Inspection intervals for equipment have in the past been defined in a prescriptive manner. However, industry is now embracing the Risk Based Inspection (RBI) approach which in contrast prioritises inspections based on an assessment of the risk to each individual item.

The key outcome of any RBI scheme is a prioritised and focused inspection schedule. This ensures high-risk items get correct scrutiny and produces a safety-focused and cost-effective inspection scheme. RBI is now recognised as a key tool in meeting legislative requirements, as detailed in the HSE’s best practice guidelines.

There are many RBI schemes in use, but they have a number of common elements:

- Assessment of the credible threats to an item of equipment
- Potential failure modes and mitigation measures
- Resulting consequences
- Associating a measure of risk with each item
- Combining risk with inspection history to determine future inspection intervals and methodologies.

**Economic approach to RBI — increasing the value of information**

The RBI process, nominally carried out at the Design stage, is adequate for initial assessment and to control initial risk, but must be continuously updated and revisited to ensure it remains a ‘live’ system once the equipment goes into service. Assessments often include more detail related to safety and environmental risk, and while business risk is normally included, the consequences are not always evaluated in great detail. An overview of the RBI process is shown in Figure 1, including the qualitative process used when updating takes place during a noted substantial change in process.
The obvious limitation of the RBI process is the lack of a clear link between cost/business information (notably, detailed analysis of historical and financial data) and RBI activities. An additional limitation is the qualitative style approach which depends greatly on the knowledge of the team of experts involved in the process and the assumptions made during the process.

Once the equipment has been commissioned and goes into active service significant value can be added by analysing information that is captured. This is detailed in Figure 2.

The following potential sources of information for review would normally exist:

- Production records: records relating to shutdowns are generally good, and when used in conjunction with high-level accounting information can provide actual and hidden shutdown and production activities costs. Again there is a compromise between the detail of the analysis and the associated economic gain.
- Accounting information: this information may generally be accurate with respect to cost, but less accurate with respect to descriptions and understanding the nature of the expense without detailed analysis of each item. A high-level analysis will give:
  - Overall production cost per asset
  - Overall income per asset
Evaluation of the cost associated with an unplanned shutdown, specifically with respect to the direct cost of repairs and indirect costs arising from the loss of production while operating costs are still incurred.

Evaluation of the cost associated with a planned shutdown, again specifically with respect to the direct cost of shutdown and indirect cost related to loss of production.

- Inspection history: large amounts of data stored but not fully analysed after inspection is completed and alarm levels checked. Further analysis is normally possible in the form of corrosion rate trending, extreme value analysis to assess degradation outwith the inspection regions, refinement of inspection intervals and locations, and reduction in the risk of unplanned failure if updated regularly.

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**Trade-off between cost and benefit**

When reviewing the information stored, the value gained from the Inspection history can be capitalised upon through a number of options, however the inherent costs of reducing business risk include:

- An increase in inspection expenditure as some inspection is required from a safety standpoint
• An increase in analysis of the inspection data
• An increase in fabric maintenance via ‘pro-active’ replacement of equipment prior to failure — rather than ‘reactive’ replacement on plant failure — which can incur minimal extra cost.

With pressure on short-term cost, some operators have chosen to reduce inspection expenditure by, for example, substituting prescribed advanced technologies with conventional NDT approaches, utilising conventional service contractors to provide specialist technologies at reduced rates, and using an inappropriate Non-Intrusive Inspection (NII) process to defer Internal Visual Inspection (IVI).

Ultimately the above ‘cost-savings’ approach often fails. Experience shows that the costs (lost production, unplanned repair etc) far outweigh any short-term savings.

**Optimising level of detail**

The total cost of production is the sum of operating cost and cost associated with reducing operating cost as depicted in Figure 3. This can be optimised but an understanding of associated costs and benefits is required. If the systems are in place to make this evaluation possible then a better decision can be made with regard to the level of inspection/maintenance required.

![Figure 3 Optimising Trade off Between Cost and Benefit](image)

Often the cost incurred is much less than the potential saving, but as expenditure is required before savings are made, commitment from all parties (Production, Integrity etc) is needed.
Prior analysis allows a rigorous demonstration of cost/benefit prior to incurring cost in order to motivate ‘extra’ expenditure, an example of which is shown in Figure 4.

Setting up a system to effectively evaluate cost/benefit usually requires initial set-up costs which require long-term commitment to realise gains, and it is often difficult to see gains in the short term when cost are associated with events (e.g. leakage from a pipe).

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When revisiting data, the following issues should be taken into account:

- If components are not deteriorating rapidly and have a long remaining life, then over-analysis will not yield significant value
- Conversely, if the component is deteriorating rapidly, or the integrity is unknown, there could be significant value in conducting further analysis
- Clearly, it would in the above cases be an advantage to be able to optimise the level of intervention. This can be achieved by a phased approach:
  - Initial phase: Broad analysis and system setup
  - Analysis of planned and unplanned events
  - Analysis of cost associated with events and general operating costs
• Development of simplified but realistic methodologies to facilitate cost benefit of future events.

• Subsequent phases should focus on;
  – Identification of regions of maximum cost benefit
  – Evaluation of individual cases
  – Refinement of the initial analysis.

