Digital Twin model for pro-active pipeline maintenance - An external corrosion case study

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1 ABSTRACT

A digital twin model was deployed for a significant part of the pipeline network with the objective to assess, monitor and improve the external corrosion prevention program. Pipeline properties, survey data, soil maps, ILI data were used to construct and calibrate the digital twin model of the network. Third party systems such as high-voltage power lines pipeline crossings were included as well.

Historical data were utilized to run the models for the different operational conditions that occurred in the past with the objective to identify the events that adversely affect pipeline's corrosion integrity. Besides pipe-to-soil potentials more advanced calculations such as corrosion rates and metal loss are a result of the digital twin. The digital twin model was also used to identify the critical rectifiers, test stations and mitigation systems by performing what-if studies followed by a validation campaign in the field. Corrective measures and monitoring strategies were proposed through modelling prior to implementation which ultimately led to reduction in operational costs on a short term and pipeline repairs on the long term.

A case study is presented on an existing pipeline corridor in co-location with high voltage power lines. Simulated corrosion risks are compared with ILI data and dig reports.

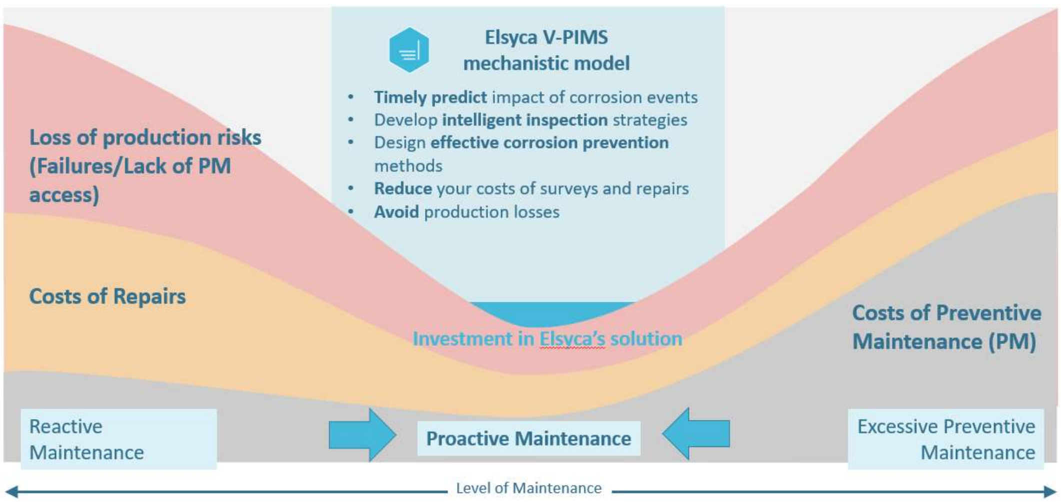
2 INTRODUCTION

Today's pipeline integrity assessment for corrosion threats is based on annual overline surveys and inline inspection runs. Such operations are in general cost intensive not always effective. Overline surveys based on pipe-to-soil potential readings are indirect measures of the corrosion risk but do not provide information the corrosion rate. They are also limited to the locations of the test station unless a more costly close interval survey is performed. In case of insufficient protection it is not always clear where anode beds must be installed. Moreover in case of AC and DC interference from third party powerline and pipeline systems, corrosion assessment based on overline surveys at test stations may be challenging. In some cases additional countermeasures may even destabilize the CP system and accelerate corrosion attack. On the other hand inline inspection (ILI) tools detect corrosion features if the corrosion attack is sufficient deep (<10% wall thickness). Although pipeline integrity is not yet compromised, corrosion was not properly detected and controlled by overline surveys. In case of poor maintenance corrosion will further grow resulting in digs and pipeline repairs with a significant increase capital cost of the asset.

