RELIABILITY BASED INSPECTION FOR CORRODED PIPELINES

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Abstract: Pipeline Integrity Management is a growth industry. Much of the material published in the last few years has been directed to optimising maintenance cost by accepting and managing some level of risk. Risk is typically established by complex statistical calculations based on available data. The method used in the present study works well when both the accuracy and confidence of the data used in the calculations are very high. This method works less well when the data is less accurate and can lead to underestimating both the degree of risk and its associated cost. This project is a general review of industry practice for determining risk and its cost. The project reviews also other specifications (accuracy and confidence) of in-line-inspection tools with regard to the use of data as a basis for complex calculations (based on Monte Carlo Simulation) to determine the acceptable risk and the optimum inspection interval. Currently the facilities protection department of the Sonatrach's transportation branch has no risk-based models that consider both the risk of failure along the pipeline network and the cost of inspection as a basis for management decisions on ILI (in-line) inspection scheduling and repair activities. Furthermore the ILI inspection decision is generally based on a fully subjective assessment. The facilities protection department does a good job of maintaining the pipelines, but the decision as to where to allocate resources and when in some cases may be a reactive measure. The present study applies risk-based model to show that the accepted risk has a quantifiable cost commensurate with the accuracy of the data used in the risk assessment process. The proper use of risk assessment / risk management principles and tools in the present study can help the pipeline operator to maintain the flow of pipeline integrity data and the analysis of this data. In the other hand the risk can be estimated and its attributes can be defined through an algorithm (series of relationships and mathematical simulations). This risk-based model may aid in the rational, prioritisation of resources and identification of improvement opportunities.

Keywords: Risk-based inspection, In line inspection, Corroded pipelines, Total business impact.

1.INTRODUCTION:

During the last decade, the reported incidents, and their impact on the environment have been steadily increasing in the transportation branch of Sonatrach. Furthermore the increased public and regulatory attention to the pipeline industry has prompted operators to look beyond pipeline compliance maintenance and inspection programs into enhanced risk integrity management. Recent high profile failures in the gas and oil transmission pipelines, such as:

The January 22, 1995 OK1 pipeline 34" failure in Oued -Seguin (MILA in east of Algeria), the September 23, 1997 OK1 pipeline 34" failure, and the major accident in 1992 of the GK2 42", has refocused attention at the risk mitigation measures that the company should take above and beyond standard code compliance. An important number of incidents are due to subsurface corrosion and the others have historically been related to Third Party damage.

Some of these may be avoidable through an integrated risk integrity program. Several companies have acknowledged the technical and economical benefits of pipeline risk assessment methodologies as an integral part of pipeline operators overall risk management program. Formalised risk management programs can be used as an alternative approach to pipeline operator so that higher integrity and safety standards can be achieved by:

- Identifying pipeline-specific risks
- Allocating resources to the most effective risk control activities
- Monitoring safety and environment
- Performance leading to superior safety and environmental protection
- Improving efficiency and reliability of pipeline operations

2.BACKGROUND:

The pipeline industry is a profitable element of hydrocarbon business in Algeria. The Pipelines of the transportation branch of Sonatrach branch suffer degradation due to a variety of causes. However the main cause of many pipelines deterioration is corrosion. The appropriate remedy for this problem used by the company is cathodic protection. Moreover a good pipeline protection requires a regular monitoring of the pipe thickness, so that further measures can be established either by reinforcing the cathodic protection through higher electric potential, or a rehabilitation of the pipeline if the degradation achieves a advanced level. In line inspection is one of the main methods used by the company to monitor the pipeline thickness. The gap registered is that inspection intervals are determined subjectively following personnel judgements. Furthermore there is no quantified method to set precisely the right inspection intervals. For that purpose I propose the application of Risk Based Inspection as it enables the organisation to identify inspection intervals through a quantified Risk-Cost optimisation.

