

## **THE UTILIZATION OF A PIPELINE INTEGRITY MANAGEMENT SYSTEM FOR ECDA MANAGEMENT WITHIN GASUNIE**

M.T. van Os, P. van Mastrigt and G.G.J. Achterbosch  
N.V. Nederlandse Gasunie  
P.O. Box 19  
9700 MA Groningen, The Netherlands

### **ABSTRACT**

Gasunie has utilized External Corrosion Direct Assessment (ECDA) as proposed by the NACE as a valuable method to assess the corrosion threat to unpiggable pipelines. In addition, a new probabilistic methodology has been adopted to quantify the results of an ECDA and to account for any uncertainties experienced throughout the process. This approach, based on Structural Reliability Analysis (SRA) and Bayesian statistics, uses the data gathered in the pre-assessment to calculate a failure frequency for each ECDA region defined. In the indirect inspections step, the method allows automatic updating of the expected number of both coating and corrosion defects based on the results of two aboveground surveys (one for the detection of each). In the direct examinations step, the method uses the results from excavations to automatically update the performance characteristics of the survey techniques (e.g. probability of detection and probability of false indication), the time of initiation of corrosion defects, the defect depth, corrosion growth rate and several other relevant parameters. The failure frequency is updated accordingly. If desired, this updating can be performed after each excavation, until the failure frequency is sufficiently low. This allows the integrity manager to minimize the total number of excavations and thus reduce the overall cost of the ECDA process. Finally, in the post-assessment step a reassessment interval is calculated for the pipeline under investigation. In 2007 Gasunie has implemented the abovementioned methodology as part of its pipeline integrity management system, PiMSlider. The DA module has now become an integral part of the system, thereby enabling highly accurate, reproducible and time saving integrity analyses of the Gasunie grid. The DA module will be described in this paper by using an example of a part of a Gasunie pipeline that has recently been subjected to ECDA.

Keywords: Bayesian Statistics, External Corrosion Direct Assessment (ECDA), Failure Frequency, Pipeline Integrity Management System (PIMS), Structural Reliability Analysis (SRA)

### **HISTORY**

The Gasunie grid consists of approximately 12,000 km of high-pressure pipeline, most of which were built between 1960 and 1980. Especially on the older pipelines, mechanical damage or coating degeneration, followed by corrosion, has resulted in areas with reduced wall thickness. Of the various existing corrosion threats, Microbiologically Induced Corrosion (MIC), detected firstly in 1999, has found to be the major threat to the integrity of the Gasunie grid. After MIC had been discovered, Gasunie's in-line inspection (ILI) program was significantly intensified, resulting in a large increase in the amount of inspection data to be analyzed. Gasunie implemented a new software system, PiMSlider,<sup>1</sup> in support of their pipeline integrity management, to allow efficient and reliable data processing.

The PiMSlider system 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.

Although the major part of Gasunie's pipeline grid is conventionally piggable, there is also a significant part that is considered to be non-piggable for various reasons. For these lines, an ECDA program was put into place in 2004. One year later, it was decided to develop a computerized Direct Assessment module for PiMSlider, enabling integrity analyses of unpiggable pipelines and meeting the requirements of the ECDA process described in NACE RP0502-2002.<sup>2</sup>

This paper describes the functionality of this Direct Assessment module, which has been implemented in PiMSlider in the course of 2007, illustrated by a case study of a Gasunie pipeline which has been subjected to ECDA. The ECDA software has been developed by Gasunie in corporation with Andrew Francis & Associates Ltd. (Derbyshire, UK), ATP Ltd. (Hampshire, UK), and Neftegazsystema (Gomel, Belarus).

### THE DIRECT ASSESSMENT MODULE

The DA module that has been developed is based on the ECDA process as described by NACE RP0502-2002 and 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).<sup>2</sup> SRA in combination with Bayesian updating techniques 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.<sup>3-6</sup> 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.

The pre-assessment includes data collection and visualization, the identification of ECDA regions and the calculation of the a priori failure frequency 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 a reassessment interval and to assess the overall effectiveness of the ECDA process. The four different steps of ECDA will be explained in the following section, using a case study of an actual ECDA process as an example.

### CASE STUDY

#### General

In 2004, a substantial part of a Gasunie pipeline was inspected by detailed aboveground surveys in the framework of an ECDA project. Inspections were carried out using DCVG, CIPS, soil resistivity measurements and dGPS equipment. A total of 842 coating defects were indicated by DCVG at the time. After interpretation of the survey results, 21 of these indications were selected for direct examination and excavated in the course of 2005. The remaining part of the pipeline is planned to be inspected in 2008. Table 1 gives an overview of the relevant pipeline parameters.

**TABLE 1  
RELEVANT PIPELINE PARAMETERS**

Length of pipeline	40.2 km
Length of pipeline inspected	13.7 km
Year of construction	1953
Nominal diameter	165 mm
Nominal wall thickness	4.50 mm
Steel grade	Grade A
Coating type	Bituminous
Pressure	40 bar

