

Tools and Methodologies for Pipework Inspection Data Analysis

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Abstract. The sample nature, non-intrusive character and sheer volume of data are just some of the factors that complicate pipework inspection data analysis. In this paper we will explain in more detail these and others factors that affect data analysis. For data analysis elements such as data cleansing, wall thickness trending, inspection and maintenance planning typical and improved practices will be reviewed. It will be shown how these improved practices have been incorporated in a software tool. A brief overview of this tool will be presented, including the role of statistical methods that support the tool, the degree the tool is able to automatically process the data, and how it fits in the inspection process.

1. Introduction

Pipework inspection is, by its nature, done with NDE tools and is, in most cases, carried out with a sampling approach. Traditional inspection is set up by dividing pipework in corrosion loops that see a similar corrosion environment, and inspecting it at so-called corrosion measurement locations. Wall thickness is measured and replacement is initiated when sections of pipework reach the minimum required thickness. This approach works well in pipework of uniform design, and when corrosion rates and the pattern in which the corrosion develops are rather stable over time and in place.

Planning inspections for pipework becomes more challenging if it is built from many different diameters and thicknesses, and if it has developed a mature corrosion condition that requires regular replacement of sections of pipework. We have been involved in a number of projects where a more proactive approach was required. In the course of this work we developed a number of data analysis steps which we have also incorporated in a software package called S-IDAP; Shell Inspection Design, Analysis and Plotting [1]. Some of these data analysis steps will be discussed in more detail in this paper.

2. Key Features of Pipework Inspection Data Analysis

There are a number of steps in the inspection work process where data analysis is important:

- Evaluate reliability of measured local corrosion rates.
- Analyse and visualise corrosion rates on higher (corrosion loop) level.
- Review Inspection coverage to determine if current inspection locations provide a good enough sample of corrosion loop integrity.
- Planning future inspection based on above steps and RBI rules.

Each of those steps will be discussed in more detail below. It will be shown that it is important to focus on wall loss rather than remaining wall thickness as the main variable for data analysis as already indicated in our overview paper [2].

2.1 Accurate Assessment of Local Corrosion Rate

Knowledge of the local corrosion rate at each inspection location is essential for the understanding of the corrosion behaviour in a pipe circuit or corrosion loop. By looking at actual wall thickness readings over several years, one can often observe that relatively large errors occur in NDT data, that the corrosion rate may not be constant over time and that the number of measurements in a series can be very limited. These data are therefore not an ideal basis for forecasting using conventional linear regression techniques. Hence we used a statistical trending software tool. This tool, based on Bayesian techniques, deals with anomalies in the data in a natural way, predicts wall thickness and corrosion rate over time and gives an estimate, with confidence bounds, of the remnant life of the pipeline, vessel or other structure under consideration.

The method consists of simultaneously fitting four different corrosion rate models. In the main model (1) the wall thickness and corrosion rate vary linearly over time. Furthermore three alternative models (Figure 1) are fitted to cope with the following anomalies in the data:

- outliers, a wrong measurement (model 2);
- change in wall thickness, e.g. occurring due to a wrong instrument calibration, use of different procedure or a pipe replacement (model 3);
- change in corrosion rate, a genuine change, e.g. caused by a change in operating conditions that need to be detected and taken into account as early as possible (model 4).

The posterior probabilities of the four models, given the data at a particular time instant, are calculated and a weighted mixture is used for prediction.