A digital twin is a computer model that represents the corrosion health status of the pipeline by utilizing the field data (overline surveys and ILI). A 3D mechanistic model computes the current and potential distribution between the CP anodes, soil, pipeline and all its connections. It combines cathodic protection and DC stray current with the induced AC voltage and current from overhead powerlines, buried cables and AC traction systems. The resulting digital twin is a replica of the real-world condition with a resolution at pipeline joint level for its full pipeline length. The current and voltage output of the rectifiers is utilized for updating the model for changes in operational conditions. Fluctuations in the field data are captured and translated into

IR-free potentials, AC and DC current densities and corrosion rates at coating defects along the pipeline. As such monitoring and assessing the pipeline's corrosion health status is fully automated and enables the operator to anticipate on events that increase corrosion rates before corrosion attack is detected during the next ILI run (post mortem analysis). The digital twin mechanistic model can be used to elaborate countermeasures to reduce the corrosion rates and to verify their effectiveness before implementing them in the field. The most strategic location as well as the type of countermeasure or monitoring strategy is determined on the design table. As such an optimal pro-active maintenance program at minimal cost is achieved. Figure 1 represents the benefits of a digital twin based on mechanistic modeling whereby a minimum cost in digital twin prevents unnecessary costs in excessive countermeasures and pipeline repairs.

Figure 1 - pro-active pipeline maintenance with digital twin mechanistic modeling



3 CASE STUDY

3.1 PROJECT DESCRIPTION

The pipeline under study is 85 miles (136 km) long running from north to south as shown in Figure 5.

Figure 2 – vintage of pipeline

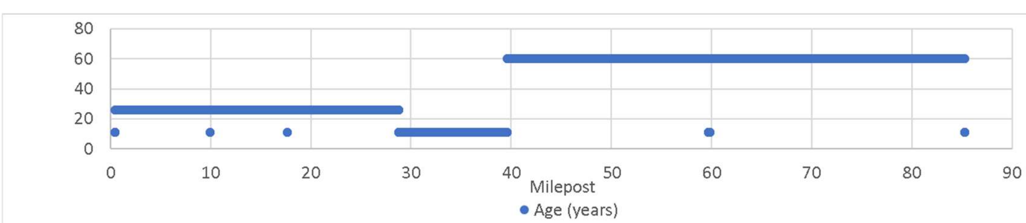


Figure 3 – wall thickness of pipeline

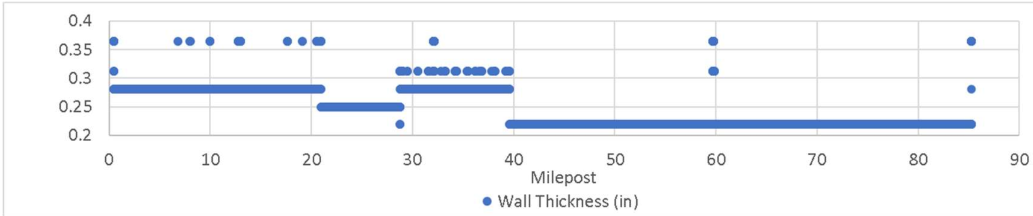
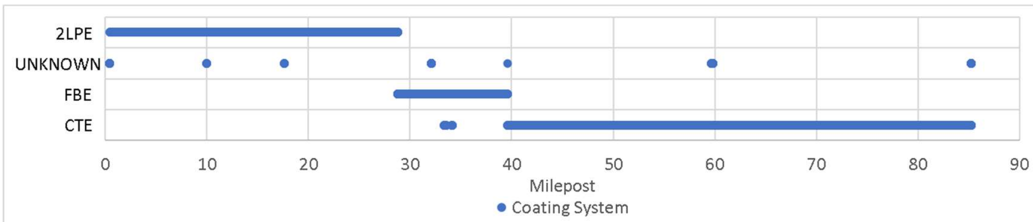


Figure 4 – coating system of pipeline



Numerous foreign pipelines cross the pipeline as summarized in Table 1. There are two known bond locations near MP 0 and 29, neither of which are considered “critical” bonds.