3.INSPECTION DEFINITION:

Inspection refers to the evaluation of the quality of some characteristic in relation with a standard or a specification. The main purpose of inspection is to determine whether components, systems or products conform to specifications. An overall Inspection consists of the following series of actions:

- Interpretation of the specifications
- Measurement and comparison with a specification
- Judging Conformance
- Classification of conforming cases
- Classification of non-conforming cases
- Recording and reporting the data obtained.

Risk based approach is a systematic approach[1] that helps facilities managers to make business decisions regarding inspection and maintenance spending. The risk-based approach has been introduced to industry after two eras of inspection strategies fig 1, which are time-based inspection where inspection interval was defined as a fixed time period for each equipment and condition based inspection where inspection interval depends on the equipment condition. The new approach is based on evaluating both the probability of failure and the associated consequence. The base of technical literature dealing with risk analysis and integrity management using the risk-based approach is extensive. As applied to pipelines, risk is usually defined as the probability of failure multiplied by consequence of its occurrence.

The consequence of failure is a topic that is handled according to the impact of the failure on business, personnel, assets, and environment.

The probability of failure is related to the number of features in a pipe section, accuracy of the inspection data, accuracy of the modelling technique, consistency of operating conditions and many other factors. Furthermore risk based analysis has considered for a long time the upset conditions (worst case approach) where the pipeline is supposed to be exposed to operating conditions at the upper design limit.

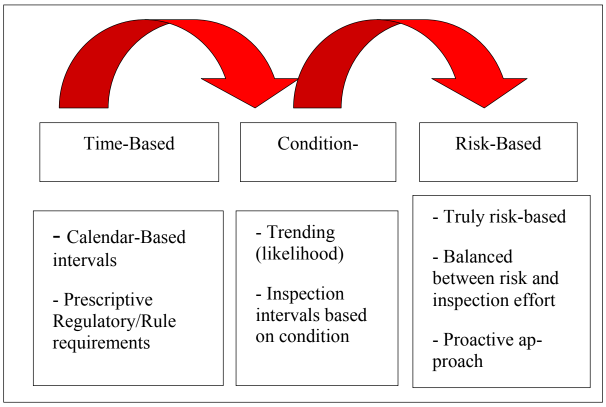


Fig 1 The Evolution of Inspection Strategies

4.RISK MANAGEMENT:

Risk has only two dimensions:

Likelihood – the chance or uncertainty of the event happening

Consequence – positive or negative consequences that may result from the event

There are two main types of risk:

- Business risk, which considers both chance of gain or loss.
- Pure risk which considers only have one outcome, that of loss.

Risk management principally deals with managing the pure risk. However business risks named also speculative risks are generally the concerns of financial managers.

Risk is an essential element of business and every organisation at some point will take risks, it believes to be reasonable, so as to try and gain. In order to flourish and thrive, the organisations manage different risks to a level called as low as reasonably practicable (ALARP). An effective management of risks within the organisation helps it to harvest many benefits such as financial gain by reducing losses and increasing incomes down to employee benefits through reducing major losses resulted of accidents. Reducing the risk level can be achieved by handling two key drivers, which are:

- Reducing the probability of occurrence through preventing the occurrence of incidents (preventive measures).
- Reducing the consequences of such incidents through mitigating the impact of such incidents to:
    - Asset
    - Personnel
    - Production
    - Environment

5.DEFINITION OF RBI:

RBI is a risk assessment and management process[2] that is focused on failure modes initiated by material deterioration, and controlled primarily through structure inspection. RBI combines risk assessment and risk management techniques with all inspection activities, such as planning, inspecting, documentation and data analysis, to develop inspection plans that direct inspections towards the areas of highest risk. RBI can be applied to all types of material deterioration processes that may cause loss of integrity for pressure retaining equipment.

