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AN EXTERNAL CORROSION DIRECT ASSESSMENT MODULE FOR A PIPELINE INTEGRITY MANAGEMENT SYSTEM

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ABSTRACT

A significant part of the high pressure gas transport system of Gasunie cannot be examined by in-line inspection techniques. To ensure safe operation of these pipelines, an External Corrosion Direct Assessment (ECDA) module for *PIMSLIDER* (a pipeline integrity management system) is currently under development. The functional specifications of this module are based on NACE RP0502-2002, a recommended practice for ECDA. In addition to this, a new probabilistic methodology has been adopted, to take account for uncertainties associated with ECDA and to quantify the contributions from aboveground surveys and excavations to the integrity of a pipeline. This methodology, which is based on Structural Reliability Analysis (SRA) and Bayesian updating techniques, is presented in more detail in paper IPC2006-10092 of this conference.

The DA module of *PIMSLIDER* enables computerized storage, retrieval and processing of all appropriate pipeline data and therefore guarantees highly accurate, reproducible and time saving integrity analyses of the Gasunie grid. Another important function of this system is the ability to use the complete database of all pipelines to pre-assess the integrity of a particular pipeline. This automated retrieval of data from pipelines with similar characteristics and/or environmental conditions results in a substantial increase of accessible data and enables Gasunie to improve the reliability of applied statistics throughout the process. As a consequence, the overall cost of inspections and excavations can be greatly reduced.

In the Pre-Assessment phase, the DA module assists the integrity manager in gathering and analyzing data necessary to determine the current condition of a pipeline. After collection and visualization of the available data, the user can identify suitable ECDA regions. Furthermore, the gathered data are used to construct prior distributions of parameters relevant to the SRA model, such as the number and size of corrosion defects and pipeline-related parameters. In the Indirect Inspections step, the DA module allows the user to store and analyze the data from aboveground surveys, in order to identify and define the severity of coating faults and areas at which corrosion activity may occur. The probabilistic methodology accounts for the individual performance of each applied survey technique in terms of missed defects and false indications, in general a major source of uncertainty in ECDA. In the Direct Examinations phase, excavations are carried out to collect data to assess possible corrosion activity. Subsequently, the ECDA module uses this information to update, among other things, the parameters concerning the performance of survey techniques, the number of defects and the corrosion rate. As a result, updated failure frequencies are calculated for each ECDA-region (after each excavation if required), which are then used by the DA module to advise the integrity manager if additional

mitigating activities are necessary, or by defining a reassessment interval.

HISTORICAL BACKGROUND

Gasunie owns ± 12,000 km of high-pressure pipeline in the Netherlands. The major part of this grid has been constructed in the period 1960-1980. Aging of the grid results, to an increasing extent, in locations with deteriorated coating and reduced wall thickness, caused by corrosion as well as mechanical damage. On top of this, Microbiologically Influenced Corrosion (MIC) was detected on the high-pressure grid in 1999. This strengthened the opinion of the Asset Management department that reconsideration of the prevailing policy on pipeline management was required in order to maintain the high standard on risk- and integrity control within Gasunie. As a result, it was concluded that the policy on pipeline management had to change from verification of preventive measures to verification of the actual condition of the pipelines.