Table 1 – overview of foreign pipeline crossings

Pipeline	Section	Type of collocation
Foreign line A	MP 2.1090 and MP_ 8.0011	Paralleling within 140m
	MP9.0387 and MP_12.7838	Paralleling within 80m
	MP_19.0984 and MP_20.9546	Paralleling within 50m
Foreign line B	MP_24.5637 and MP_26.6862	Paralleling within 50m
	MP_29.4723	Crossing
Foreign line C	MP_32.1589	Crossing
Foreign line D	MP_46.8163	Crossing

The cathodic protection system consists of six rectifiers with shallow anode ground beds. The pipeline ends in a tank terminal containing several rectifiers. The current flowing to the pipeline under study was measured with a Swain meter such that the current value was imposed in the model. Two additional current sources at foreign pipeline crossings and three CP current losses at valve stations were defined in the model such that the simulated ON potentials aligned with the readings at the test stations.

Two AC overhead powerline in the south run parallel to the pipeline between MP59 and 68 (69kV) and between MP59 and 85 (115kV). The induced voltage on the pipeline did not exceed 4V and AC corrosion was not expected nor considered.

Table 2 – overview of current delivered by rectifiers and interference sources

Milepost	FacilityID	Current
0.0	facility	0.168
9.0837	rectifier	1.71
17.6480	rectifier	1.62
28.7752	foreign line	4.00
32.1013	rectifier	2.77
43.5918	rectifier	10.81
46.8163	Foreign line	-3
59.7335	rectifier	4.40
85.2714	rectifier	1.31

Figure 5 – project overview with pipeline (blue), AC powerlines (yellow) and foreign pipelines (red)

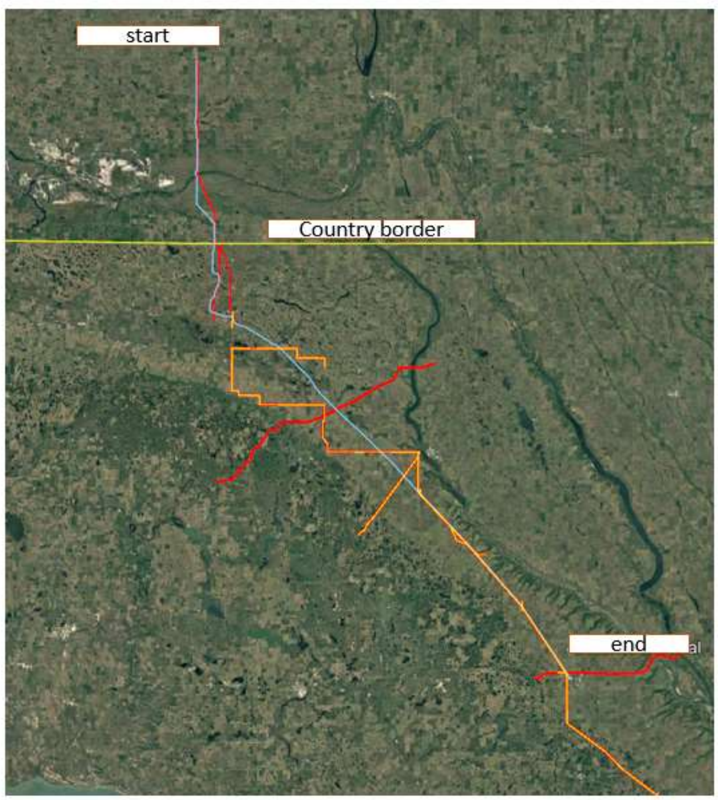
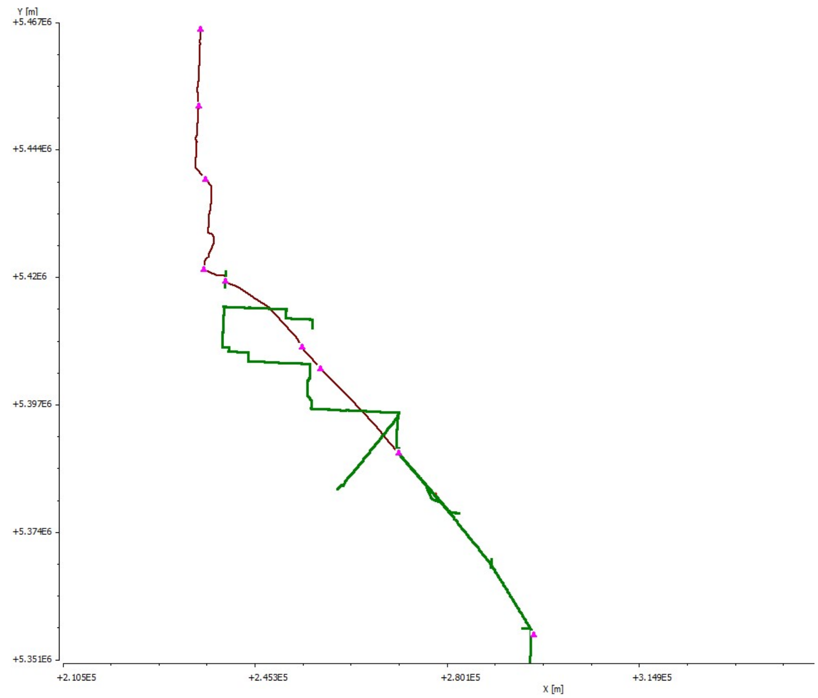