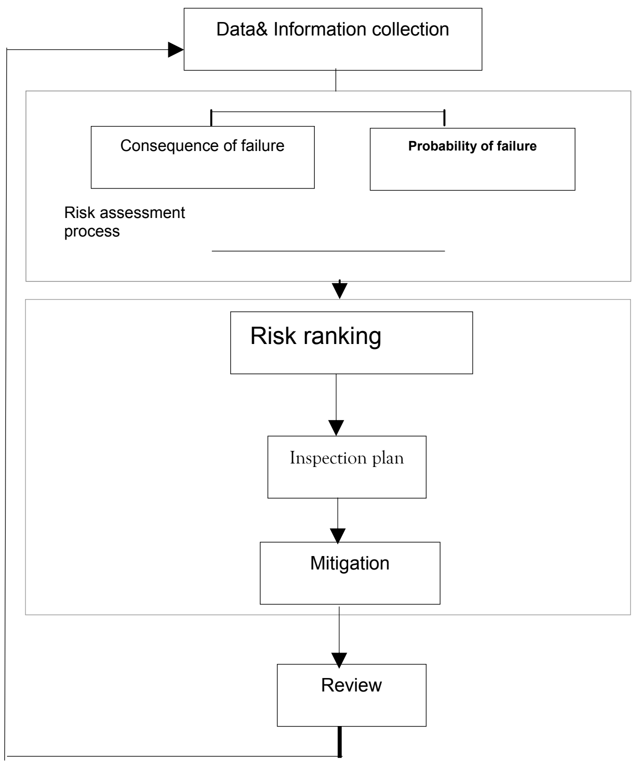


Fig. 2 RBI methodology

6.WHY RBI ?

The reasons for operators to adopt a risk based approach in the management of their pipeline networks can be varied. It is generally agreed that one of the main drivers is to optimise the costs of dealing with risks related to business and statutory obligations for Health and Safety. However the main reason for carrying out an RBI analysis is to manage properly the likelihood and consequences of network failure to an acceptable level and thereby avoid unreasonable risks of harm to people and environment. In the other hand RBI enables operators to control industrial losses since network failures have always a direct or indirect effect on the business:

For example:

- Lost production,
- Costs of follow-up to an incident such as investigation, replacement of the damaged pipe segment and its auxiliary equipments (valves, diaphragms, etc)
- Loss of any public image the operator may have established within the community,
- Higher insurance premiums,
- Costs of legal action

7.BENEFIT OF AN RBI PROGRAMME:

The basic benefits of an RBI program are:

- The capability to define and measure risk, by then creating a powerful tool for managing pipelines inspection in the organisation.

- Allows management to review safety in an integrated cost effective manner.

- Systematically reduces the likelihood of failure by making better use of inspection resources.

- Prioritise investments in inspection, rehabilitation, and renewal along the pipeline network.

Different consequences may arise due to pipeline failure due to different types of risk. Pipeline operators may consider potential financial consequences as well as Health and Safety issues. The RBI programme ensures that financial considerations and broader company concerns do not alter or reduce the importance of personnel safety.

8.DIFFICULTIES IN RBI PROGRAMME IMPLEMENTATION:

Benefits of an RBI programme may take a long time to emerge and the cost of implementing and maintaining the RBI programme can be high. In addition to the cost and commitment involved in adopting the method and the drain on resources, particularly in implementing the RBI programme can be intimidating. Furthermore

RBI programmes typically require large amounts of up to date and accurate data.

However in real life the existing data is often out of date, inaccurate, and difficult to find or missing.

As an overall there are 5 main reasons why RBI programmes generate disappointment. These are:

1. Problems with basic pipeline network data (bad quality)

2. RBI methodology too complicated for company team members especially for non-technical members.

3. Analysts did not understand company systems

4. Lack of commitment by some or all of the organisation managers

5. No measurable return on investment.

9.THE APPLICATION OF RBI ON THE PIPELINE SEGMENT (SCE-TA SKIKDA):

The chosen pipeline segment for this project is a 143.56km long, 40" main gas transportation pipeline in Algeria. It relates the boosting station E located in Ain Djessar with the pipeline terminal of Skikda (510 Km east Algeria). Then the gas is distributed to the LNG plant, the petrochemical plant, and the refinery of Skikda. It is an onshore pipeline constructed in API 5L X52 and X70, with a nominal wall thickness varying from 12.7 to 19.43 mm, and it is over ten years into its period of operation, with a design life of 25 years. The pipeline is currently operated at a pressure of 45 Bara where the maximum allowable operating pressure (MAOP) is 50 Bara. The susceptibility of the pipeline to internal corrosion threats including microbial corrosion, sulphide stress corrosion, CO2 corrosion and solids erosion is very low due to gas high quality.