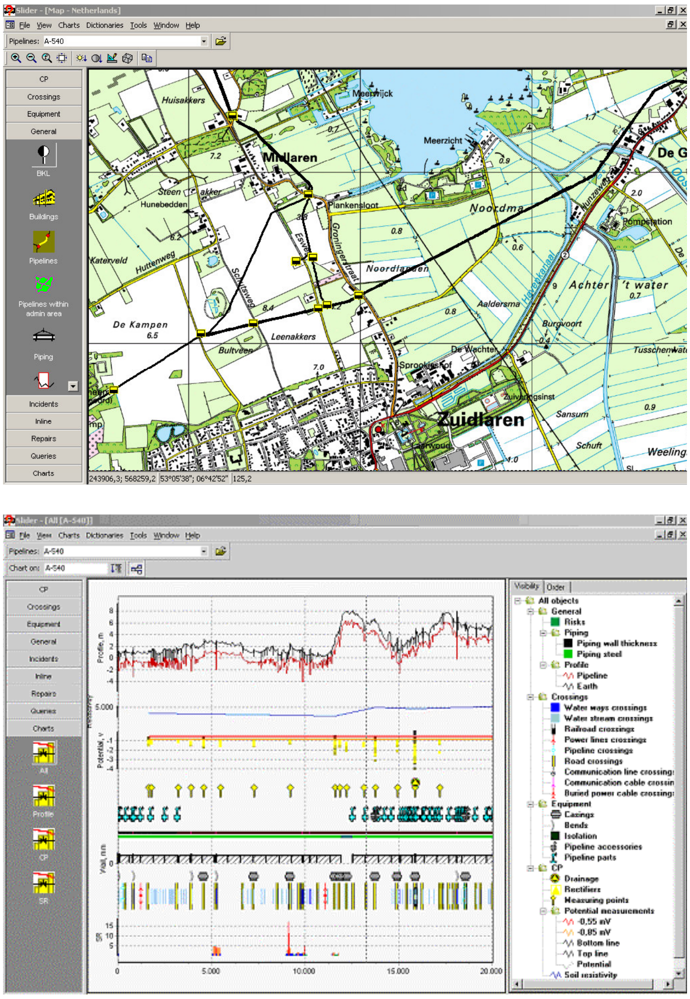
As a consequence the In-Line Inspection (ILI) program was intensified (5-10 ILI-runs per year), which obviously resulted in a significant increase of the amount of inspection data to analyze. Simultaneously a new IT solution was implemented, in order to ensure efficient and reliable data processing and to support all processes on pipeline integrity management (*PIMSLIDER*).

Since only ± 50% of the pipelines of Gasunie are conventionally piggable, it was decided in 2005 to develop a computerized Direct Assessment module for *PIMSLIDER*. The purpose of this module is to enable the integrity analyses of unpiggable pipelines, meeting the requirements of the ECDA process described in NACE RP0502-2002.[1] This paper focuses on the Direct Assessment module of *PIMSLIDER*, which is currently being developed by Gasunie in cooperation with AFAA and ATP Neftegazsystema.

The *PIMSLIDER* system[2] consists of a number of modules, of which the heart is formed by Slider. The modules cover the whole range of data management (pipeline-, environmental- and incident data), Cathodic Protection (CP) system monitoring data, analyses of ILI data, defect assessments and quantitative risk calculations, in consideration of the economics involved. A brief description of the modules is given in the following paragraphs.

Slider (including Archives and Arclib)

This module can be seen as the heart of the system and is used for storage of all pipeline-related data concerning the position of the pipeline, equipment, crossings, operational data, ILI data, maps, photographs, population density along the pipeline etc. It is mainly used for information retrieval. The operator can track the relationships between various figures, as illustrated in Figure 1 and schedule actions accordingly (surveys, repairs, maintenance etc).



FIGURES 1A AND 1B: EXAMPLES FROM *PIMSLIDER*; GEOGRAPHICAL POSITION OF A PIPELINE AND PIPELINE RELATED AND OPERATIONAL DATA

CP Expert

This module enables the operator to analyze the effectiveness and the efficiency of an existing CP system. A modeling function supports the CP engineer in the design of the CP system in case of construction or modification of a pipeline. CP Expert utilizes data from Slider. It also allows calculation of the optimum operation mode for CP stations, to ensure reliable and effective protection of the pipeline.

GDLI

All the pipeline incidents that have occurred on the Gasunie grid in the past have been stored in the GDLI database. The GDLI module is designed for the analysis and visualization of these incidents.

Inpipe

Inpipe enables the analysis of any kind of pipeline defect based on the data provided by ILI tools. This involves the linking of the features to map coordinates and an accurate positioning of the in-line data along a three-dimensional model of the pipeline. The software supports the calculation of the remaining strength of the pipeline using the methods ASME B31G and RSTRENG.

Rehab Expert

This module enables the operator to assess the significance of defects in the pipeline and to define the most appropriate repair program. Defects can be assessed by the use of defect-geometry data as reported by the ILI contractor, or by the use of the raw data from the inspection tool (such as individual sensor signals). When more than one ILI has been performed, an individual defect can be assessed at different stages of its lifetime. This enables the operator to optimize the economics of his inspection and repair program.

PSL

This module is the core element of the system with respect to risk management of gas transmission pipelines. It is a hazard- and risk-assessment package, which enables automatic quantitative risk calculations to be made at any moment for any pipeline in the Slider database. In addition, it enables the engineer to calculate the effect of risk mitigating measures on an existing pipeline. PSL is based on approaches and assumptions used in PIPESAFE, a risk-assessment model for gas transmission pipelines that was developed by a group of international gas transmission companies.