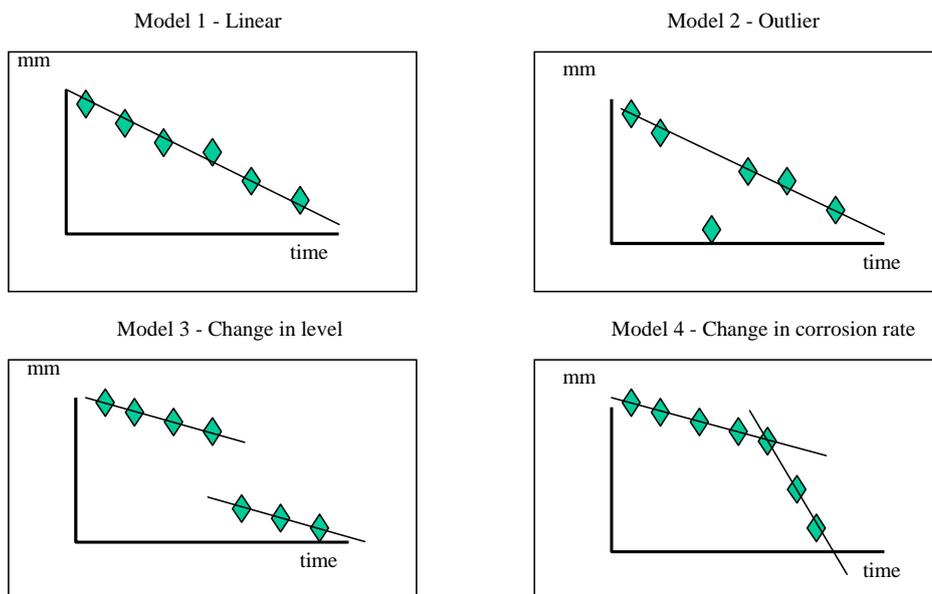


Figure 1, the four models applied in the trending software tool

With the trending software tool large numbers of data are processed automatically and only those locations where an anomaly in the data (model 2, 3 or 4 prevails) has been detected can be selected for manual review and possible re-inspection.

The first measurement point of the trend plot becomes an important data point when only few readings per locations are available. Usually the schedule nominal wall thickness is used for that purpose. This poses high demands on the reliability of the inspection database such that correct feature diameter and piping class are assigned to a pipe feature. Data cleansing may be required to achieve this. A further improvement can be realised by requesting the NDT technician to not only measure remaining wall thickness but also the uncorroded wall thickness near a wall loss feature. This way the schedule wall thickness can be replaced by the as-built nominal wall thickness of that feature.

2.2 Corrosion Circuit Analysis

After trending the wall thickness data at each location, we continue the analysis by displaying the corrosion rates in different plots per corrosion circuit, which is initially the smallest unit in the pipework for which a similar type and level of corrosion is expected. For some circuits a further breakdown of a corrosion circuit is necessary, this process is called stratification. Corrosion measurement locations are typically identified for each pipework “feature” in a circuit. A feature can be a straight section of pipe, bend, tee, weld, end cap, etc.

Figure 2 shows a circuit overview plot. The corrosion rates of all features in the circuit are shown, colour-coded per feature type. The dotted line is the RBI-selected corrosion rate for the circuit. From this plot it can be easily seen whether certain features show different corrosion behaviour or whether corrosion is more severe in certain parts of the circuit. From this overview of measured local corrosion rates the RBI-selected corrosion rate can easily be updated.

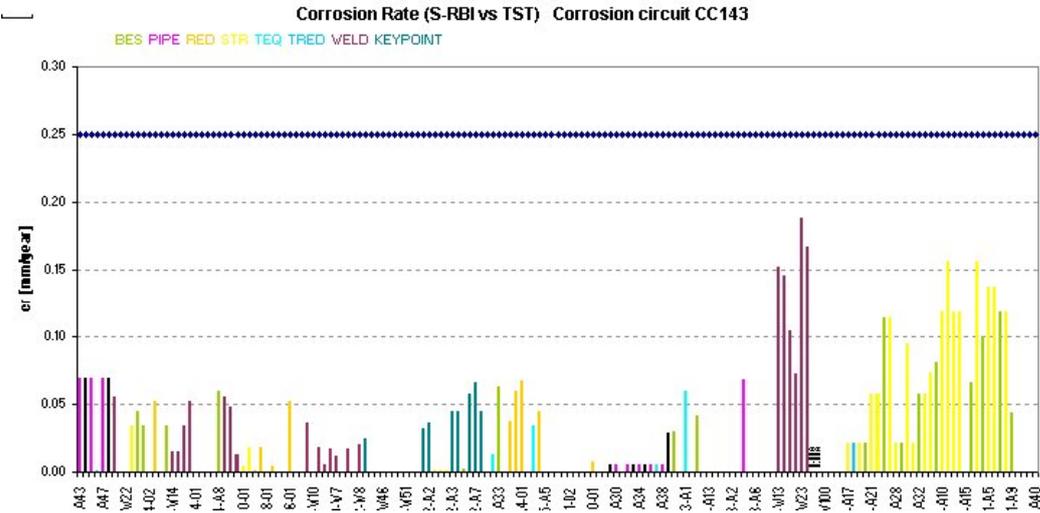


Figure 2, Circuit overview plot. Corrosion rates of adjacent features are shown, colour-coded per feature type