10.FAILURE PROBABILITY IN THE RISK ASSESSMENT:

There are three approaches to probability of failure estimation in the risk estimation. The traditional deterministic approach to the assessment of pipeline corrosion risks which is typically based on the judgement of “competent engineering personnel” as the paradigm for identifying risk. Semi-quantitative (deterministic) methods essentially substitute the analytic of science for the fallible judgement of “competent personnel”, with the explicit notion that scientific treatment provides a superior basis for reliable prediction. Probabilistic approach deals with uncertainties in the input data through employing probability density distributions. For the probabilistic approach, statistical analyses of the input data are performed in order to discern the form of each probability density function. However, limited knowledge of certain of the primary input variables did preclude statistical analysis. In these, instances a normal distribution of values were assumed (the accident costs was assumed to be normally distributed)

11.THE KEY ELEMENTS CONSIDERED IN THE PROBAILISTIC APPROACH:

The factors affecting the selection of an optimum inspection interval in the probailistic project[3] are shown in the figure below:

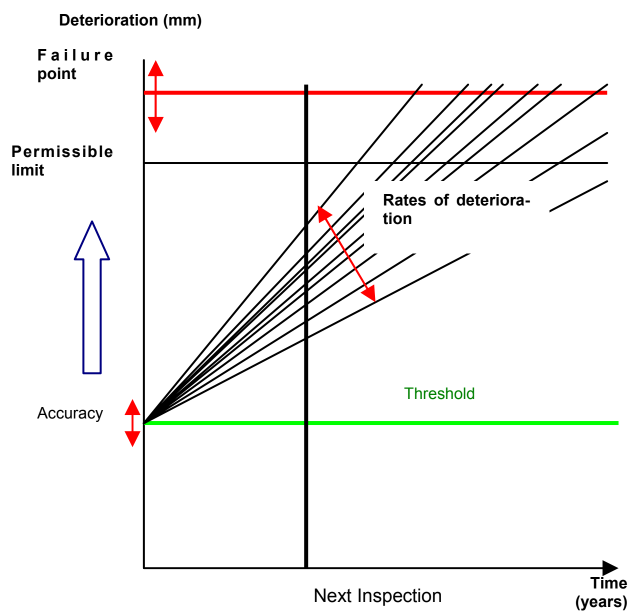


Fig 3 The measurement accuracy

11.1.The Point of Failure:

The point of failure distribution corresponds to the distribution of functional failure that means where generally leaks are developed and may lead to accidents .The mean value of the distribution is estimated according to previous accident data occurring along the pipeline and using personal judgement. The point of failure estimation depends on the perception of the organisation to failure. There are several distributions that may be considered according to the organisation being risk adverse or risk taker.

11.2.The Rate of Deterioration:

The rate of deterioration answers on how fast the deterioration would occur. It is obtained from the measures of the smart (ILI) pig inspection. The rate of deterioration in calculated using the following formula (1):

$$Rate\,of\,deterioration(mm/year)=\frac{[Ep(measured)-Ep(nominale)]}{[t(current)-to)]} \quad (1)$$

Ep (Measured): Measured thickness

Ep (nominal): Nominal thickness

t (current): Current time

to: Initial time

The rate of deterioration is the main element in inspection interval determination. In addition the rate of deterioration is the first source of uncertainty, see Fig 3. The lognormal distribution presents a safer assumption to the rate of deterioration .

11.3.The Measurement Accuracy:

The accuracy of measurement depends on the tool used during inspection. Measurement accuracy is generally provided by the designer of the inspection tool .