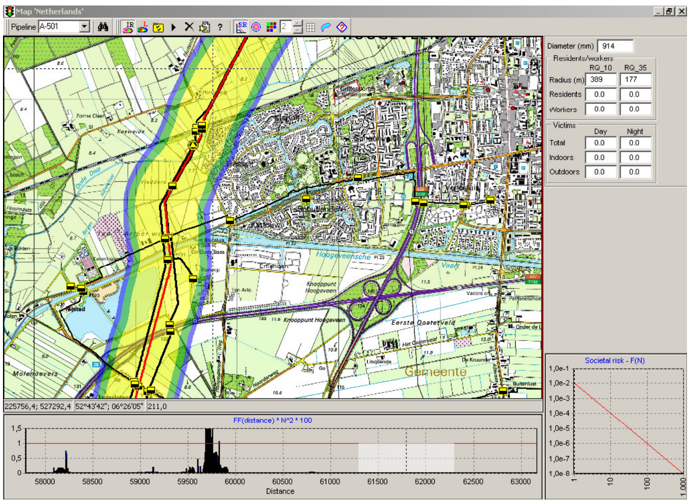


FIGURE 2: AN EXAMPLE FROM THE PSL MODULE; THE RELATIVE SOCIETAL RISK

Risk Expert

This module, a ranking tool for operational pipelines, enables the operator to carry out a relative risk assessment of the pipeline. It is a tool for prioritization of maintenance and inspection programs. This data-based method uses a model that identifies and quantifies the major threats and consequences of pipeline objects and the pipeline environment. The likelihood of all threats is quantified based on operational experience, expert judgment or industry experience. The calculations are performed for all pipeline sections, defined here as parts of the pipeline with similar conditions. This makes it possible to identify local high-risk areas.

THE DIRECT ASSESSMENT MODULE

The DA module that is currently being developed is based on the NACE Recommended Practice for ECDA[1] in combination with SRA. The ECDA process integrates information on the pipeline's physical characteristics including operating history (pre-assessment) with data from multiple field examinations (indirect inspections) and pipe surface evaluations (direct examinations). SRA in combination with Bayesian statistics allows one to quantify the effect of inspections and excavations on the integrity level of the pipeline and, as a consequence, supports the integrity manager in determining the optimum inspection program.[3-7] The increase in reliability that can be achieved by application of SRA and Bayesian statistics, can result in substantial savings on the cost of inspections.

Of many known possible failure modes, external corrosion is modeled in detail. Contributions from other failure modes are represented by constants. The model as developed by Gasunie originally in 2004[8] has been improved significantly since, through an intensive collaboration between Gasunie Engineering & Technology and AFAA.[9] In accordance with NACE RP0502-2002, the module consists of the following parts, which will each be explained further in this paper:

- Pre-Assessment
- Indirect Inspections
- Direct Examination and Post-Assessment

The Pre-Assessment includes data collection and visualization, the identification of so-called ECDA regions and the calculation of the a priori probability of failure of the pipeline. The objective of the Indirect Inspections step is to identify and define the severity of coating faults, other anomalies and areas at which corrosion activity might be occurring. The Direct Examinations are used to determine which indications from the indirect inspections are most severe, to collect data to assess corrosion activity and to repair critical defects. Finally, the objectives of the Post-Assessment are to define reassessment intervals and to assess the overall effectiveness of the ECDA process. In this step all ECDA-regions are integrated and the failure frequencies of other failure modes are included.

FAILURE MODES

When the integrity management of a pipeline is considered, all the potential threats to this pipeline (failure modes) have to be considered. For the DA module the scheme of the ASME[10] is used. In this module the integrity of a pipeline is evaluated by assessing the failure rate, expressed as the probability of failure per km per year.

The direct assessment of external corrosion is modeled in detail. If required, models for other relevant failure modes can be added to the DA module in the future. At present, the contributions of other failure modes to the overall integrity of the pipeline are modeled in a simple, straightforward manner, namely as a constant.

Classification of failure modes

In general, the first step in pipeline integrity management is to identify the potential existing threats. All possible threats to the integrity of the pipeline need to be taken into consideration. The Pipeline Research Committee International (PRCI) has analyzed and classified a large number of gas pipeline incidents in twenty-two different causes. Subsequently, the ASME has grouped these causes in nine different categories.[10] Table 1 contains an overview of those failure modes which are considered to be most relevant. In the DA module, a division in failure modes to the level of the subcategories mentioned in this table is used.