In Figure 3 the histograms for two circuits, CC014 and CC012 are given. The first histogram shows a low corrosion rate for the whole circuit, while the second shows that higher corrosion rates are also present. Circuit CC012, for instance, needs to be further analysed to decide whether further stratification within this circuit is necessary. In Figure 4 a categorised box plot is shown. From this plot it is clear that corrosion rates in bends on average are considerably higher than those in the other features, requiring a split up of this circuit into 2 corrosion strata. Remember that a circuit could contain varying diameter and

nominal wall thickness values and such a corrosion hot spot would therefore be much more difficult to detect when only remaining wall thickness information was available.

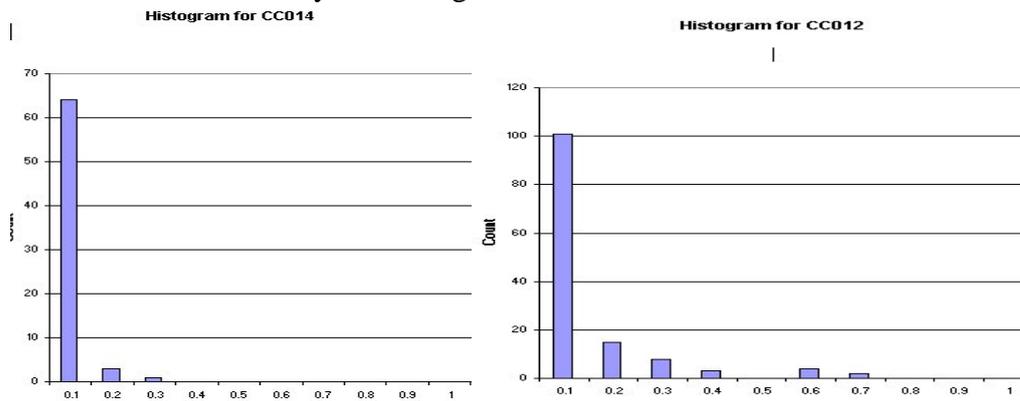


Figure 3, Histograms of corrosion rates from 2 circuits

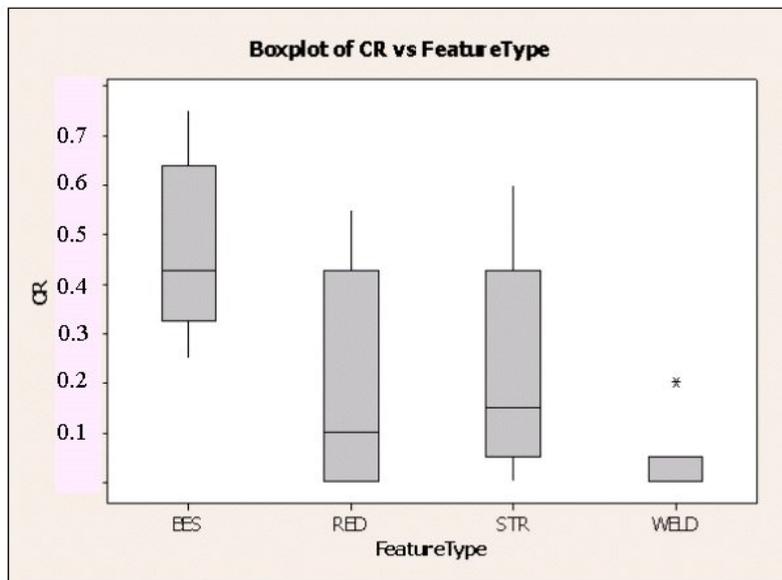


Figure 4, Categorised (per feature type bend, reducer, straight, weld) box plot of corrosion rates

Further understanding of the behaviour of the corrosion mechanism(s) can be obtained by marking up isometrics with the corrosion rate at each measured location (See also Figure 5). Such marked-up drawings provide an overview at a glance of the locations where high corrosion rates occur. This often supports the explanation for such extreme corrosion rates, for instance because a feature is a dead leg or a high-flow area. Data points that possibly contain an error are specially marked so as to avoid false interpretations because of data errors. The drawings are also used to display other information, such as remnant life, date of inspection, or wall loss. It can also give a good indication for the necessity of further stratification.