11.4.The Thresholds:

The recorded threshold defines the sensitivity of data recording during the run of the smart pig (Rosen smart pig documentation). Rosen smart ILI pig is an ultrasonic inspection pig, which was used during the last inspection of the gas pipeline network GK1 (Hassi-R'mel reservoir-Gas pipeline terminal). The recorded threshold can be translated into the minimum depth of metal loss features to be reported.

11.5.The Cost of Inspection:

That corresponds to the direct and the penalty cost of inspection; such information is provided through CBS (cost breakdown structure) by the production, pipeline engineers and the inspection team (i.e. contractor). It is too complex to consider every element of the cost breakdown structure; furthermore most of the costs can be neglected comparing with the cost of the operation itself (Cleaning + Scanning)

11.6.The Current Thickness:

It corresponds to the current degree of deterioration measured; the ILI inspection tool provides such information. The current thickness has different values along the pipeline. A matching process was followed using crystal ball software to identify the distribution that fit closely to the measured sample.

11.7.The Cost of Failure:

The cost of failure corresponds to the financial impact of downtime, secondary damage, injuries, and environment.

The potential consequences are very dependent on the operating pressure, pipeline length, diameter and content and size of the failure/release. The latter has been based on historical failure rates, for the eastern gas pipeline network "RTE". Potential fatalities, damage to adjacent installations and environment are assessed using a cost breakdown structure reflecting each element of the whole accident cost.

The consequences evaluated according to historical data including:

- Consequential production losses
- Contract penalties
- Cost of repairing the pipeline
- Cost of repairing any damage to adjacent installations and environment
- Potential fatalities
- Cost of negative publicity

12.FAILURE PROBABILITY ASSESSMENT

The basic concept of classical reliability theory involves the evaluation of the probability of failure by considering specific performance criteria and the associated load and resistance parameters; it is the functional relationships that define load and resistance that is of primary interest, where mathematically this is generally defined by the following "limit state" equation [4]:

$$G(x) = R(x) - L(x) \tag{2}$$

Where R is "Resistance" (or strength), and L is "Load". The conditions for which failures will occur are those when the random parameter variables which define the loads exceed those which define variable resistances (i.e. when G (x) < 0); the points at which failures are likely to commence therefore, are where the load and resistance variables are equal. This is the limit state, which if over-stepped, would cause a failure to occur and is definable for all G (x) = 0.

The "failure" delineates the boundary between the safe and unsafe regions in variable parameter space and represents a state beyond which a pipeline can no longer fulfil the function for which it was originally designed. Fig 6 illustrates the service limit assessment –probability density distributions of cumulative corrosion for TIME increments T1 and T2 with respect to the corrosion allowance

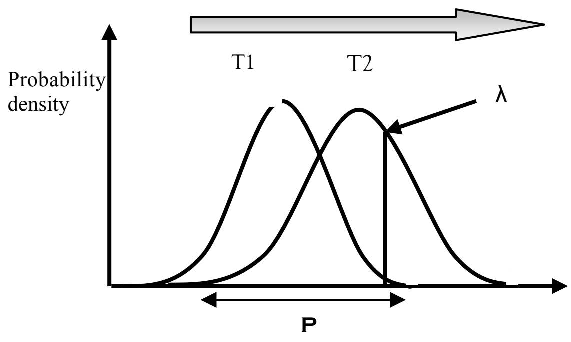


Fig (4) Probability of failure determination

13.MONTE CARLO SIMULATION:

The numerical technique, Monte Carlo simulation, involves the random sampling of the "load" and "resistance" variables to artificially simulate a large number of experiments and to observe the outcome. In the case of corrosion failure probabilities analysis involves sampling each of the random variables from their respective distributions and evaluating the failure surface considering the point of failure distribution as a strength random variable and the thickness at time t as a load random variable.