Main category	Subcategory	Failure mode
Time-dependent	External corrosion	
	Internal corrosion	
	Stress Corrosion Cracking (SCC)	
Time-independent internal cause	Manufacturing related defects	• Defective pipe seam • Defective pipe
	Welding/fabrication related	• Defective girth weld • Defective fabrication weld (fittings a.o.)
	Equipment	
Time-independent external cause (Incl. operations)	Third party damage	• Immediate failure • Previously damaged pipe
	Incorrect operations	
	Weather related and outside force	• Cold weather • Lightning • Heavy rains or floods • Ground movements

TABLE 1: OVERVIEW OF FAILURE MODES

Important failure modes at Gasunie

All incidents that have occurred in the past on the Gasunie grid have been recorded in the Gasunie Database for Pipeline Incidents. The incidents include leaks and ruptures, but also coating damage and damage caused by corrosion. The main failure modes for Gasunie are:

- External interference (third party damage) 71%
- External corrosion 6%
- Material and (mostly) welding defects 4%
- Ground movement (sinking) 2%

Therefore it can be concluded that for Gasunie the most important failure modes are external corrosion and external interference. External interference and its consequences are already covered in detail by the PSL module. External corrosion will be covered in the future by the DA module. This failure mode is becoming increasingly important due to the time-dependent nature of corrosion and the ageing of the pipeline grid.

Comparison of the incident database of Gasunie with other studies (by EGIG, UKOPA and PRCI),[11-13] shows that for many other pipeline operators material and welding defects and internal corrosion are also significant failure modes to consider. With respect to external corrosion, Gasunie holds the opinion that external corrosion should not contribute significantly to the total incident frequency. At present, a criterion for the maximum failure rate has yet to be determined.

Modeling of external corrosion

For External Corrosion Direct Assessment (ECDA), the NACE Recommended Practice is followed. In addition, a probabilistic model has been developed, based on the work of Francis et al.[9] This model will be implemented in the DA module of *PIMSLIDER* and is presented in more detail in paper IPC2006-10092 of this conference.

For other corrosion Direct Assessments, such as Internal Corrosion (ICDA) and Stress Corrosion Cracking (SCCDA), recommended practices have been developed by the NACE, but no comprehensive models are readily available yet. The set-up of these practices is largely comparable to that for external corrosion. If necessary, models for these methodologies can be added to *PIMSLIDER* when corresponding probabilistic models become available.

A variety of causes is known to lead to external corrosion. When a coating defect is present (however small) and the CP applied is not sufficient (or even too high), corrosion reactions may occur under influence of stray-currents, AC-interference, bacteria (MIC), tensile stress (SCC), shielding of CP or overprotection. MIC, SCC, shielding of CP and overprotection are not covered by ECDA. Since Microbiologically Influenced Corrosion (MIC) is often associated with disbonded coating (i.e. shielding of CP), ECDA should not be applied in areas where MIC is known to occur.

Other forms such as general corrosion, AC corrosion or stray current corrosion are in principle covered by ECDA. Finding MIC using ECDA techniques may not be ruled out completely, since experience with MIC at Gasunie has turned out that this form of corrosion often occurs in combination with (or leads to) degenerated (bituminous) coating. This implies that an initially shielded defect suffering from MIC may eventually become accessible to CP currents due to degeneration of the coating, thereby enabling aboveground detection of the defect.

PRE-ASSESSMENT

In this section the Pre-Assessment step is described in general. In addition it will be discussed which data are considered to be relevant for Gasunie to implement in the DA-module and how this can be done. Finally, it is described how the relevant data can be used to quantify the integrity of a pipeline, using the SRA based approach developed by Francis et al.[3-7,9]

There are essentially three purposes of the Pre-Assessment step in the DA module, namely:

- Data collection and visualization
- To identify ECDA regions
- To establish the prior condition of the pipeline

Category	Data elements
Pipe-related	• Material and grade • Diameter • Wall thickness
Construction -related	• Year installed • Year of route change/modification • Locations of valves, clamps, supports, taps, couplings, insulating joints etc. • Locations and material of casings • Depth of cover • Underwater sections; river crossings • Locations of river weights and anchors
Soils/environmental	• Soil characteristics/types, including o Type of soil (e.g. presence of peat, anaerobic soils) o Electrical influence (e.g. proximity of DC railways, AC power lines) o Pollution o Drainage o Land use (e.g. paved roads)
Corrosion control	• Locations of rectifiers • Test point locations • Type of coating • CP survey data/history
Operational data	• Pipe inspection reports, excavation reports • Repair history/record (e.g. repair sleeves, repair locations) • Data from previous aboveground surveys • Inline inspection data