If preferred locations for corrosion occur in a circuit, this may result in an adverse effect on planning and effectiveness of the inspection. At the end of the corrosion loop analysis process we should have identified any additional stratification required as input to further analysis and inspection planning.

2.3 Inspection Coverage Assessment

Pipework inspection is in most cases carried out with a sampling approach. The inspection coverage assessment step described in this section is a structured approach where sampling inspection results are extrapolated to the whole stratum with statistical tools. If measured condition is much better than a certain rejection criterion (allowable wall loss) then sampling can be used to assess integrity of the pipework system. If this is not the case a 100% inspection is required to prove integrity. The strict use of compliance sampling is treated in a separate paper [3], while this application to pipework is a loose interpretation of it.

A prerequisite for coverage assessment is that the corrosion circuit analysis has been carried out properly including stratification. Another prerequisite is that sampling by taking data at corrosion measurement locations (CML) has uniform and sufficient coverage over a particular circuit or stratum. The ability to link corrosion rate (and other inspection data) to inspection isometrics is a very useful tool to assess uniform coverage, see Figure 5. In this example, any high corrosion rates in the not inspected part would go unnoticed.

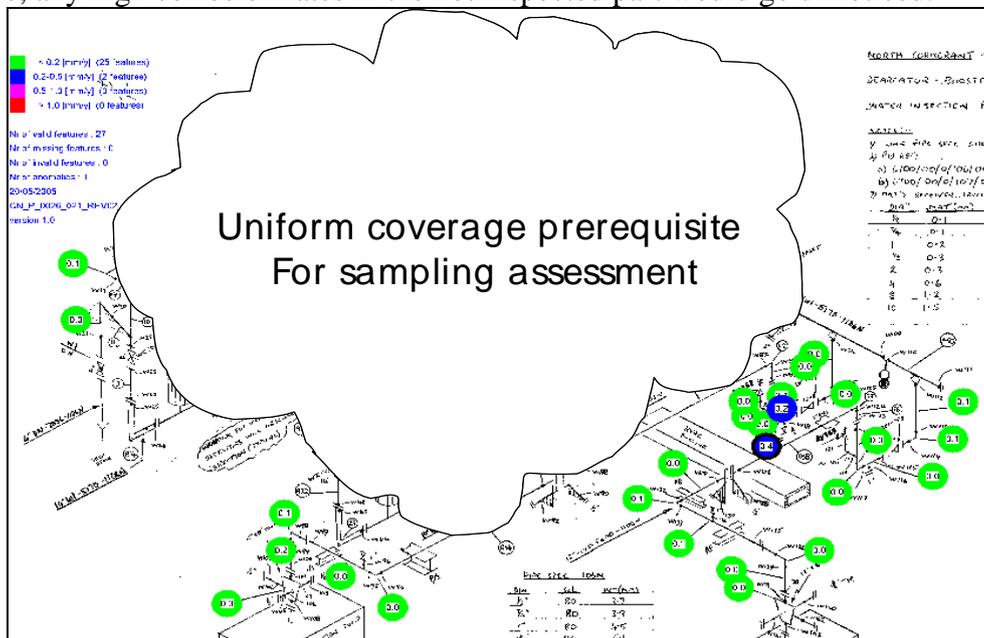


Figure 5, Overview of a pipe circuit where a coloured circles indicate a feature with measurement. The clouded area does not have any inspection data.

The key element of the coverage assessment process is to set up and interpret a so-called “cumulative wall loss histogram” as a way to assess if more inspection is required or not. This is achieved by going through the following steps:

1. Determine allowable wall loss per CA group.
2. Calculate cumulative wall loss per feature.
3. Build into histogram and compare with allowable wall loss.
4. Determine if additional inspection is required from the histogram.