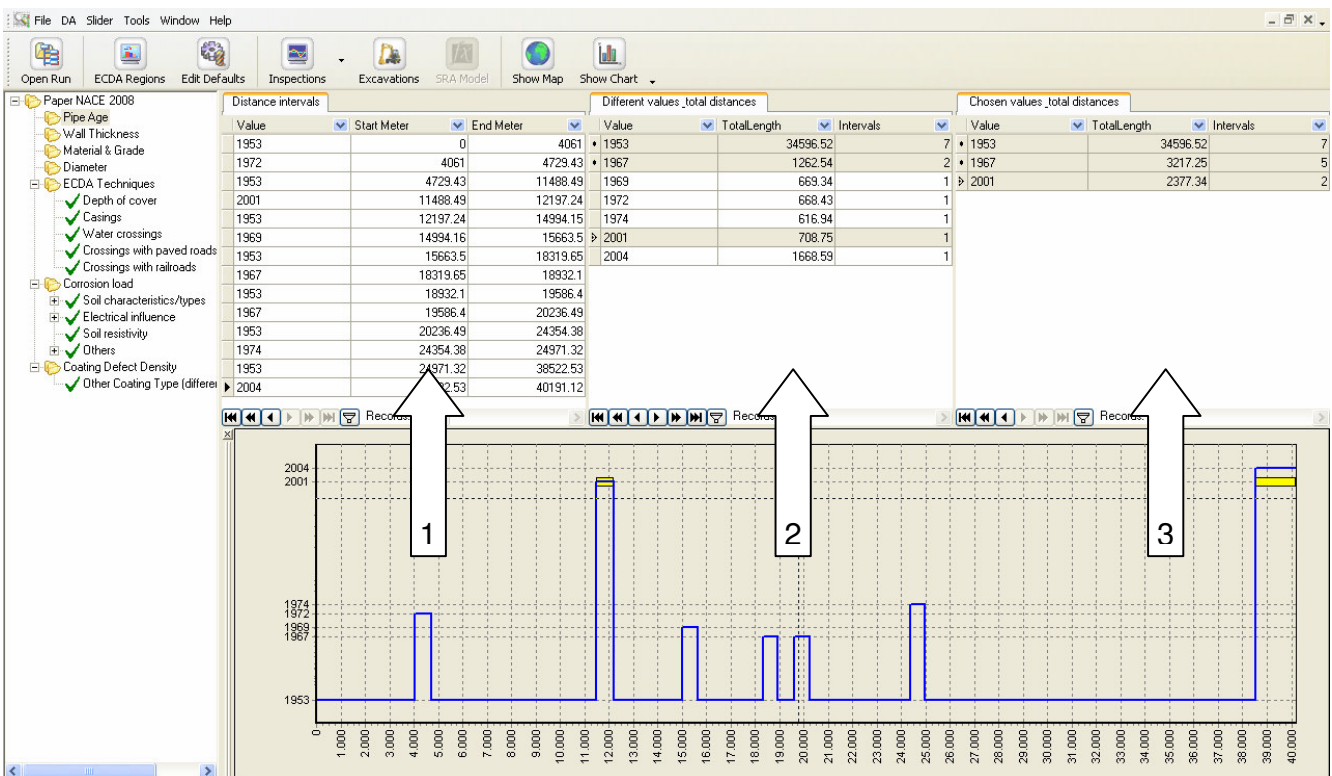
## Pre-assessment

In this section it is illustrated how the Direct Assessment module assists the integrity manager in assessing the prior integrity of the pipeline under investigation. The pre-assessment step in the ECDA module has the following three objectives:

1. data collection and visualization
2. to identify ECDA regions
3. to establish the prior condition of the pipeline

**Data collection and visualization:** Consistent with RP0502-2002, 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. As an example, Figure 1 shows an example of the different pipe ages occurring along the length of the pipeline. It can be seen from this screenshot that, although the pipeline was constructed in 1953, several sections have since then been replaced for various reasons.

The first set of data in this figure, indicated by arrow 1, contains all the respective pipe ages for each section of the pipeline. The second set shows all the occurring pipe ages, as well as the total length of pipeline associated with each pipe age. The third set is a result of the selection made by the operator. In this case, only three out of the occurring seven pipe ages are selected for identification of ECDA regions, to avoid that too many ECDA regions are created in the next stage of the pre-assessment. The pipe ages that have not been selected, are “conservatively” added to the next occurring earlier year of construction (e.g. for the section that has been replaced in 1974, it will be assumed that it has been replaced in 1967 by the SRA model).



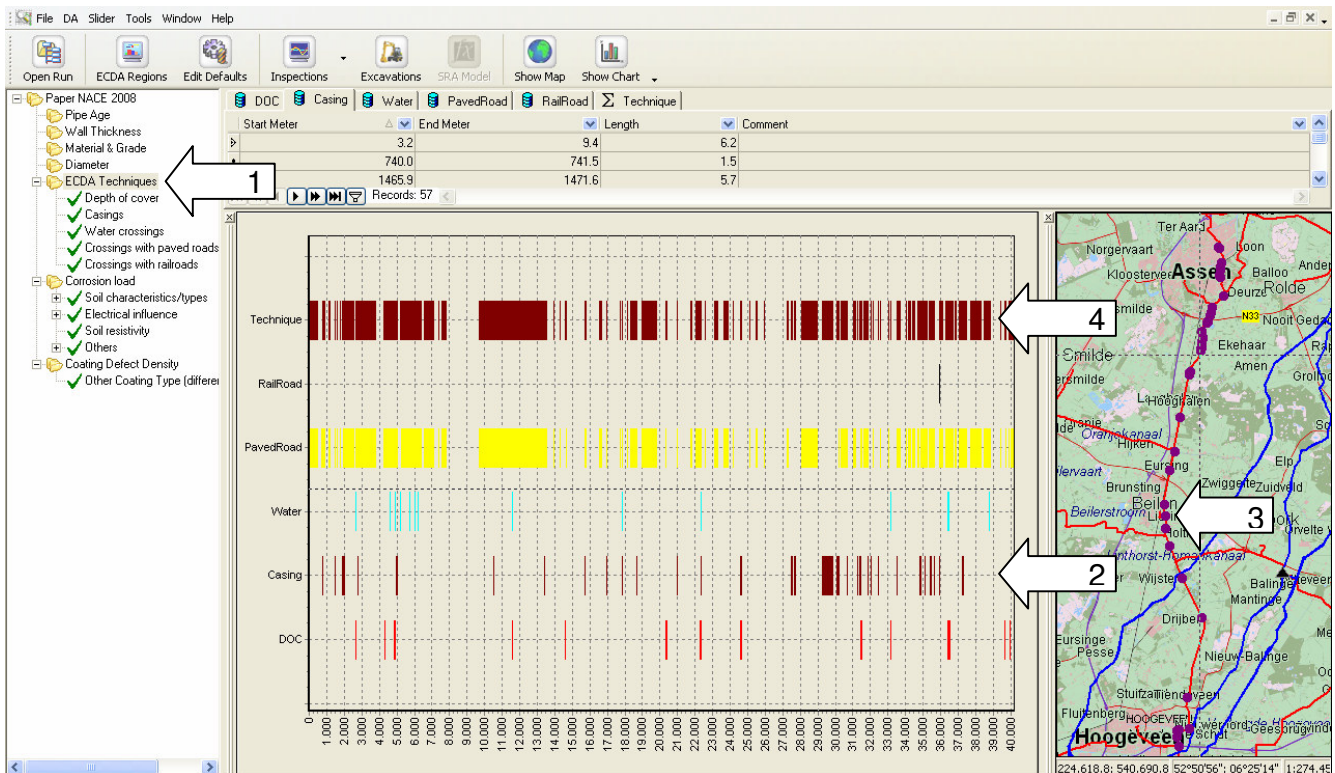
**FIGURE 1 – Pipe age along the pipeline**