TABLE 2: RELEVANT ECDA DATA ELEMENTS FOR GASUNIE

Data collection and visualization

Consistent with the NACE, this first part of the Pre-Assessment requires a sufficient amount of data collection, integration and analysis. All parameters that impact the selection of the Indirect Inspection tools and the definition of the ECDA regions shall be considered for initial ECDA applications. Specifically for the Gasunie grid, the elements listed in Table 2 have been identified as essential information in order to assess the prior condition of the pipeline.

Identification of ECDA regions

In the second part of the Pre-Assessment, the gathered information is used to define a number of ECDA regions. An ECDA region consists of one (or more) section(s) of the pipeline with similar physical characteristics, corrosion histories, expected future corrosion conditions and where the same indirect inspection tools can be used. After the user has defined the parameters and criteria that are to be considered for identification of ECDA regions, the DA module calculates the regions. These ECDA regions can then assist the user throughout the Direct Assessment process to interpret results, to decide which indirect inspection tools can be used and where direct examinations should be performed.

The prior condition of the pipeline

In the third part of the Pre-Assessment, the prior condition of the pipeline under investigation is quantified, by assessing the failure probability of each ECDA region. In order to calculate this probability of failure, estimations must be made for, among other things, the following key parameters:

- Time of initiation of corrosion defects; during the time period between the year of construction and the time of initiation, the conditions for corrosion are being established and the first instances of early corrosion growth take place.
- Defect density (both for coating and corrosion defects); this firstly consists of a starting value representing the damages originating from the transportation and construction phases of the pipeline. Secondly, this consists of a term representing the rate of introduction of new defects, starting from the time of initiation.
- Defect depth; a certain initial distribution for the defect depth is assumed at the time of initiation, after which it gradually increases, depending on the corrosion rate.
- Corrosion rate; the rate at which the defect depth grows. This is in general a major cause of uncertainty and is likely to vary considerably between pipelines.

These estimations will be based on the information that was collected during the first part of the Pre-Assessment. Data regarding factors such as the age of the pipeline, coating type, level of CP, soil conditions etc are appropriately combined to determine prior distributions of the densities of coating and corrosion defects and prior distributions defining the geometry of corrosion defects. If relevant information is not available for a specific pipeline, the user can fall back on the complete database of all pipelines for the required analysis. This functionality (automatic retrieval of data from pipelines with similar specifications or environmental conditions) results in a huge increase of accessible data (now and especially in future) and makes it possible to reduce the cost of inspections substantially by applying statistics. In practice, parameters concerning the geometry of the pipeline (e.g. wall thickness) or material properties (e.g. flow stress) are also subject to uncertainties, especially in the case of older pipelines. In the DA module, these quantities are treated as probability density functions as well, rather than using constant values.

To predict the failure pressure of part-wall corrosion defects in pipelines, guidelines from a Joint Industry Project, the Linepipe Corrosion Group Sponsored Project,[14,15] have been used, developed through a combination of analysis and full scale testing. The methods developed from this project have also been incorporated into a DNV Recommended Practice, RP-F101.[16] In these guidelines, which are based on plastic collapse, the critical defect depth a_c is defined by

$$\frac{a_c}{w} = \frac{\left(1 - \frac{\sigma_h}{\sigma_f}\right)}{\left(1 - \frac{\sigma_h}{Q\sigma_f}\right)} \tag{1}$$

where w is the wall thickness of the pipeline, σ_h is the hoop stress, σ_f is the flow stress and Q is known as the Folias factor, given by

$$Q = \sqrt{1 + 0.31\left(\frac{l}{\sqrt{Dw}}\right)^2} \tag{2}$$

where l is the longitudinal length of a defect and D is the outside diameter of the pipeline.

When appropriate prior distributions have been established for the relevant parameters, the probability that a single defect will fail can be calculated by the model. This probability is defined as the probability of a single defect exceeding a certain critical depth a_c within the time interval $[t_i, t_{age}]$, which is given by

$$P(a_c, t_{age}) = \int_{a_c}^{\infty} p(a, t_{age})\, da \tag{3}$$

where a is the defect depth, t_i is the time at which corrosion growth commenced and t_{age} is the age of the pipeline.