2.3.1 Allowable Wall Loss

For each group of features the maximum allowable wall loss (MAWL) has to be determined. In its simplest case this is just the design corrosion allowance, which is typically 1 or 3 mm for many carbon steel piping classes. A next step is the use of a level 1 fitness for service assessment, where the minimum allowable wall thickness is, for example, two-third of the design thickness (excluding corrosion allowance). This leads to a

maximum allowable wall loss that is diameter and piping class dependent. It typically leads to a number of different MAWL values per circuit.

2.3.2 Cumulative Wall Loss

It can be difficult to compare various measured wall loss values in a circuit if these were measured at different inspection dates. For a more meaningful comparison, we consider predicted wall loss as well. The wall loss is predicted at a certain date that is called the end-date. This is typically the end date of an inspection planning cycle, for example 31/12/10 if we have a yearly inspection plan and would like to develop the plan for the year 2010. The sum of the measured wall loss and predicted wall loss is called cumulative wall loss; see Figure 6 where this principle is illustrated.

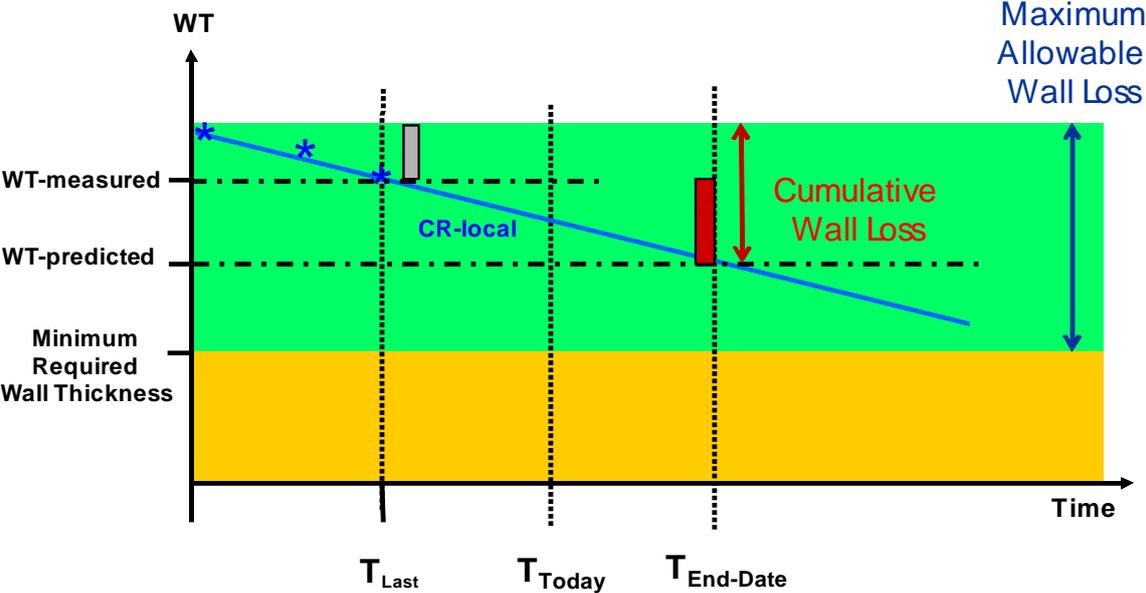


Figure 6. Remnant life plot indicating measured wall loss (grey bar) and predicted wall loss (red bar)

2.3.3 Cumulative Wall Loss Histogram

The process above is repeated for all features in a circuit such that a bar chart of all features and a corresponding histogram can be produced, see figure 7. The histogram also indicates a number of values for MAWL for certain groups of features.