The parameter “ECDA Techniques”, indicated by arrow 1 in Figure 2, assists the operator in identifying where the application of general indirect inspections may cause problems due to safety issues or a reduced performance of the ECDA techniques. This parameter consists of a number of sub-parameters, namely:

- depth of cover: if greater than a certain threshold value, the indirect inspections techniques are assumed to have a lower probability of detection (POD) and a higher probability of false indication (POF)

- casings: the presence of casings may require additional indirect inspection techniques or integrity assessments
- water crossings
- crossings with paved roads: inspection of paved roads may raise safety issues or require the drilling of holes to improve the contact with the electrolyte
- crossings of railroads: gives rise to safety issues

For illustration purposes, the screenshot in Figure 2 also shows where the pipeline is protected by casings (arrow 2), the exact position of these casings in a GIS environment (arrow 3), and where the application of indirect inspections (or the interpretation of their results) may not be possible or needs extra attention (arrow 4). In other words, the parameter “ECDA Techniques” (arrow 1 and 4) applies where at least one of the subparameters (e.g. depth of cover, casings, water crossings, crossings with paved roads, crossings with railroads) apply.



**FIGURE 2 – ECDA Techniques**

The factors that may somehow influence the corrosion or the corrosion growth rate of the pipeline can be found under the parameter “Corrosion load” (see arrow 1 in Figure 3). This parameter is subdivided into four different categories, namely:

1. soil characteristics/types
2. electrical influence
3. soil resistivity
4. others

In this particular case, a significant part of the pipeline suffers from DC interference, due to the close vicinity of a DC railway. Therefore the parameter “Close vicinity of DC Railways” (under “Electrical influence”) is selected (arrow 2 in Figure 3). The other Corrosion load parameters are discarded, since none of them are expected to be applicable or relevant to the pipeline under investigation. The length of the section that can be expected to be influenced by DC is approximately 21 km long, part of which is indicated by arrow 3. Finally, arrow 4 in this same figure refers to the parameter “Coating defect density”. This parameter is related to the type of coating of the pipeline. Where most of the Gasunie pipelines constructed after 1970 have been coated with PE of relatively good quality, most of the older pipelines, such as the one described in the case, contain bituminous coatings of

much poorer quality. This coating type information from the PiMSlider database can clearly be used to estimate the coating defect density for each ECDA region, a parameter which can be updated later in the process upon receiving new information from the indirect inspections and excavations.