(Definable for all G (x)= 0) as the limit state for those values to determine whether a failure situation (which is definable for all G (x)< 0), is likely to occur Fig 7.3. This artificial experiment is repeated many times, each time with a new random vector of variables. Therefore for N trials, the probability of failure is determined as:

$$P_f = \frac{n(G(x) < 0)}{N} \tag{3}$$

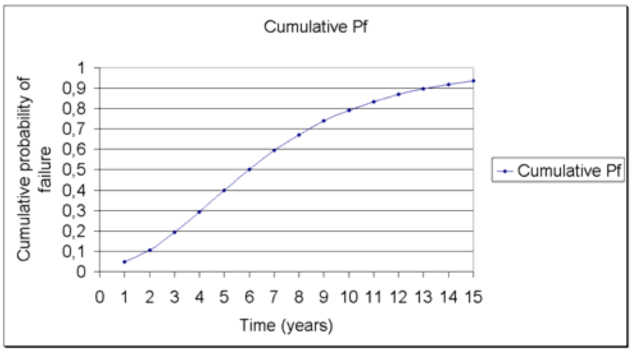
Where n (G (x) <0) denotes the number of trials for which

G (x) <0:

In the case of Monte Carlo simulation, there is an obvious relationship between the number of trials N and the degree of accuracy on Pf. By performing a large number of iterations, the ratio of the number of failure outcomes to the total number of iterations tends to the exact probability of failure. In the present study the Monte Carlo simulation is done using Crystal Ball software.

The results of Monte Carlo Simulation are presented below

In the fig (5)



Fig(5) Failure Probability

14.THE COST-RISK ANALYSIS:

Financial incentives are the main reason for RBI implementation. In practice organisations would spend money through inspection in order to reduce risks to an acceptable level; however the capital spent on such inspections must be weighed up against the potential benefits, which should of course be greater than the cost outlay.

There are many occasions where this is not the case and it is not cost effective especially when carrying out expensive inspection such as ILI (In Line Inspection). The cost risk analysis is the suitable method to set the optimum inspection interval considering both inspection cost and risk financial impact. The decisions made according to cost risk analysis are based on the magnitude of potential losses, control measure costs and are influenced by the magnitude of possible losses in relation with risk control costs as it is shown in fig (6).

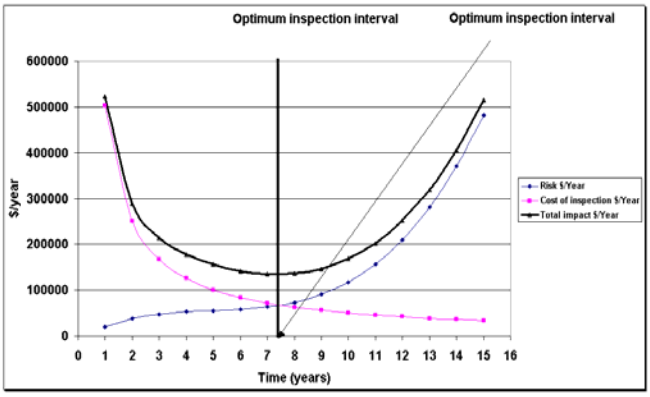


Fig (6) The optimum inspection interval

15. CONCLUSIONS AND RECOMMENDATIONS:

Reliability based inspection assessment combined with cost-risk analysis is an efficient tool which leads to more informed inspection and enables the organisation to identify cost effective inspection interval objectively "Optimum inspection interval"

Higher benefits are gained from more informed inspection since it enables pipeline industry to set inspection priorities

on the basis of the specific risk of failure and able to improve targeting and timing of inspections. The cost-risk approach offers industry the potential benefits of:

- Improved management of Health and Safety and other risks of network failure.
- Timely identification and repair or replacement of deteriorating pipelines segments.
- Cost savings by eliminating ineffective inspection, extending inspection intervals Reliability risk based inspection assists industry and the regulator to identify the most suitable inspection interval and best practices for pipeline integrity management.

It will be of particular use for costly inspection such as ILI. It will also interest pipeline engineers, safety managers, site inspectors and others involved in industrial risk assessment.

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