By combining the probability of failure for a single defect with the a priori defect density, the probability of failure for each ECDA region can be calculated.

INDIRECT INSPECTIONS

The objective of the Indirect Inspection step is to identify and define the severity of coating faults, other anomalies, and areas at which corrosion activity may have occurred or may be occurring. The NACE requires the use of at least two aboveground inspections over the entire length of each ECDA region. Within Gasunie, indirect inspections for ECDA purposes usually consist of the following measurements:

1. Direct Current Voltage Gradient (DCVG) survey: to detect and pinpoint coating defects along the pipeline
2. Close Interval Potential Survey (CIPS): to measure the on- and off-potentials over the pipeline, as well as the on- and off-potential gradients to remote earth. These measurements are used to determine whether a possible coating defect is sufficiently protected by the Cathodic Protection (CP) system
3. Wenner measurements: to measure the soil resistivity at regular intervals along the route
4. dGPS-measurements: to measure the position of coating defect indications, soil resistivity measurements and characteristic features along the pipeline

With regard to the DA module, complete derivations have been made by Francis et al[9] for situations where one of the following is applicable:

- Use of one coating survey
- Use of two coating surveys
- Use of one coating survey and one corrosion survey (along the whole length of the pipeline)
- Use of one coating survey and one selective corrosion survey (applied only at indications of the coating survey)

Figure 3 shows a photograph of a typical survey team. In the approach followed by Gasunie, CIPS is not used as a method to detect coating defects, but to assess corrosion activity at possible coating anomalies detected by DCVG. For this reason, CIPS is treated as a selective corrosion survey rather than as a coating survey. Gasunie Engineering & Technology is currently developing a new Coating Survey Set (CSS) in which the functionalities of DCVG, CIPS and dGPS are combined. Expectations are that the new equipment will significantly reduce the overall cost of indirect inspections and improve the quality of the acquired data.

FIGURE 3: A TYPICAL DGPS/DCVG/CIPS SURVEY TEAM IN ACTION FOR GASUNIE

Since no inspection technique is 100% reliable, it is important to take the performance of the used inspection tools into account, possibly depending on factors such as type of coating, soil conditions, depth of cover etc. This performance is characterized by the following two variables:

- Probability of Detection (PoD): the probability that a defect present is detected by the survey technique
- Probability of False Indication (PoFI): the probability that the survey technique gives an indication where no actual defect is present

The Indirect Inspection step can be divided in the following four parts:

1. Data storage: the data from the aboveground surveys are stored in a database for processing and for future reference.
2. Data processing, interpretation and visualization: if required, the data from the surveys can be corrected for factors such as the depth of cover or currents through the pipeline. Furthermore, the DA module calculates the so-called IR-free potential (the potential of the steel at the exact point where the surface of the steel meets the surrounding environment, not distorted by the soil resistance between reference electrode and the pipeline) and its uncertainty. The DA module presents the required data in a clear and comprehensive manner by plotting (combinations of) graphs on the screen, to simplify interpretation of complex data by the operator.
3. Generation of a priority list for direct examinations (excavations): This list will be generated based on certain criteria for parameters chosen by the operator, such as coating defect size, expected corrosion, soil resistivity etc or combinations thereof.
4. To establish the condition of the pipeline after the indirect inspections: based on the findings from the aboveground surveys, the distributions of the numbers of coating and corrosion defects are updated using Bayesian statistics. Obviously, the performance characteristics of the applied survey techniques play an important role in these calculations. The prior distributions of the PoD and the PoFI of a survey technique can be constructed from previous experience with the technique or from recommendations of the manufacturer.

DIRECT EXAMINATION AND POST-ASSESSMENT

Direct examination

In the Direct Examination step all ECDA-regions that have been inspected are evaluated sequentially, starting with the ECDA-region with the highest risk according to the Pre-Assessment step. This step is set up such that after each number of excavations the pipeline integrity can be evaluated. Based on the outcome of that evaluation, additional excavations may need to be carried out, after which the pipeline integrity must be evaluated again.