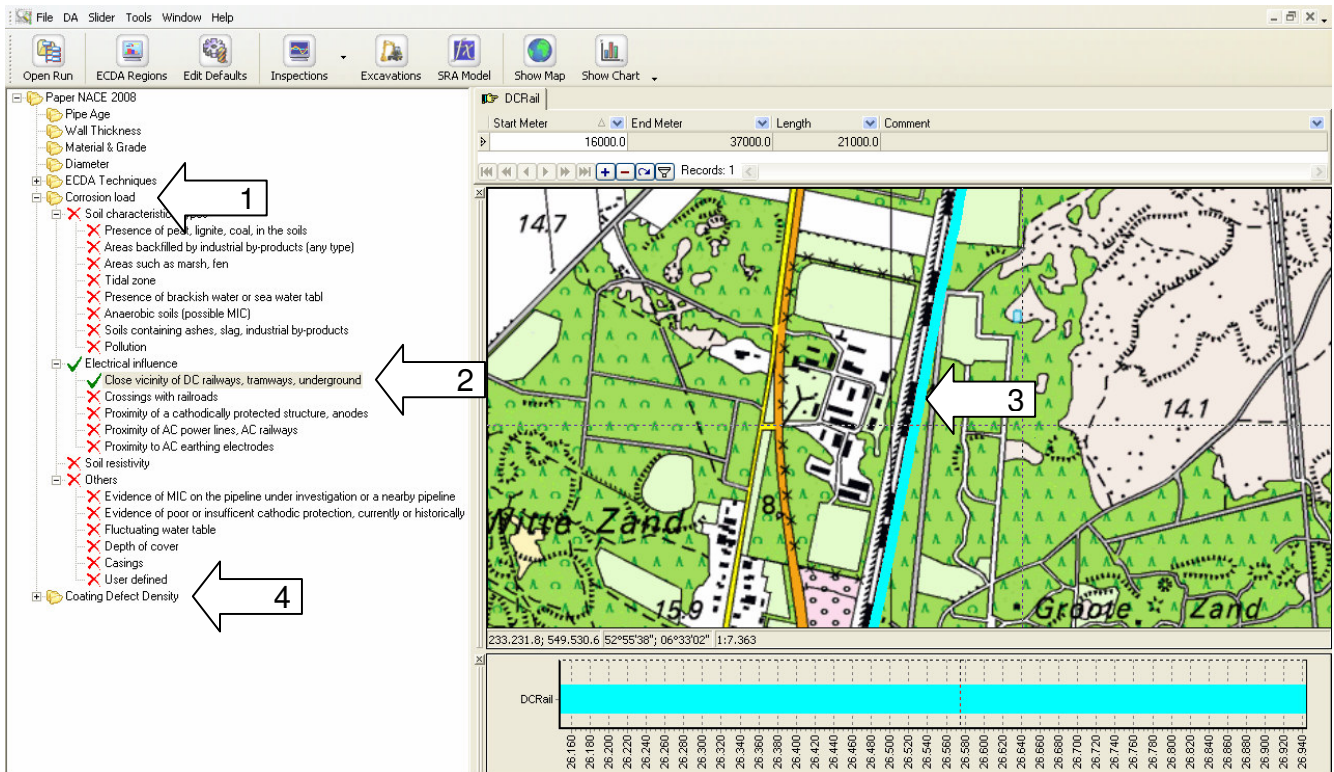


FIGURE 3: DC interference

**Identification of ECDA regions:** In the second part of the Pre-Assessment, the gathered information is used to define a number of ECDA regions. After the user has defined all the parameters to be taken into account for the definition of ECDA regions, the ECDA module calculates the regions automatically, as illustrated in Figure 4. The assumptions made in the previous step result in 14 different ECDA regions, varying in length from 60 m to 13 km. 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:** Thirdly, the prior condition of the pipeline under investigation is quantified, by assessing the failure frequency for each ECDA region. In order to calculate this failure frequency, estimations must be made for, among other factors, the following key parameters:

- Time of initiation of corrosion defects; corrosion can start to take place immediately after construction (for instance as a result of mechanical damage and insufficient CP), but also many years later (for instance due to deterioration of the coating).
- Defect density (both for coating and corrosion defects); this parameter 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.
- Defect depth; a certain initial distribution for the defect depth is assumed at the time of initiation due to mechanical damage, which then increases annually depending on the corrosion growth rate.
- Corrosion growth 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.

The estimations of the parameters listed above can generally be based on information collected in 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 numbers and geometry of corrosion defects. If relevant information is not available for a specific pipeline, data of pipelines with similar specifications or environmental conditions can be used for the required analysis. 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. Therefore these quantities are also represented by distributions rather than constants.