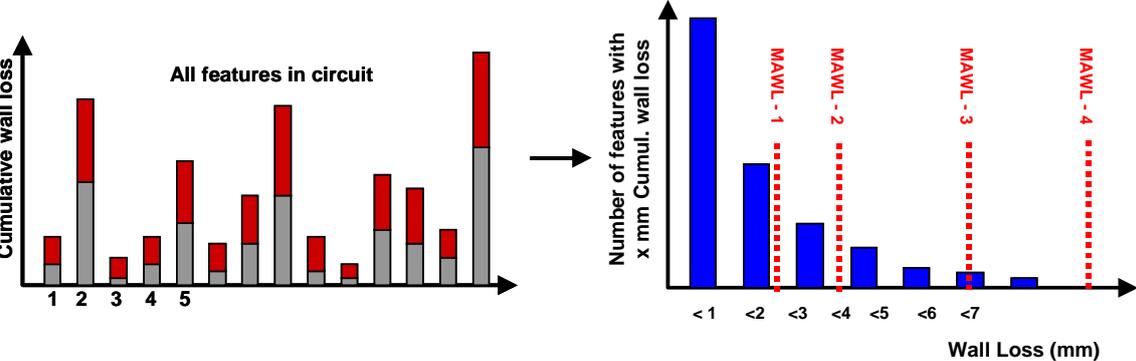


Figure 7. Bar chart with cumulative wall loss per feature (left) and histogram (right) of entire circuit

2.3.4 Determine Additional Inspection Requirements

We can now apply sampling principles to groups of features with the same MAWL and assess if more inspection coverage per group is required. As we already applied stratification the corrosion rates are assumed to be randomly distributed over the different MAWL classes. But since the tolerance to corrosion differs per class, a certain wall loss value can be insignificant for high MAWL values but may be critical for low values. This is illustrated by two example cumulative wall loss histograms shown in Figure 8. In the top figure all cumulative wall loss values are low and are much lower than the MAWL value. Therefore the existing sampling coverage is adequate and no additional features need to be selected to monitor integrity. The bottom figure shows that cumulative wall loss up to 4.5 mm is possible in this circuit. Low diameter features have a MAWL below or near this value and sampling is therefore not adequate anymore for these categories (up to and including 4" diameter in this example), i.e. all features with these MAWL values need inspection to ensure integrity.

