for pressure equipment.

- It is a **life cycle** process which is applicable to all stages of an asset’s life.

- Operations comes with many **risks**, thus cost effective decisions are required for **safety and reliability** of such assets.

- To make **effective decisions**, it is important to understand the **associated risks** and this relies on sound **knowledge of the equipment condition and how that may evolve over time**.

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Integrity Management Decisions

- Decisions have **business impacts**:
  a. Repair or replacement of pressure vessels, pipework and pipelines
  b. Re-rating
  c. Frequency and type of inspection
  d. Detailed Fitness for Purpose studies

- These decisions are based on evaluation of information from a range of sources and with varying levels of **uncertainty**.

- It is important to understand the **accuracy of the information** for reliable decision making.
Inputs to IM Decisions

- Effectiveness of decisions made relies on the accuracy of the theoretical based information and indirect measures which comes with uncertainty.

- Inspection is aimed to provide direct indication of equipment actual condition – but there are (often significant) uncertainties associated with inspection information.
NDT Data and Decision Making

- Inspection provides **key information** for use in corrosion and integrity management.

- Inspections will always have **limitations**, these being dependent on the type of NDT techniques and condition of the equipment.

- **These limitations affect** the extent to which inspection provides information on the real condition of the equipment.

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**Perfect knowledge of equipment condition**

**Good knowledge of equipment condition**

**Poor knowledge of equipment condition**

**Optimal decisions**

**Good decisions**

**Poor decisions**

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**Increasing operational costs and consequential costs of failures**
NDT Data and Decision Making

- **Understanding the limitations** of the inspection data and making best use of the available information is *fundamental to integrity management decisions* that are aligned to the real condition of equipment.

- The significance of this is often *overlooked* in practice.

- Failing to understand the *limitations of inspection data* and on how to make best use of the data often affects decisions. Hence, leading to *major business impacts* as follows:
  - Unnecessarily short inspection intervals leading to additional inspection cost
  - Excessive expenditure on corrosion control
  - Unnecessary or premature replacement involving large capital cost
Impact of Inspection Limitations on IM Decision Making
Pipework Example

- Most operators make use of RBI. Decisions on intervals and locations are updated on consideration of inspection results.

![Diagram of the RBI process]

- Corrosion Risk Assessment
- Probability of Failure
- Risk ranking
- Define locations
- Inspection
-Define intervals
- Integrity Assessment
- Consequence of Failure
- Integrity review
- Risk ranking

This part of the process is only as good as the inspection.
Pipework Example

• 0 degree manual ultrasonic (MUT) wall thickness measurement is the main form of inspection for pipework (>2”) in most process industries.

• The approach typically involves scanning over grids at selected locations and recording the minimum thickness.

• Inspection conditions are **challenging** involving access restrictions and variable surface conditions.
Sonomatic has carried out statistical analysis of many large (1k’s - 10k’s point) inspection history databases for UK offshore operators.

The graph illustrates typical in-service performance of MUT for pipework where there is no corrosion active.

Graph shows variations for repeated measurements (over a 12 year period) at the same locations in a system where there is limited actual change.

Approx 10% (<0.01) of readings have underestimation of more than 1 mm.

Approx 10% (>0.99) of readings have overestimation of more than 1 mm.
Pipework Example

• IM system will tend to focus on areas where the readings are lowest.

• Given the high error levels in the inspection, in any situation in which there are a large number of readings, the extremes will tend to be those measurements with the largest errors.

Decision making can be driven by the measurements with the largest errors. This is what happens in many current database driven approaches.
Pipework Example

• It's not only current condition that is of interest. Remaining life has to be considered in decision making – rate of degradation is important.

• Impact of measurement error tends to be more significant on corrosion rate.

• Negative corrosion rate tend to be ignored – but they are indicative of error.

• Example from a system with some active degradation.

This is where the drivers for integrity management decisions will tend to be. This coincides with the region in which the largest errors can be expected.
Pipework Example

• Presence of measurement errors can give rise to inappropriate decisions being made.

• The priorities for inspection in current practise for many RBI managed systems are defined as:
  – Locations where the “wall loss” relative to nominal is largest,
  – Locations where the “corrosion rates” are highest,
  – Locations where the shortest “remaining life” is calculated.

• All three points are often locations with largest errors.