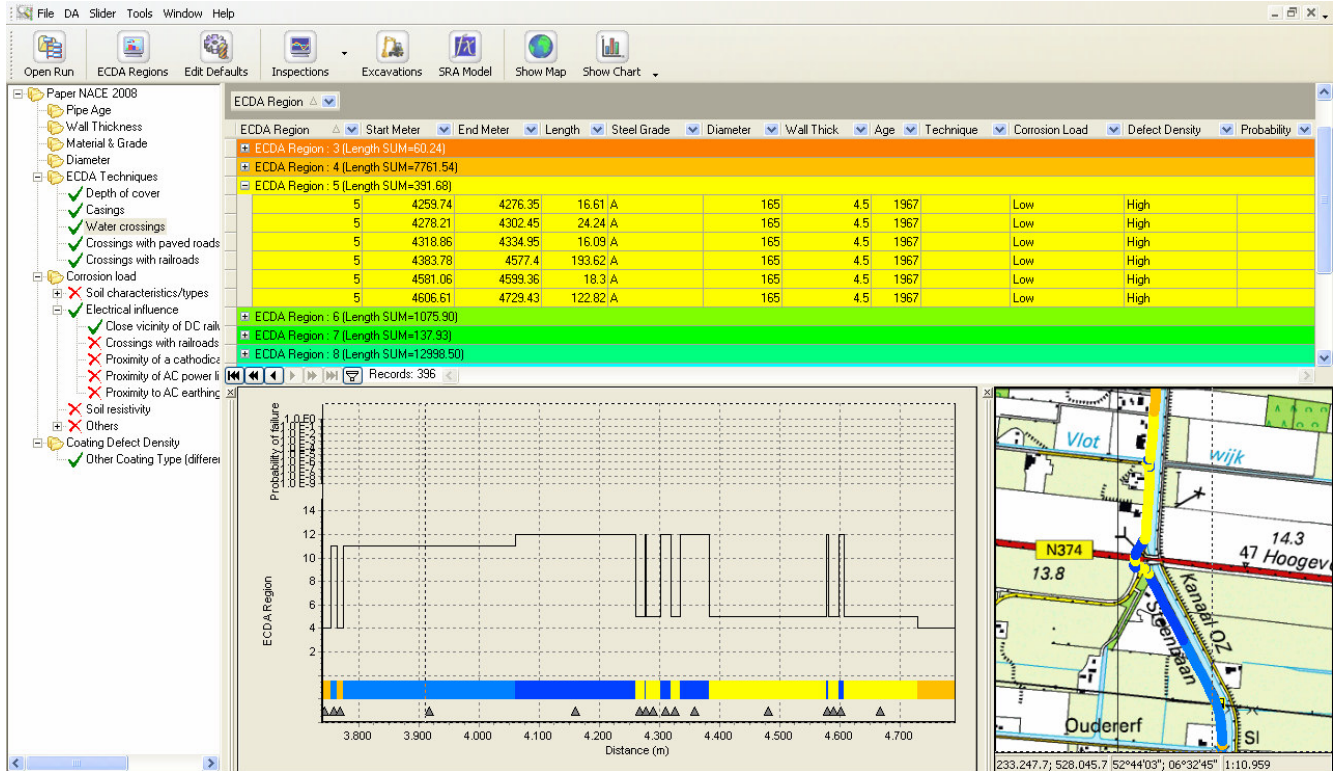


FIGURE 4 – Identification of ECDA regions

To predict the failure pressure of part-wall corrosion defects in pipelines, guidelines from a Joint Industry Project, the Linepipe Corrosion Group Sponsored Project,<sup>7,8</sup> have been used, developed through a combination of analysis and full scale testing. The methods developed from this project have also been incorporated into DNV Recommended Practice RP-F101.<sup>9</sup> In these guidelines, which are based on plastic collapse, the critical defect depth  $a_c$  is defined by

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

where  $w$  is the wall thickness of the pipeline,  $\sigma_h$  is the hoop stress,  $\sigma_f$  is the flow stress and  $Q$  is known as the Folias factor, given by

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

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 SRA 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

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

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.

As an example, Table 2 gives the assumptions made in the pre-assessment phase of the SRA model for ECDA region 8. This region is likely to be subject to DC interference, and is therefore assumed to have a relatively high corrosion growth rate. Also due to the pipe age in this region, it is the highest risk region that can be inspected using regular indirect inspection techniques.

**TABLE 2  
MAIN PARAMETERS PRE-ASSESSMENT ECDA REGION 8**

INPUT	Pipe age	Constant	54 years	
	Length	Constant	13.0 km	
	Maximum operating pressure	Constant	40 bar	
	Nominal outside diameter	Constant	165 mm	
	Nominal wall thickness	Normal distribution	Mean	4.50 mm
			Standard deviation	0.26 mm
	Material yield strength	Normal distribution	Mean	242 MPa
			Standard deviation	13 MPa
	Initial defect depth	Weibull distribution	Shape parameter $\beta$	2.33
			Scale parameter $\eta$	0.81
	Initial defect length	Weibull distribution	Shape parameter $\beta$	0.88
			Scale parameter $\eta$	130
Time of initiation	Uniform between year of construction and current year			
Corrosion growth rate	Normal distribution	Mean	0.054 mm/yr	
		Standard deviation	0.025 mm/yr	
OUTPUT	Number of coating defects at $t_{age}$	Lognormal distribution	Mean	52 per km
			Standard deviation	32 per km
	Number of corrosion defects at $t_{age}$	Lognormal distribution	Mean	2.6 per km
			Standard deviation	6.3 per km
Failure frequency at $t_{age}$	Constant	$9.7 \cdot 10^{-3} (\text{km} \cdot \text{yr})^{-1}$		

For this ECDA region, the uniformly distributed time of initiation, the chosen initial defect depth, the average corrosion growth rate of 0.054 mm/yr and the estimated number of corrosion defects per km of this region, result in an a priori failure frequency of  $9.7 \cdot 10^{-3} (\text{km} \cdot \text{yr})^{-1}$ .

### Indirect Inspections

With respect to the Indirect Inspections step, the ECDA software can assist the corrosion engineer in achieving the following four goals, which are all briefly explained in the following paragraphs:

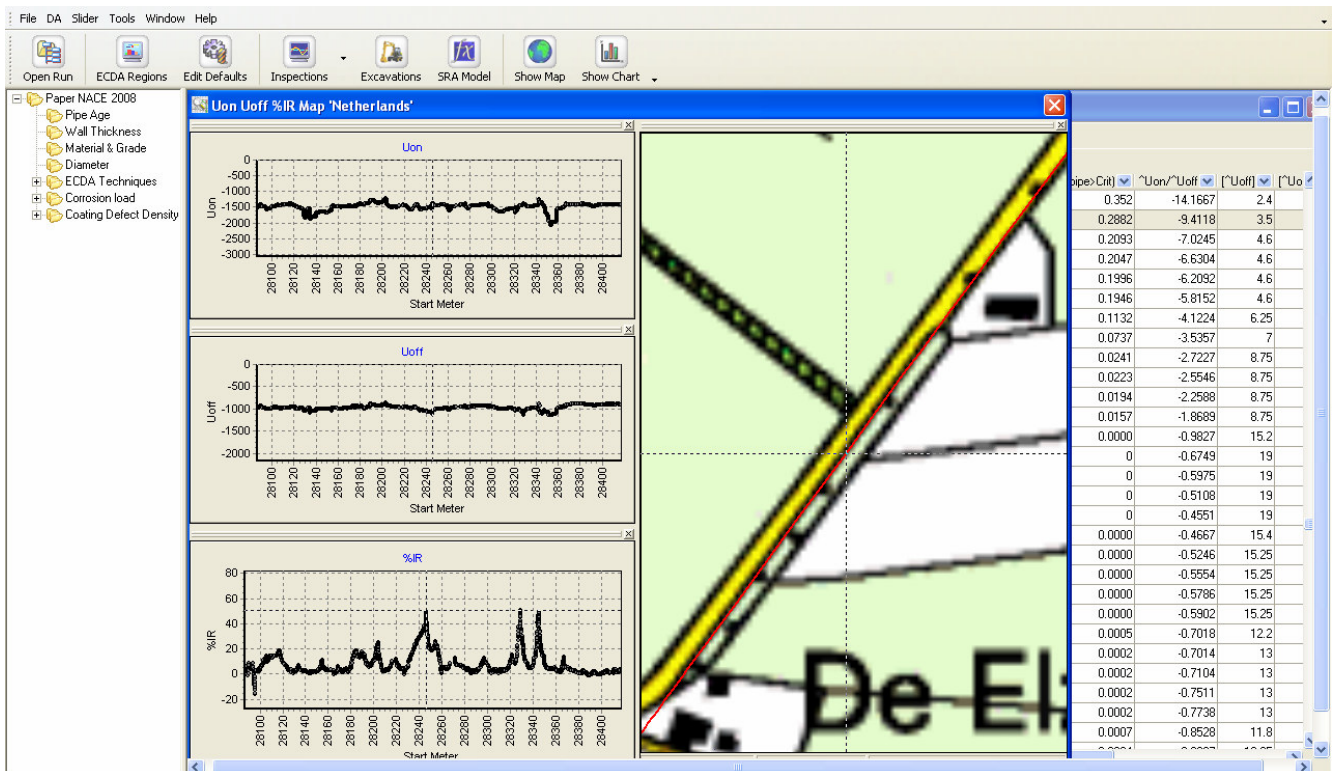
1. Data storage
2. Data processing, interpretation and visualization
3. Generation of a priority list for direct examinations
4. Update the condition of the pipeline