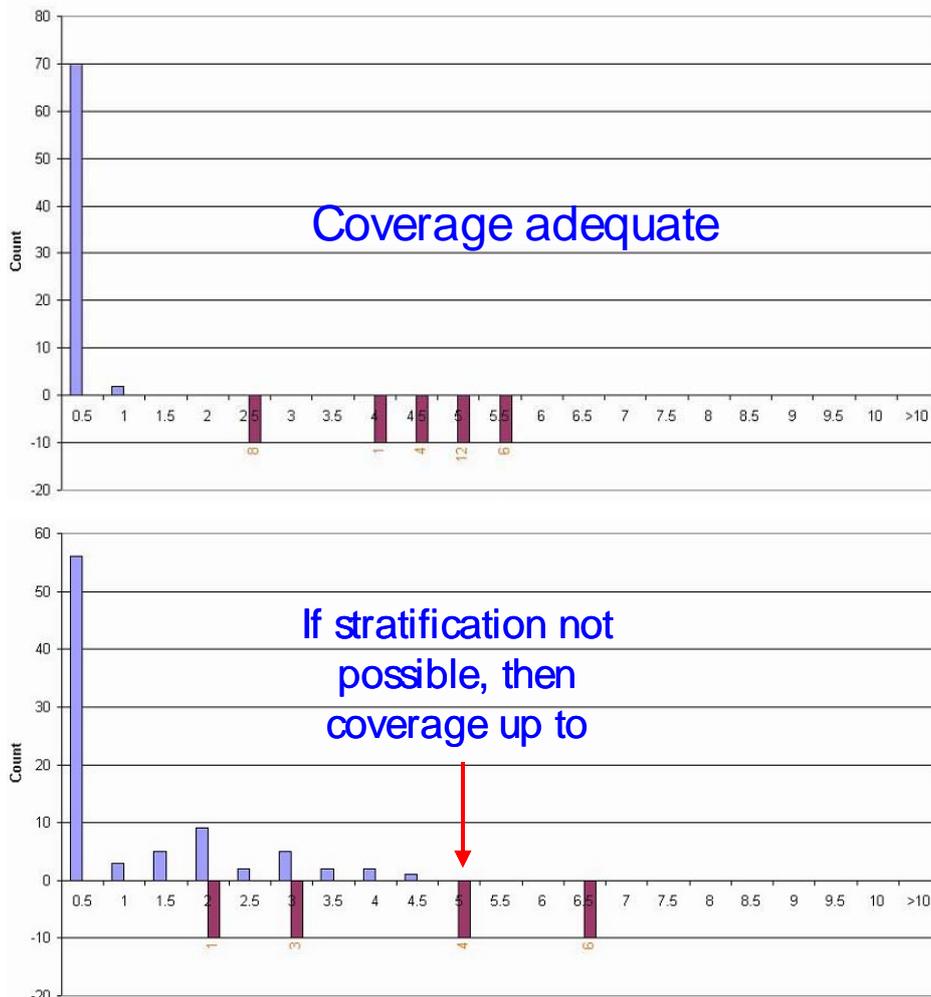


Figure 8. Two examples cumulative wall loss histograms indicating sufficient inspection (top) and additional inspection required (bottom). The negative bars indicate MAWL values for a certain diameter (number below the bar).

2.4 Inspection Planning

We have seen that limitations in traditional inspection databases forced people to apply RBI on a circuit level, i.e. the next inspection date is set for a complete circuit, often based on the worst spot in that circuit. This leads to non-optimised inspection plans, often resulting in manually adjusting the extent of coverage, a rather subjective process. With the S-IDAP data analysis capabilities we are now in a much better position to determine an effective and optimised pipework inspection plan.

Basically we split pipe features into two groups: ones that have already been inspected before and the others that have not had any inspection yet.

2.4.1 Features Already Inspected

Features already inspected can be added to the work pack from the corrosion rate analysis (section 2.1) to check an anomalous trend. However, the large bulk of feature inspection requirement will come from RBI rules. The typical rule applied in the Shell-RBI methodology is that next inspection date (T_{next}) is determined by last inspection data, T_{last} , the interval factor, IF , and the Remnant Life (RL):

$$T_{next} = T_{last} + IF \times RL = T_{last} + IF \times \left(\frac{WT_{last} - MRWT}{CR} \right)$$

The interval factor is determined by equipment risk and a parameter called “confidence rating” [3]. With accurate corrosion rate information per feature available we can plan the next inspection more accurately than when just applying an average or worst case corrosion rate for the entire circuit.

2.4.1 Features Never Inspected Before

Selection of these features will come from coverage assessment. First there could be new features required in the work pack to achieve a more uniform coverage or to start with a certain sample if the entire circuit has never been inspected.

The next step is to include those features that belong to a MAWL class where the coverage assessment has indicated that 100% inspection is required.

3. Integrated Tool of S-IDAP

We have been involved in a number of projects where an accurate prediction of the remnant life was required using statistical tools and data analysis steps described above. These tools are not available in commercial inspection database programs and therefore we developed a software package called S-IDAP; Shell Inspection Design, Analysis and Plotting. It is a library of modules for cleansing of inspection data, visualisation, trending, analysis and work pack generation. It's not a replacement of the inspection database but rather works as an add-on to an existing database for enhanced analysis. It provides multiple, linked windows with information (charts, graphs, tables, isometrics) about the inspection database, see Figure 9. Important aspects of pipework inspection data analysis, including statistical tools, which we discussed above, are incorporated in the tool but it also has more functionality as described further in this section.