• The above are established by direct analysis of the information in the inspection database, without any understanding or knowledge of the implication of the measurement errors.
Pipework Example: Improved Approaches to Reduce Measurement Errors

• **Accuracy and reliability** of thickness measurement methods can be improved by:
  • Inspection techniques, e.g. automated corrosion mapping vs MUT
  • Inspection procedures, e.g. set-ups and locations for repeat inspection
  • Minimisation of surface related error, e.g. paint thickness correction

• IM decisions are made on **large datasets** and hence need for appropriate **statistical analysis** to assess the impact of measurement errors.

• A range of statistical analysis methods can also be applied to assist in more reliable decision making, i.e. decisions better aligned to actual condition and variation within a system.

• **Closer integration** of inspection and analysis activities is **essential** to making best use of inspection within integrity management.
Implementation of Statistical Analysis

• Statistical analysis methods are fundamental to understanding the effects of measurement error and making appropriate allowances in decision making.

• Statistical analysis methods are also applicable to assessments of corrosion. Corrosion processes across a wide range of conditions are found to be amenable a simple parametric description. For example, analysis of Sonomatic corrosion mapping data indicates typically regular behaviour of the corrosion process for the following:
  - Pressure equipment (vessels, pipework, pipelines) with active CO$_2$ corrosion
  - Pressure equipment with H$_2$S corrosion
  - Pressure vessels and pipework with internal O$_2$ corrosion
  - Pressure vessels with external O$_2$ corrosion (CUI)
  - Pipework with naphthenic acid corrosion
  - Pipework and tanks with under-deposit corrosion
  - Petrochemical and minerals refinery vessels with acid corrosion
There are two distributions:

- **Normal distribution** associated with as-manufactured wall thickness variations of the material.
- **Exponential distribution** (linear on log scale) representing the distribution over the degradation area. (Approx. 10% of the inspected area)
Statistical Analysis in Non-Intrusive Inspection (NII) of Vessels

NII Assessment and definition of requirements

\[ P(\theta_1 | X) = \frac{P(X|\theta_1)P(\theta_1)}{\int P(X|\theta_j)P(\theta_j) \, d\theta_j} \]

Workscope meeting requirements

Evaluation of inspection including Statistical Analysis of results

Inspection
NII Statistical Analysis

• Statistical analysis is a fundamental requirement to NII carried out in accordance with the HOIS Recommended Practice.

• Outputs of analysis cover
  – Is degradation present
  – Estimates for minimum thickness
  – Estimates of probabilities for limiting conditions
  – Evaluation of whether the inspection meets the requirements, i.e. is the coverage sufficient, is the information provided by the technique suitable

• Outputs of analysis also feed into the RBI
  – Updated estimates of worst degradation
  – Corrosion rate estimates
  – Nature of distribution of degradation

• The analysis also allows assessment of the capability and limitations of the inspection technique as deployed.
Statistical Analysis for Inline Inspection (ILI)

• Current analysis for ILI data tends to ignore negative corrosion rates, which are due to measurement errors.

• Also, ignoring errors associated with positive corrosion rates.

• For illustration, let’s consider two ILI runs which were carried out on a pipeline.

• Figure represents the wall loss for the matched defects for the two ILI runs.
Statistical Analysis for Inline Inspection (ILI)

- Normal probability plot is generated for the matched defects data,

- Red line is the normal distribution fit to the data with mean of -0.5% and a standard deviation of approx. 4.6%.

- Negative mean, suggest on average no corrosion has occurred between 2009 and 2011 for the matched defects.

- Symmetrical nature of the differences indicates most of them are due to measurement errors,

- As such, this will strongly affect any estimation of corrosion rate.
Correction of Measurement Errors

- **Correction approach** developed by Sonomatic based on the distribution of measurement error and use of an appropriate distribution for the depths of the matched defects.

- **Deconvolution process** is carried out on the measured data to produce the Weibull distribution (in red) and the measurement error (in green).

- Measured data shows an **overestimation** of the actual wall loss.

- With this approach and considering the measurement error, more realistic actual condition and hence remaining life can be derived.
Summary

- Integrity management relies heavily on information on equipment condition gathered during inspection.

- Inspection approaches have limitations affecting reliability of the information.

- As such, integrity decisions can be severely affected if these limitations are not well understood and considered.

- Improvements can be made in terms of inspection approaches to provide increased accuracy and reliability for more effective decision making.

- The use of statistical analysis ensures the value of the inspection data is maximised and decisions are aligned to provide more reliable view on actual condition of equipment and its remaining life.

- Closer integration of inspection and analysis activity is essential to making improvements to integrity management practise that Operators are beginning to expect.
Thank You!