Data storage: the data from the aboveground surveys are stored in a database for processing and for future reference. Within Gasunie, indirect inspections for ECDA purposes usually consist of the following measurements:

- Direct Current Voltage Gradient (DCVG) survey: to detect and pinpoint coating defects along the pipeline

- 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 CP system
- Wenner measurements: to measure the soil resistivity at regular intervals along the route
- dGPS-measurements: to measure the position of coating defect indications, soil resistivity measurements and characteristic features along the pipeline

Data processing, interpretation and visualization: if required, the data from the surveys can be corrected for factors such as the depth of cover, the soil resistivity, or for currents through the pipeline. The ECDA module also calculates the 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 pipeline) and the surrounding uncertainty of this potential. The software presents the required data in a clear and comprehensive manner by plotting (combinations of) graphs on the screen, thereby simplifying interpretation of data by the operator. An example is given in Figure 5, where the on-potential, the off-potential and the DCVG %IR are plotted below each other, linked to the GIS environment.



**FIGURE 5 – Indirect Inspections**

Generation of a priority list for direct examination: the corrosion engineer can use various sorting and filtering functions to determine which indications need to be excavated for direct examination. Although generation of the priority list by itself is an automatic process, the success of this important process step depends only on the experience of the corrosion engineer interpreting the data, and of course the quality of the gathered data.

Update the condition of the pipeline: after new information has become available in the form of indirect inspection results, this information can be used to update the prior view on the integrity of the pipeline (e.g. numbers of coating and corrosion defects) by using Bayesian updating techniques. Before doing so, the uncertainties associated with the inspection tools must also be addressed. Since no inspection technique is 100% reliable, the performances of the used inspection tools are also taken into account by the SRA model. The performance of an aboveground survey technique often depends on factors such as coating type, soil conditions, depth of cover, experience of the operator etc.. It can be characterized by the following two variables:

1. Probability of Detection (POD): the probability that a defect present is detected by the survey technique

2. Probability of False Indication (POF): the probability that the survey technique gives an indication where no actual defect is present

The prior distributions of the POD and the POF of a survey technique can be constructed from previous experience with the technique or from recommendations of the manufacturer.

**TABLE 3  
MAIN PARAMETERS INDIRECT INSPECTIONS ECDA REGION 8**

INPUT	Coating survey technique (DCVG)	Average	Standard deviation
	POD (Beta distribution)	0.80	0.10
	POF (Beta distribution)	0.10	0.05
	Corrosion survey technique (CIPS)	Average	Standard deviation
	POD (Beta distribution)	0.60	0.20
	POF (Beta distribution)	0.20	0.10
	Number of indications		
	DCVG	98 per km	
OUTPUT	CIPS (number of indications at which the IR-free potential does not meet the applicable protection potential)	21 per km	
	Updated number of defects	Average	Standard deviation
	Coating defects (lognormal distribution)	114 per km	2 per km
	Corrosion defects (lognormal distribution)	40 per km	1 per km
	Updated failure frequency	$1.6 \cdot 10^{-1} \text{ (km} \cdot \text{yr)}^{-1}$	

The results obtained for the same ECDA region described earlier are shown in Table 3. Based on previous experience with aboveground survey techniques on pipelines with similar characteristics, initially an average number of 52 coating defects per km were expected for this kind of pipe with bituminous coating. The DCVG survey however revealed even a much higher number of indications, namely 98 per km. The results from the CIP survey were used by the ECDA module to calculate the IR-free potentials<sup>(1)</sup> at the DCVG indications. These potentials were then compared with the applicable protection criterion as described in the European standard EN 12954:2001,<sup>10</sup> which depends on the local soil resistivity. As a result, an average of 21 indications per km seemed to be insufficiently protected by CP currents according to this standard, and were therefore assumed to be possible corrosion anomalies. Taking into account the estimated POD and POF of both DCVG and CIPS, the estimated corrosion defect density was updated from 2.6 per km in the pre-assessment, to 40 per km after the indirect inspections. Due to this increase, the failure frequency increases accordingly, from  $9.7 \cdot 10^{-3} \text{ (km} \cdot \text{yr)}^{-1}$  in the pre-assessment to  $1.6 \cdot 10^{-1} \text{ (km} \cdot \text{yr)}^{-1}$  after the inspections.