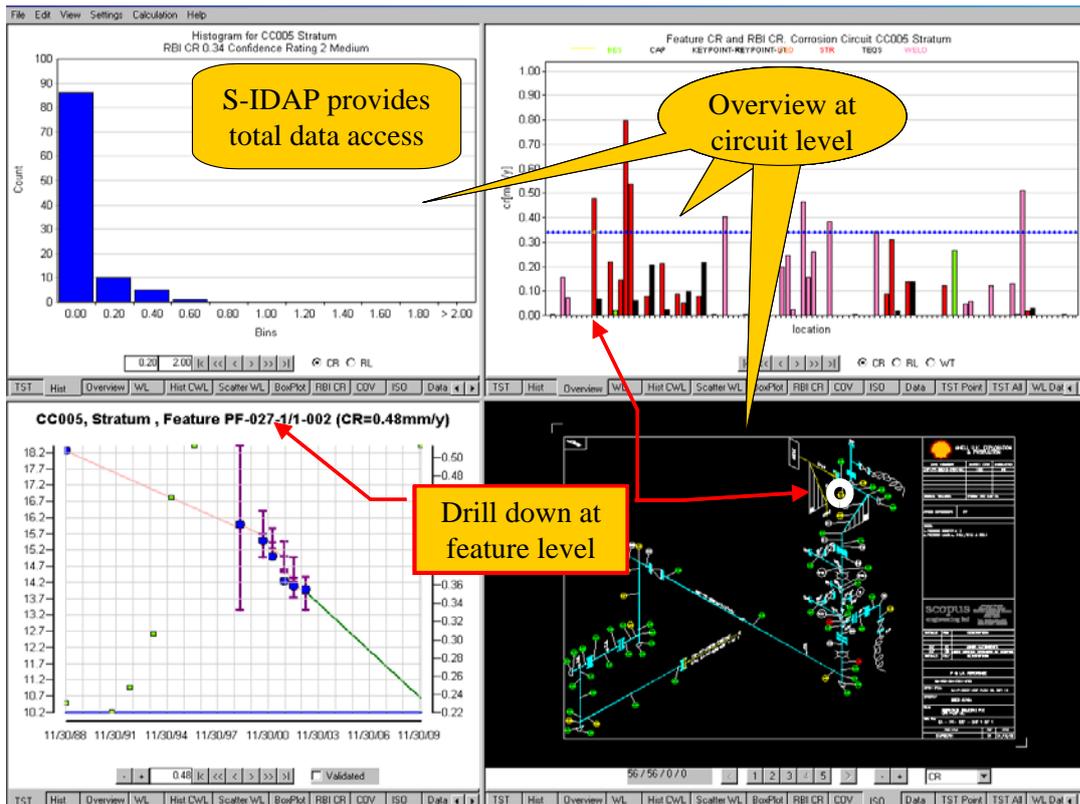


Figure 9. The S-IDAP graphical user interface

3.1 Data Cleansing

Data cleansing is of utmost importance since various data errors and inconsistencies occur. Cleansing data manually is extremely time consuming (1-6 months is not unusual for data from an offshore installation) and can introduce new anomalies if not done rigorously. In the data cleansing module of S-IDAP several algorithms have been developed to: validate inspection data and inspection isometrics, flag suspicious data points, clean data and prepare data for upload to inspection database. This automated process has dramatically reduced the effort to get good quality data in the inspection database.

3.2 Extreme Value Analysis (EVA)

The EVA module will enable the user to fit the Gumbel or Generalised Extreme Value distribution to extreme data (e.g. maximum wall loss of HX-tubes) and/or fit the Generalised Pareto (or the Exponential) distribution to measurements with a high detection threshold. Both extrapolation to larger surfaces (larger number of tubes) and extrapolations in time are calculated. The user can choose between options for goodness of fit tests, graphical displays, etc.

3.3 Compliance Sampling Recipe

The compliance-sampling recipe as presented in our other paper [3] is also incorporated in this tool. S-IDAP will get all the necessary RBI information to model corrosion rate distributions and can perform the complicated calculations of required area coverage for compliance sampling.

4. Conclusions

A key aspect of pipework inspection data analysis is the ability to translate local wall thickness in local wall loss and hence corrosion rates. This allows the use of wall loss as a clean statistical variable, which enables: i) stratification to be recognised, ii) assess inspection coverage requirements of uninspected pipe sections and iii) true risk based inspection planning of corrosion measurement locations.

Pipework inspection data analysis as described in this paper requires an inspection database with highly reliable data. As much of the data analysis functionality is not present in commercially available software, we developed software, called S-IDAP. It works as an add-on to an existing inspection database and offers more functionality for pipework inspection data analysis.

References

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- [2] Use of Statistical Techniques for Sampling Inspection in the Oil and Gas Industry, S. Terpstra, 4th European-American Workshop on Reliability of NDE, Berlin, 24-26 June 2009.
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