Figure 6 – 3D mechanistic model with pipeline (brown), AC powerlines (green) and rectifiers (pink)

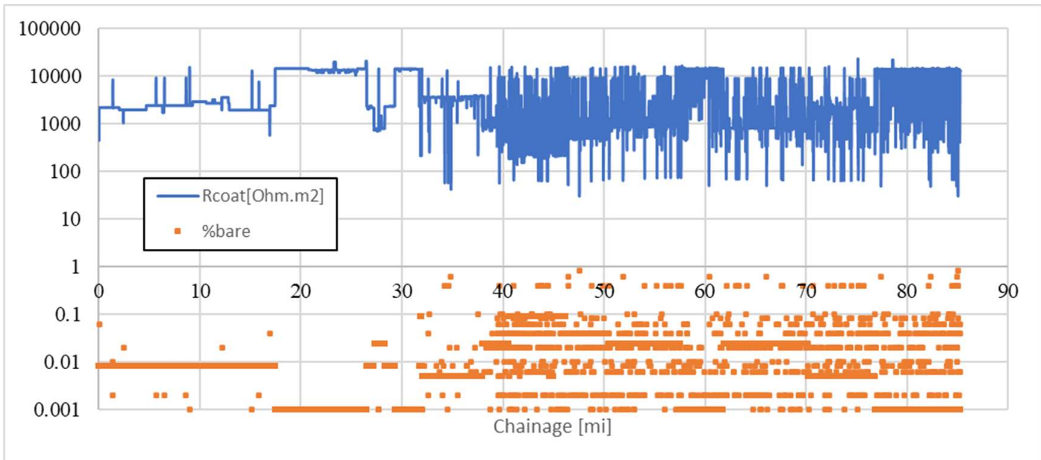


3.2 MODEL CALIBRATION

The coating properties were derived from the ILI data. The length and width of the corrosion anomaly size was used to calculate the surface area of the coating defect, assuming a non disbonded coating. In case of multiple corrosion features in a single joint, the largest corrosion feature was considered for calculating the coating defect diameter. The coating defect diameter and the total surface area of the all features together, determined the number of coating defects and the percentage bare steel. The coating resistance is a result of the coating size/number and the soil resistivity.

Figure 7 shows the results per individual joint (8335 pieces in total).

Figure 7 – coating resistance (Rcoat) and percentage of bare steel per joint



The soil properties are retrieved from public data bases. Based on the soil texture and moisture content, the soil resistivity was computed. The corrosivity of soil is then translated a polarization curve which defines the current density required to achieve a desired polarization level with respect to the native pipe-to-soil potential. The intersection between soil polygons and pipeline poly line was determined in a GIS program such that the correct soil properties and polarization curve is attributed for each pipeline joint.