### Direct examination and post-assessment

Direct examination: in the direct examination step, indications from the previously mentioned priority list are excavated, starting of course with the highest-risk ECDA region found in the pre-assessment where indirect inspections could be performed. The outcome of each excavation determines whether additional excavations need to be carried out for the respective ECDA region, after which the pipeline integrity is evaluated again. Excavations generally take place at locations:

- where both indirect inspection techniques (DCVG and CIPS) have given an indication; usually to determine the size of corrosion defects and repair any critical defects.
- where only one of the surveys has given an indication; usually to check the survey characteristics and 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).

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 POF of each survey technique
- the number of defects (coating and corrosion)

<sup>1</sup> 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 pipeline

- the defect depth, corrosion growth rate and time of initiation
- the critical defect depth

Based on these updates, new values are calculated for the probability of failure of a defect and the failure frequency for the ECDA-region. The direct examination step is illustrated by Figure 6. A total number of 11 defect indications have been excavated altogether in ECDA region 8. However, as shown by the arrows 1a-d in Figure 6, the 11 indications are located close to each other, resulting in only four (extended) Bell holes. In other words, the 4 most severe indications were selected for direct examination, but if less severe indications were present in the vicinity of those severe indications, they were subjected to direct examination as well, in order to generate more data for little extra cost.

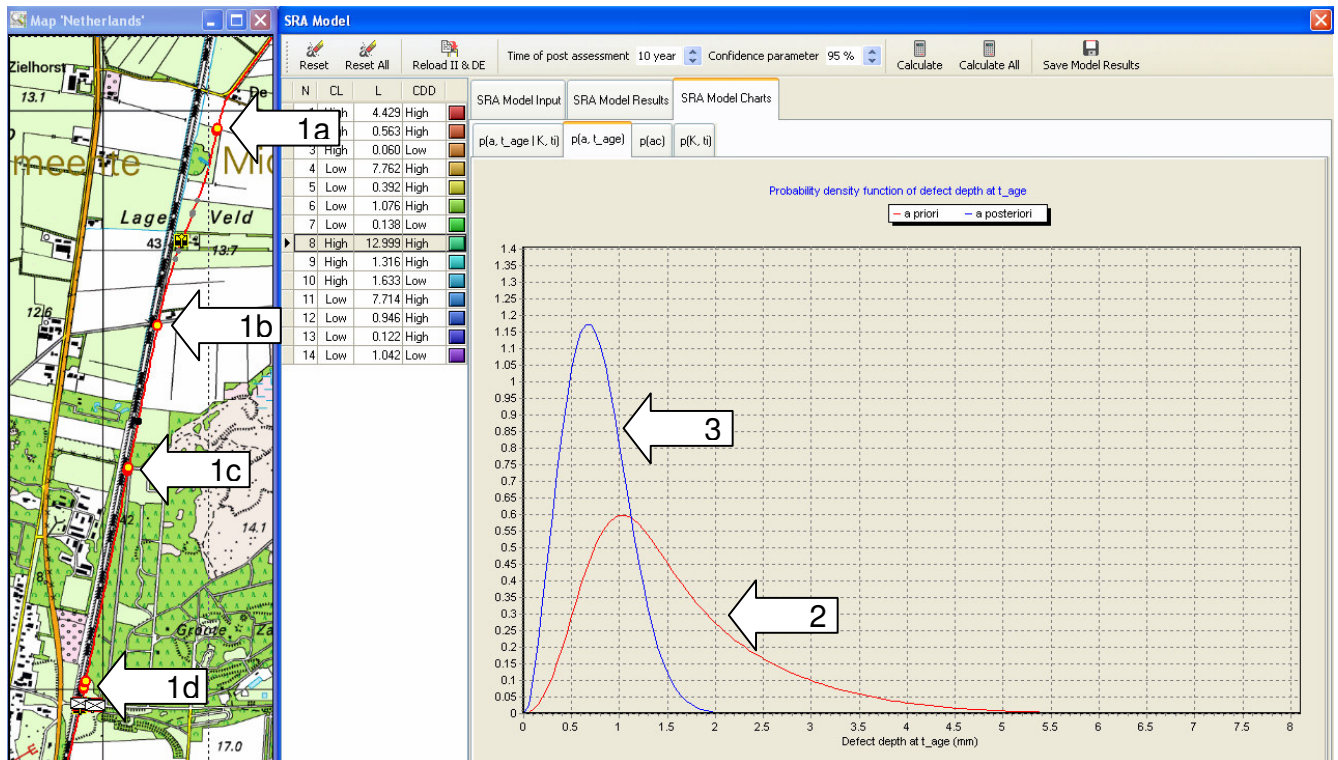


FIGURE 6 – Direct Examination

During the excavations, mild, general corrosion was found at 5 out of 11 indications, with a maximum defect depth of 1.2 mm. Finding defect depths less than estimated in the pre-assessment (arrow 2 in Figure 6) results in an overall shift to the left of the defect depth distribution (arrow 3).

The probability of failure for a single defect will change with each excavation where corrosion is found as the distributions of the corrosion growth rate and time of initiation also change. In general, when the parameters have been chosen conservatively in the pre-assessment, the failure frequency decreases until the criterion used for failure frequency is met, showing that sufficient excavations for the specific ECDA region have been carried out.

Again, the main parameters involved in the SRA calculations are summarized in the table below. Most importantly, due to the mild corrosion defects found during the direct examinations, the corrosion growth rate significantly decreases from the a priori average value of 0.054 mm/yr in the pre-assessment to 0.031 mm/yr on average in the year 2005. As a result, the failure frequency of ECDA region 8 now decreases from  $1.6 \cdot 10^{-1}$  (km·yr)<sup>-1</sup> to  $3.1 \cdot 10^{-6}$  (km·yr)<sup>-1</sup>.

