CAAP Quarterly Report

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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: 10/01/2024-12/31/2024

Project Activities for Reporting Period:

The research team has been working on Task 2 (data collection), Task 3 (DC interference lab testing), and Task 4 (probabilistic defect growth modeling).

Task 2 Data collection and analysis

All digitized closed interval survey (CIS) information has been integrated into the project dataset. This involved extracting survey information using regular expressions from 500 survey files, and correlating them to data quality excel sheets. From there, the spatial coordinates of the CIS were used to correlate measurements to the location on all applicable historical ILI inspections. Additionally, corrosion density measurements and maximum depth and growth rates have been correlated to CIS measurements for each ILI period.

Climate data from the National Oceanic and Atmospheric Administration (NOAA) for the years 2020 to 2023 has been correlated with each pipeline joint in this study, wherever available. Two distinct approaches were employed:

- **Standard weather station correlation**
  Pipeline joints were matched to the nearest weather station.
- **High-quality weather station correlation**
  Pipeline joints were matched to the nearest high-quality USW weather stations (e.g., airports, large facilities) that provided more variables and consistent daily measurements.

A total of 92 weather stations, including 22 high-quality stations, were utilized in this study. Using the collected data, the following environmental variables were derived for both approaches: Freeze-Thaw Cycle, Time of Wetness, Wet-Dry Cycle, Precipitation Over 1 Inch, Snow Days, Atmospheric Relative Humidity.

Historical data on rectifier circuit resistances and resistivities were analyzed to develop a seasonal model error for all rectifiers used in this study. A normal distribution was identified as the best fit for the data, based on the lowest Akaike Information Criterion (AIC). Furthermore, rectifier circuit resistivities were compared with gSSURGO soil resistivities measured during the same year at varying distances from the rectifier locations. An order-of-magnitude comparison of soil resistivity data from different sources was performed using the Root Mean Square Logarithmic Error (RMSLE) to evaluate field versus estimated results.

Finally, *inferModel* has further augmented the box-to-box matching used in this study, with an improved feature matching algorithm compared to the feature matching software used by the industry partner.

Task 3 Corrosion behavior under stray current interference

The students involved include: one Ph.D. student, Yuhan Su, and one undergraduate student, Abbi Acurio at The University of Akron. The students conducted a comprehensive literature review of over 20 scientific papers on the influence of DC interference on cathodic protection. They studied DC levels, CP levels, DC interference period, soil/solution properties, and characterization methods. They also paid attention to the type of metal samples in the papers.

After conducting a comprehensive literature review, they developed an experimental plan that considered the testing solution, metals, CP levels, and DC interference parameters. The experimental setups should include DC input, CP input, and on-line electrochemical measurements.

The metals to be investigated are X60 and X70. The metals will be fabricated into electrodes for electrochemical measurements. DC interference includes DC amplitude and interference period. Different combinations will be considered and studied. CP levels will also include a level that is regarded as overprotection potential.

Task 4 Probabilistic defect growth modeling

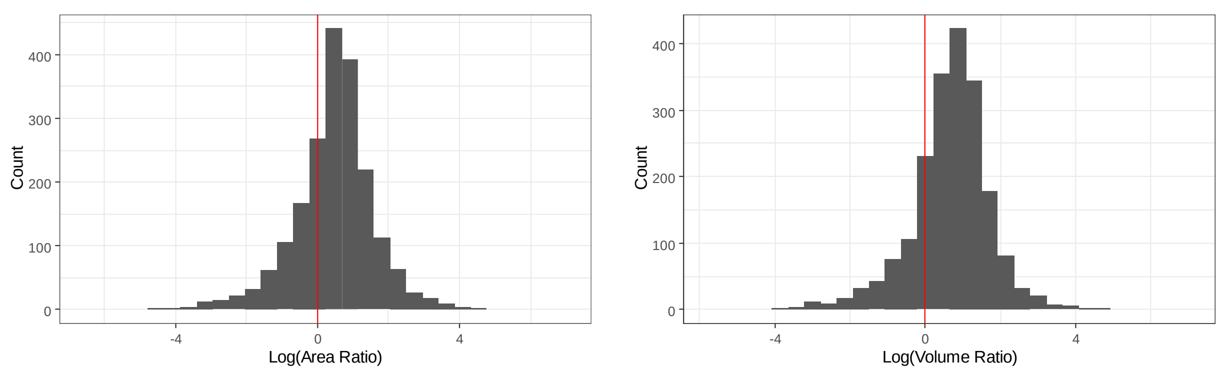
In this quarter, efforts have been made to develop probabilistic models to predict external corrosion attributes that show severity of corrosion over time, namely corrosion density estimation (i.e. total number of corrosions per pipe joint length), and corrosion surface area and volume growth.