Based on the priority list from the two aboveground surveys, locations for bell hole excavations are selected. In general, excavations will take place at locations:

- where both surveys have indicated the presence of a defect; usually to determine the size of corrosion defects and repair critical defects (if any)
- where only one of the surveys has given an indication; usually to check the survey characteristics and to determine the size of any found corrosion defects
- where no indications were given; these excavations are generally referred to as blind digs, and may be used to assess the confidence in the probability of detection of the survey technique(s)

Model

Based on the findings during the excavations, the information used in the Pre-Assessment and the Indirect Inspections will be updated, including the following parameters:

- The survey characteristics PoD and PoFI of each survey technique
- The number of defects (coating and corrosion)
- The corrosion rate and the time of initiation
- The defect length and the critical defect depth

Based on these updates, new values are calculated for the probability of failure of a defect and per km of the ECDA-region. These calculations are performed for each ECDA-region. To illustrate the updating process, Figure 4 gives an example of the result of updating the coating defect density, represented by a normal distribution. The prior estimate can be based on information collected during the Pre-Assessment step (e.g. coating condition, age of the pipeline), but may also be deducted from previous surveys on other, similar pipelines. As soon as new information becomes available from the Indirect

Inspections, the prior distribution is updated using Bayesian statistics. The excavations will allow an update of the survey characteristics, after which the number of coating defects can be updated once more.

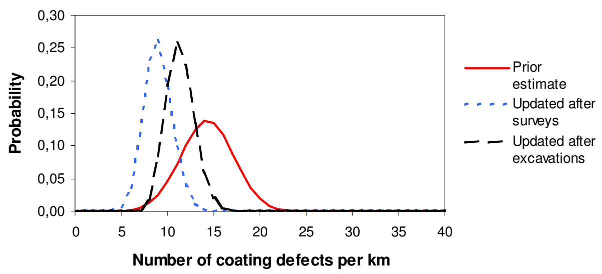


FIGURE 4: EXAMPLE OF NUMBER OF COATING DEFECTS BEFORE AND AFTER SURVEYS AND EXCAVATIONS

Figure 5 shows the effect of an ECDA on the probability of failure of a pipeline. Firstly, the probability of failure increases due to the growth of corrosion defects and the increasing number of defects. Secondly, the calculated probability of failure decreases as a result of the Indirect Inspections and Direct Examinations. Thirdly, the probability of failure will increase again due to ongoing corrosion processes.

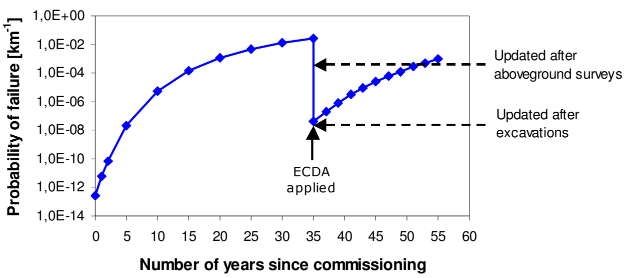


FIGURE 5: THE EFFECT OF AN ECDA ON THE PROBABILITY OF FAILURE OF A PIPELINE

For ECDA it is assumed that all found corrosion defects are repaired (or recoated). The repair of coating defects will not have a significant effect on the ECDA-calculations, but for consistency in the ECDA calculations it is assumed that all coating defects that are found, are repaired.

The updated probability of failure of a defect at the time of the excavations depends upon the updated value of the distribution of the defect depth, the distribution of the critical defect depth and the expected number of corrosion defects. The updated probability of failure per km at the time of the excavations depends on the updated distribution of failure of a defect and the length of the ECDA-region.

The probability of failure for a single defect will change with each excavation due to the changes in the corrosion rate distribution and the time of initiation. A confidence interval will be calculated for the probability of failure. As the number of excavations increases, the probability of failure per km will generally decrease, until the criterion for the probability of failure is met and sufficient excavations have been carried out.

Other ECDA regions

The ECDA-regions are treated sequentially, starting with the region with the highest initial risk. In some cases, the results from the calculations for an ECDA-region can be used as additional input for the next ECDA-region. The initial, pre-assessed values for the corrosion rate, the time of initiation and the defect density for that ECDA-region can for instance be replaced by the user with the values calculated for the ECDA-region with the higher initial risk. This should be repeated until all ECDA-regions have been covered.

Post-Assessment

According to the NACE, the objectives of the Post-Assessment are to define reassessment intervals and to assess the overall effectiveness of the ECDA process. For the developed SRA model, this step consists of the following calculations:

- calculate the probability of failure per km due to external corrosion for each ECDA-region for future years, based on the results from the Indirect Inspections and Direct Examinations
- calculate the probability of failure per km for each ECDA-region for future years for all other failure modes considered
- depending on the calculated probability of failure per km, calculate the required time interval until the next Direct Assessment

When new aboveground surveys are carried out on the same pipeline, the pipeline will be subject to a new Direct Assessment. Obviously, the results from a Direct Assessment are available for use in the Pre-Assessment step of the next Direct Assessment for that pipeline.