Statistical analysis of inspection data

Taking pipework integrity as an example, standard management usually includes measurement of wall thickness, taken at specified intervals at a large number of locations, resulting in large data sets being built up over time. Some trending may be carried out, but typically the main value of the inspection is taken as indicating the condition at the time it is made. Generally, anomaly criteria based upon original code criteria, material choice, Corrosion Risk Assessment, operating conditions and wall thickness have been pre-determined and this results in a ‘pass/fail’ assessment carried out by the inspection technician.

Statistical analysis can be used to extract additional information from the established data set and this can give substantial value to the integrity management process. Corrosion processes can appear to be random and unpredictable but there is often some underlying order, and it is often found that actual corrosion does not reflect the expected behaviour outlined in the Corrosion Risk Assessment. The order found within inspection data is demonstrated by the following diagrams.

Figure 5 depicts the output from a corrosion mapping process, which in this instance is a predetermined grid on a pressure vessel. The colour graphic shows the grid being split down into inspection grids of a pre-agreed size and the reported minimum recorded remaining wall thickness in millimetres for each grid is represented by a colour scale. Figure 6 then represents this output in a graphic format of recorded remaining wall thickness versus the proportion of area over which this is representative; the proportion of area is dimensionless.
Analysis carried out, using the distribution plotting method as illustrated above, of a wide range of data for vessels and pipework has shown that there is typically some underlying order in corrosion processes. Orderly behaviour means there is a basis for using statistical methods in which the known condition of the parts of a system is harnessed to estimate the condition of remainder of system. Typically for topside pipework inspections, the data set has thickness measurements over specific pre-determined regions/features. Measurements do not have 100% coverage for a complete system. At this point the use of statistical methods can provide additional confidence in the condition of the unmeasured portion of the
The analysis can be applied in a number of ways:

- Understanding the distribution of damage through a system
- Estimating corrosion rates
- Estimating minimum remaining thickness of lines
- Estimating likelihood of undetected damage in uninspected portion of the system
- Possible integration to form an essential part of pipework integrity management.

The use of Extreme Value Analysis (EVA) allows estimates to be made for large areas based on the inspection of small areas. Upon completion of data collection for selected areas, or from original data sets, the susceptibility is then ranked.

The objective is to use additional information from analysis as input to defining ongoing inspection requirements. It can be used to define a risk-based approach where a combination of estimated minimum and average corrosion rate defines the probability — i.e. is typically the main driver for the inspection interval. It can also be used to identify the required coverage — i.e. the extent of straights or number of features — this is driven by corrosion susceptibility and by results of extreme value analysis. (Additional coverage can improve the estimate of minimum and allow re-ranking.)

Ultimately this approach allows focused inspection effort on the most vulnerable locations within the system, which results in greater confidence in the integrity of the system and increased value for money during the inspection implementation.

The implementation process is shown below in Figure 7. It should be noted that this approach is not an alternative to existing methods for planning the inspection of pipework but provides supporting information for decision making. It uses existing available information on the actual condition as an input to planning decisions. The input is made at the integrity review stage of the RBI process. The items for inspection are selected according to the recommended coverage but corrosion/inspection engineering input should also be taken on board as per good practice.
The benefit of using a statistical method is that the process makes best use of the measured condition of pipework as planning input. There is value in the inspection data beyond ‘condition acceptable’ and the approach uses this to enhance decision making. The added advantage is that the inspection process does not need revisiting to gain the data required. However, the more accurate and the larger the data set, the greater the potential benefit given. The result of the process is improved classification of corrosion/failure susceptibility and increased confidence that future inspection is appropriately applied according to risk. The redefined inspection requirements give a structured approach to inspection planning, ensuring that the resulting value of future inspections is maximised. Ultimately the process assists in achieving a cost-effective inspection programme without compromising integrity.

Summary
RBI is a valuable tool and key to Integrity Management systems. Ultimately RBI requires to be treated as a live system and continuously revisited through the lifecycle of the asset, innovative technical methods must be embraced and incorporated to ensure continuous enhancement of the RBI Analysis and ensure that it does not become a design only exercise but truly representative of the live system.

**Craig Emslie – Integrity Services Specialist**
Craig is responsible for conducting fitness for service investigations, evaluating the feasibility for conducting non-intrusive inspection, developing inspection work scopes and developing integrity management plans. He is also involved in analysing inspection data from an integrity perspective. His experience includes consulting in the fields of design, stress analysis, failure analysis, fitness for service, fatigue and fracture mechanics, dynamic and residual stress measurement, as well as system evaluation and optimisation.

**Karen Gibson – Principal Integrity Engineer**

Karen has worked in support of the North Sea oil and gas exploitation industry for in excess of 12 years. She initially entered the industry as a safety engineer working within compliance assurance contracts and was involved in Brownfield and Greenfield work as well as various projects. She has a strong background in legislative requirements and code compliance, has a strong focus on cost and quality delivery and is extremely customer focused.

She then transitioned to a technical role supporting both the Oil and Gas Industry and the Marine Industry. This included time spent as an onsite inspector/surveyor both on and offshore and working as a design and compliance engineer on behalf of IIAs and IVBs. This role encompassed pressure systems, dive systems, lifting equipment, subsea systems and rotating machinery. She then progressed to centre her experience on process and pressure systems for both topsides and wellhead equipment, which in turn led to a role within the Inspection and Integrity sector. She has been ideally positioned as a Pressure Systems Competent Person and as a Senior Inspection Engineer in order to consolidate her experience. She is also a fully qualified Chartered Engineer and Chartered Marine Engineer.