Pipeline joint external corrosion density, that is the total number of external corrosion defects within a pipeline joint divided by its length, is an important attribute in transmission pipeline integrity management. As the probability of failure of a pipeline segment is highly influenced by the total number of defects, a reliable corrosion density prediction model could help identify problematic pipe joints as well as estimate the corrosion initiation time, which is a critical component in the corrosion growth modeling. High corrosion densities over short spans may indicate cathodic protection shielding caused by coating disbondment, which increases the vulnerability of these areas to corrosion growth.

While the number of external defects is usually obtained from in-line inspections (ILIs), the number of actual defects, N_T, is likely larger than the number of detected defects, N_D, due to detection errors (usually expressed as probability of detection, POD) in the inspection tools. While there are existing approaches that can estimate N_T based on N_D and POD, these approaches are 1) deterministic, and 2) not time dependent.

In this quarter, a probabilistic framework is under development for external corrosion density prediction over time. It assumes N_T follows a homogeneous Poisson process with an annual increase in the number of corrosion sites per unit length of λ. In addition, the initiation of the process, t_0, corresponding to each pipe joint is also considered as an unknown model parameter. POD is incorporated in the analysis to estimate the model parameters (i.e., λ and t_0) through maximizing the likelihood function of observations

Another way to compare the severity of external corrosion within pipe joints is by comparing the total value of surface area and volume of all the detected defects within each pipe joint. Hence, a probabilistic model could be used to estimate these attributes over time for one joint, and thereby, enabling comparison of these attributes between different joints. In this quarter, total surface area and volume of defects within all pipe joints of all pipelines under study are calculated using the ILI-measured depth, length, and width of defects for all ILI runs. To evaluate the growth of corrosion surface area and volume attributes over time, the value of these attributes calculated for the latest inspection is divided by those for the 2nd latest inspection. As such, a ratio greater than one suggests the growth of that attribute from the 2nd latest to latest inspection, and a ratio less than one suggests a decrease in total surface area or volume over time. Figure 1 shows the histogram of logarithm of these ratios for one of the considered pipelines when repaired joints are excluded. Note that a negative value for logarithm of ratio implies a ratio less than one. It is observed that these ratios are less than one for some of the pipe joints under this study. These ratios less than one could be due to defect detection error and defect size measurement error.



(a) (b)

Figure 1. Histogram of area and volume ratios for one of the pipelines under study

Project Financial Activities Incurred during the Reporting Period:

The financial charges include the professional service from inferModel, graduate student stipend, tuition 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. Weekly meetings were also held between Marquette research team and Project Contractor, inferModel, to discuss the preliminary analysis on the pipeline dataset.

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:

- All the experimental materials needed will be purchased.
- The experimental setup will be completed.
- The experimental testing will be conducted.

For Task 4, the research team will continue finishing the development of external corrosion density prediction over time. Meanwhile, the area and volume growth ratios will be further investigated and the effects of defects size (i.e. depth) and probability of detection on the area and volume growth ratios will be evaluated. After obtaining reliable surface area and volume growth ratios, efforts will be made to investigate the effect of influencing factors, including CP system and soil survey data, on the growth.

Potential Impacts to Pipeline Safety:

At the current phase, the project provides a better understanding of the usage limitation of CP survey data, and the needs in the existing defect analysis frameworks.