Finally, Figure 6 gives a summary of the most important routines that the operator will go through when using the DA module for *PIMSLIDER*, in the form of a flowchart. Only the steps most relevant to the model are included in this figure.

CONCLUSIONS

For unpiggable pipelines, the use of ECDA as proposed by the NACE has been recognized by Gasunie as a valuable method to assess the threats of corrosion. SRA in combination with Bayesian statistics, as originally developed by Advantica and AFAA, makes it possible to quantify the results obtained during an ECDA process. This method has now been modified and expanded further by Gasunie in cooperation with AFAA.

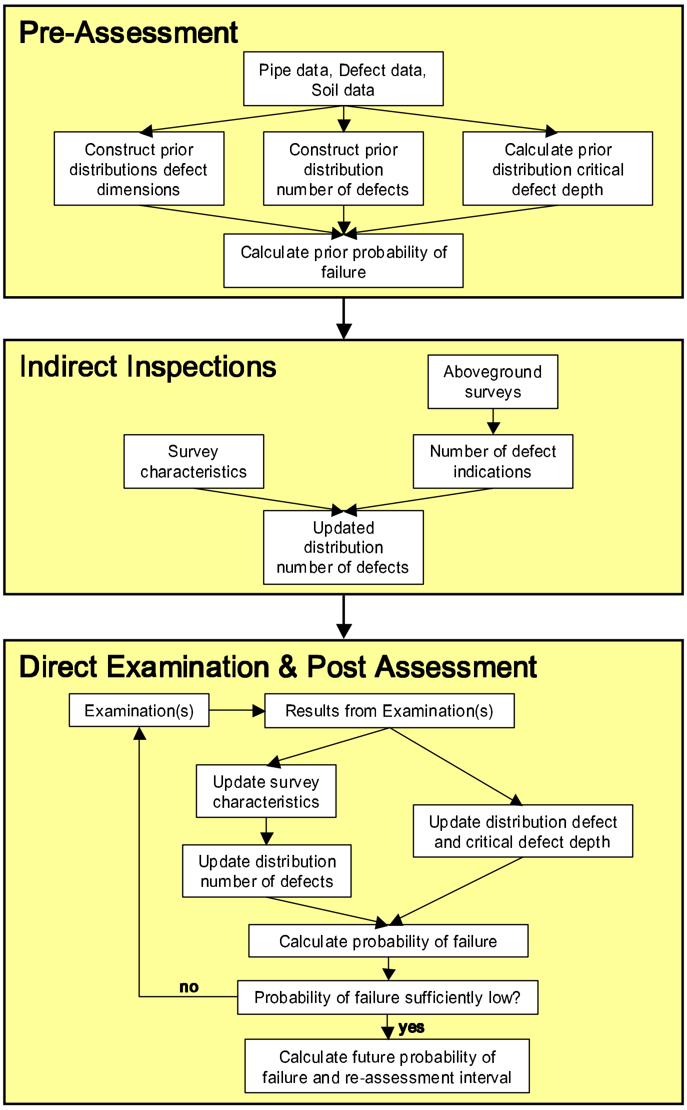


FIGURE 6: FLOWCHART OF THE MOST IMPORTANT CALCULATIONS THAT ARE CARRIED OUT IN THE DIFFERENT ECDA STEPS

With the expanded method, it is possible to automatically adjust the number of coating defects and the number of corrosion defects based on the results of two aboveground surveys (one for the detection of coating defects and one for the detection of corrosion defects).

The method makes it possible to use the results of excavations to adjust the following variables:

- The probability of detection and the probability of false indication of each survey technique
- The time of initiation of corrosion defects and the defect density
- The corrosion rate and the defect depth

Based on these updates, the probability of failure of the pipeline under investigation can be calculated. This updating process can be performed after each excavation if required, until the probability of failure is sufficiently low. This allows the integrity manager to minimize the number of excavations required.

The developed method will be implemented in the Pipeline Integrity Management system *PIMSLIDER* in the course of 2006. It will be an integral part of the system, which will bring the benefits of easy access to all relevant data of the pipeline under investigation and to the results of Direct Assessments performed on other pipelines.

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