CAAP Quarterly Report

01/05/2026

Project Name: A Novel Reliability-Based Approach for Assessing Pipeline Cathodic Protection (CP) Systems in External Corrosion Management

Contract Number: 693JK32350002CAAP

Prime University: Marquette University

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Reporting Period: 10/01/2025-12/31/2025

Project Activities for Reporting Period:

The research team has been working on Task 3 (DC interference lab testing) and Task 4 (probabilistic defect growth modeling).

Task 3 Corrosion behavior under stray current interference

During this report period, we have conducted following activities:

1. Experimental setup and test protocols are completed to study the influence of dynamic DC interference on pipeline corrosion.
2. The dynamic DC interference parameters include interference period (1:10, 5:10, and 9:10) and DC current density (0.1 A/m2 and 1 A/m2).
3. The corrosion is monitored by electrochemical measurements (open circuit potential, DC potential, Tafel, and linear polarization) and weight loss measurements for API 5L X60 steel. The morphology of the tested samples is also characterized after corrosion under different DC interference.
4. The results of this study are included in the mid-term presentation slides.

Task 4 Probabilistic defect growth modeling

In this quarterly report, a time-dependent probabilistic modeling framework has been developed to predict dimension, i.e., depth, length, and width, growth of defects in buried steel transmission pipelines using MFL ILI data, and influential environmental factors including soil survey data and Cathodic Protection (CP) survey data. This framework is built on the previous work conducted on estimating the corrosion density growth in this project, which was reported in previous quarterly reports.

As shown in the previous reports, the corrosion density probabilistic modeling framework involves two parameters, λ and t_0. Optimization was performed to estimate these model parameters through Maximum Likelihood method using real data from 4 in-line inspections of two in-service steel pipelines. The parameter λ refers to the density growth rate, i.e., number of defects added on a joint per year, and t_0 is the time from the pipe installation to the start of the Poisson process which models the occurrence of defects. As an example, Figure 1 shows the number of defects on a specific pipe joint detected over four ILIs, N_D, by red dots, and the blue solid line shows the expected value of the true number of defect, N_T, on that pipe joint predicted by the density growth prediction model obtained previously, with the slope of the line being density growth rate, i.e., λ, and the x-intercept of the line being t_0. The shaded area shows the 80% confidence interval for N_T.

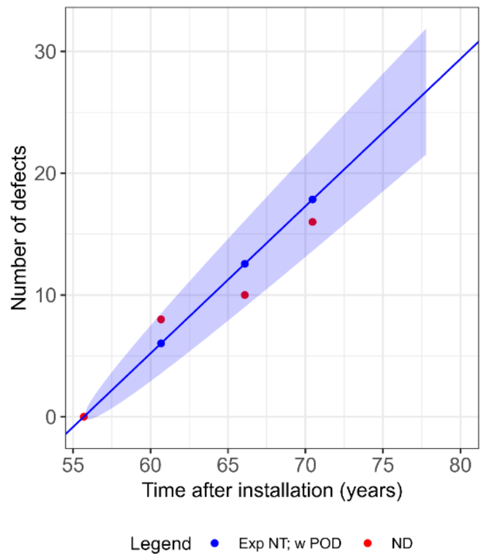

Figure 1 Prediction of density growth model initiation (t_0) and rate (λ)

Estimation of corrosion initiation time

Based on Probability Theory, considering the occurrence of defect on a pipe joint follows a Poisson distribution with parameters λ and t_0, the initiation time of a defect follows a Gamma distribution with parameters α and λ, where α is the ranking of the defect among defects within that joint, where α =1 for the deepest joint if depth is concerned and α = 1 for the longest joint if length is concerned. Therefore, the initiation of a defect dimension can be estimated using Eq. (1) in which $t_{0,d}$ is the estimated initiation time for a defect depth growth, t_0 and λ are obtained by the density growth prediction model developed previously, and α_d is the ranking is the ranking of the defect depth among defects within that joint. It is noteworthy that α_d / λ is the expected value of the Gamma distribution with parameters λ and α_d.

$$t_{0,d} = t_0 + \frac{\alpha_d}{\lambda} \tag{1}$$

Similarly, when length and width are concerned, the initiation time for a defect length and width growth are estimated by $t_{0,l}$ and $t_{0,w}$ using Eqs. (2) and (3).

$$t_{0,l} = t_0 + \frac{\alpha_l}{\lambda} \tag{2}$$

$$t_{0,w} = t_0 + \frac{\alpha_w}{\lambda} \quad (3)$$

Corrosion growth model: Formulation

In this study, a nonlinear power-law equation relationship, as shown by Eq. (4), is considered for corrosion dimension growth modelling. In this model, $d^{i,j}$=predicted depth growth for joint i, defect j, C_1^i = the growth model scaling factor for joint i, $t_{0,d}{}^{i,j}$ = initiation time of depth growth for joint i, defect j , and C_2^i = the power-law exponent for joint i. Therefore, for all the m defects within a joint i, $t_{0,d}{}^{i,j}$ changes from defect to defect however the model coefficients C_1^i and C_2^i are constant. For each joint i, the model coefficients C_1^i and C_2^i are obtained by minimizing the Residual Sum of Square RSS considering all the j defects within that joint and corresponding $t_{0,d}{}^{i,j}$ values. The coefficient C_1^i is constrained to be positive and the coefficient C_2^i is constrained to be between 0 and 1 so that the growth rate is decreasing over time.

$$d^{i,j} = C_1^i \times (t - t_{0,d}{}^{i,j})^{C_2^i} \quad (4)$$

Corrosion growth model: Case study

The introduced methodology is applied to a dataset of Box-to-Box (B2B) matched defects. Figure 2 shows, as a case study, the depth of 8 B2B matched defects within a joint measured by two consecutive ILIs. Depth values of each matched defect are connected using colored dashed lines. The initiation time of each defect is estimated using Eq. (1). Note that for this specific joint the 8 defects have 4 and 7 unique depth values measured by the first and last ILI, respectively. The 7 unique estimated depth initiation time values correspond to the 7 unique depth values at the last ILI.