It can be seen from Table 4 that the POF from DCVG marginally improves from 0.10 to 0.09, since coating holidays are found at all DCVG indications. At the same time, the performance of CIPS is worse than initially estimated, with the POD decreasing from 0.60 to 0.55 and the POF increasing from 0.20 to 0.32. The obvious

reason for this poor performance under stated conditions is the influence of stray currents on the potential measurements.

**TABLE 4  
MAIN PARAMETERS DIRECT EXAMINATION ECDA REGION 8**

INPUT	Excavations at indications	Holiday with corrosion is found	Holiday without corrosion is found	No holiday is found
	By coating survey only	1	3	0
	By corrosion survey only	0	0	0
	By both coating and corrosion surveys	4	3	0
	Where both surveys do not give a positive indication	0	0	0
Sum	5	6	0	
OUTPUT	Updated number of defects	Average		Standard deviation
	Coating defects (lognormal distribution)	118 per km		1 per km
	Corrosion defects (lognormal distribution)	33 per km		1 per km
	Updated defect depth	0.75 mm		0.33 mm
	Updated corrosion growth rate	0.031 mm/yr		0.026 mm/yr
	Updated time of initiation	48 years		11 years
	Coating survey technique (DCVG)	Average		Standard deviation
	Updated POD	0.80		0.10
	Updated POF	0.09		0.05
	Corrosion survey technique (CIPS)	Average		Standard deviation
	Updated POD	0.55		0.19
	Updated POF	0.32		0.10
	Updated failure frequency	$3.1 \cdot 10^{-6} \text{ (km} \cdot \text{yr)}^{-1}$		

Post-assessment: According to NACE, the objectives of the post-assessment are to define reassessment intervals and to assess the overall effectiveness of the ECDA process. The ECDA module assists the integrity manager in the first part of this process step, by accurately calculating the failure frequency of each ECDA region in the years to come.

Table 5 illustrates how the defect depth distribution has increased again in 2017 due to ongoing corrosion processes in the next ten years, and also how this affects the failure frequency.

**TABLE 5  
MAIN PARAMETERS POST-ASSESSMENT ECDA REGION 8**

INPUT	Year of evaluation	2017	
OUTPUT	Number of years since construction	64	
		Average	Standard deviation
	Defect depth	0.92 mm	0.39 mm
	Failure frequency	$1.3 \cdot 10^{-4} \text{ (km} \cdot \text{yr)}^{-1}$	

Until now, Gasunie is not (yet) applying a definite and absolute criterion for the failure frequency due to external corrosion, as calculated during the different steps of the ECDA process. To deduct such an “acceptable” failure frequency, the database of historical incidents could be used as a starting point. All incidents that have occurred in the past on the Gasunie grid have been recorded in the Gasunie Database for Pipeline Incidents (GDLI). The incidents include leaks and ruptures, but also coating damage and damage caused by corrosion. Analysis of the cause of these incidents has indicated the most common failure modes for Gasunie in the past:

- external interference (mainly third party damage): 71%
- external corrosion: 6%
- material and (mainly) welding defects: 4%
- ground movement (sinking) 2%
- other/unknown causes 17%

It is clear from these figures that mechanical damage due to external interference is still by far the largest threat to the integrity of the Gasunie grid. However, external corrosion is becoming increasingly important due to the time-dependent nature of corrosion and the ageing of the pipeline grid. As mentioned previously, a maximum allowable failure frequency has yet to be determined, but will most likely be based on Gasunie's current viewpoint that external corrosion should not contribute significantly to the total incident frequency.

## **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, makes it possible to quantify the results obtained during the different steps of an ECDA process. The developed method has been implemented in 2007 as part of Gasunie's pipeline integrity management system, PiMSlider.

In the pre-assessment, the ECDA module assists the operator in gathering and analyzing the relevant data, to define the ECDA regions, and to quantify the current condition of the pipeline by calculating a failure frequency for each ECDA region, using the developed SRA model.

In the second step, the data from the indirect inspections are stored in the PiMSlider database. The ECDA module assists the user in determining the severity of defect indications, and to identify areas where corrosion is likely to occur. Subsequently, the ECDA module applies Bayesian updating techniques to update the number of defects estimated in the pre-assessment, after which the failure frequency can be updated.

In the next process step, the ECDA module uses the information from direct examinations to update parameters such as:

- the POD and POF of each survey technique
- the number of coating and corrosion defects
- the defect depth
- the time of initiation and the corrosion growth rate

Again, based on these updates, the failure frequency of the pipeline under investigation is calculated. This updating process can be performed after each excavation if required, until the failure frequency for the respective ECDA region is sufficiently low. This allows the integrity manager to minimize the number of excavations required.

Finally, in the post-assessment the ECDA module can be used to calculate an appropriate reassessment interval for the pipeline.

Overall the ECDA module, being an integral part of PiMSlider, gives the benefit of easy access to all relevant data from the pipeline under investigation, as well as from other pipelines. It offers considerable time-saving (especially in the pre-assessment), increased transparency and better reproducibility throughout the ECDA process. In addition, it enables quantification of each mitigating activity to the overall integrity of the pipeline, thereby minimizing the overall cost of mitigating measures. And finally, the ECDA module accounts for most of the uncertainties generally encountered within ECDA processes.

## **ACKNOWLEDGEMENTS**

Firstly, the authors express their gratitude to Andrew Francis, AFAA, for his collaboration on this project. Henk Horstink and Paul Wesselius, N.V. Nederlandse Gasunie, are acknowledged for their contributions to the testing of the software and their input throughout the project. Finally, ATP Neftegazsystema is acknowledged for support and feedback during the process of developing the functional specifications of the ECDA module for PiMSlider, and for building the DA module.

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