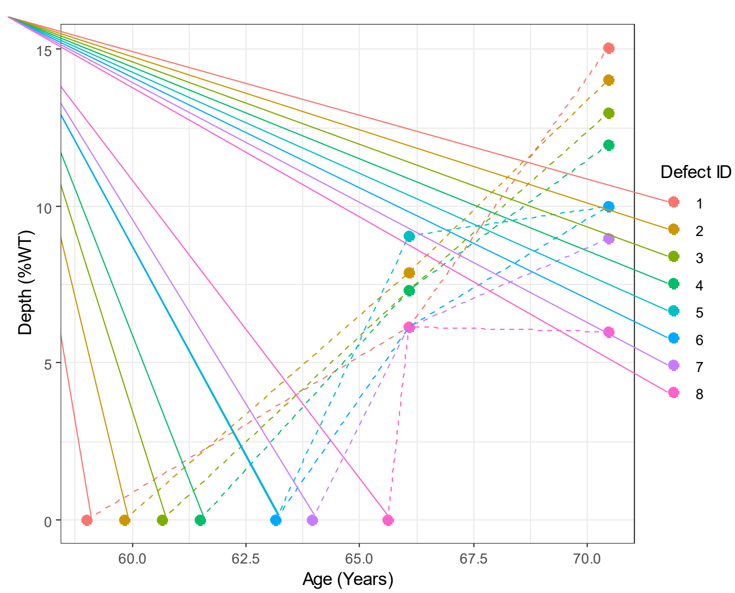

Figure 2 Depth of 8 defects within a case study joint measured by two consecutive ILIs

An optimization problem is set up and solved to obtain the coefficients C_1 and C_2 values for this joint following the methodology described above. The coefficients C_1 and C_2 values are obtained to be 0.488 and 0.267, respectively, and Figure 3 shows the predicted depth dimension growth paths in solid lines for defects within the case study joint. The deviation of the dots and the solid lines show the prediction model error.

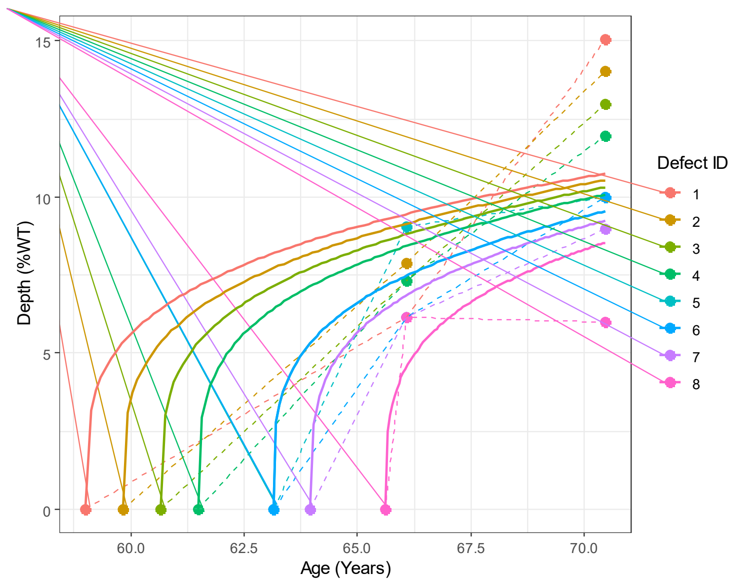

Figure 3 Predicted depth dimension growth paths for defects within the case study joint

Project Financial Activities Incurred during the Reporting Period:

The financial charges include the graduate student stipend, and corresponding fringe benefit, and indirect cost.

Project Activities with Cost Share Partners:

Cost share has been charged as planned.

Project Activities with External Partners:

Monthly meetings were held with our external industry partner to discuss the data collected and preliminary analysis results.

Potential Project Risks:

So far no risk has been identified.

Future Project Work:

In the next quarter, the following items will be taken for Task 3:

1. Continue weight loss tests for dynamic DC interference conditions

2. Design experimental setup and test protocols to study CP-protected pipeline steel coupled with dynamic DC interference

For Task 4, the following activities will be conducted:

- A dataset of defects with depth values measured by two consecutive ILIs will be constructed and the described methodology is applied to multiple joints with multiple defects.
- A possible relationship between the obtained coefficients C_1 and C_2 and explanatory variables are explored.

Potential Impacts to Pipeline Safety:

At the current phase, the project provides a useful model for predicting the defect growth. In addition, the experimental study provides deep understanding of the influence of dynamic DC interference on pipeline corrosion.