Figure 8 – soil composition and moisture content along the pipeline

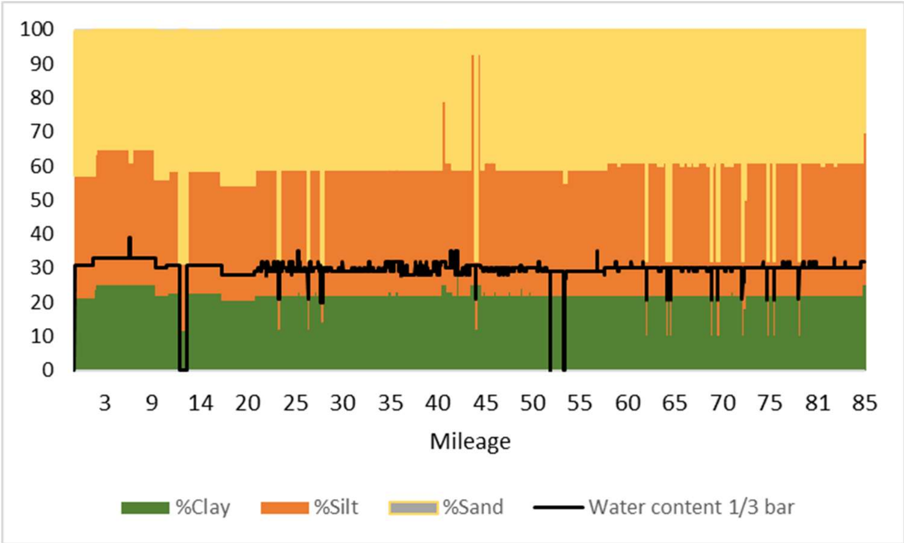
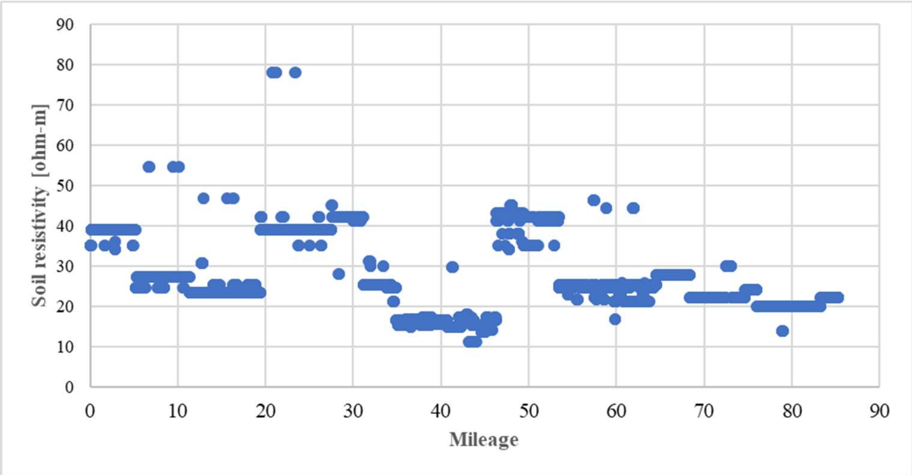


Figure 9 - computed soil resistivity profile along pipeline



3.3 Modeling results

The calibration of the digital twin mechanistic model is typical an iterative process. Unknowns such as coating resistance of joints that have no corrosion features, eventual current losses that have not been documented and soil corrosivity must be refined within acceptable boundaries. Figure 10 and Figure 11 show the simulated ON and IR-free potential profile along the pipeline. The digital twin mechanistic model aligns well with the field data measured at the test stations. The quality of the model calibration is verified in unity plots shown in Figure 12. Further refinement of the model might be required in some pipeline segments where discrepancy exceeds ±10% deviation. It should be noted that the mechanistic model computes the IR-free potential without any IR-drop error which may partly explain the deviation with the measured instant OFF potential. Additional field test such as soil resistivity measurements could be organized to retrieve the information.

Figure 10 – comparison between simulated and measured ON potentials at test stations

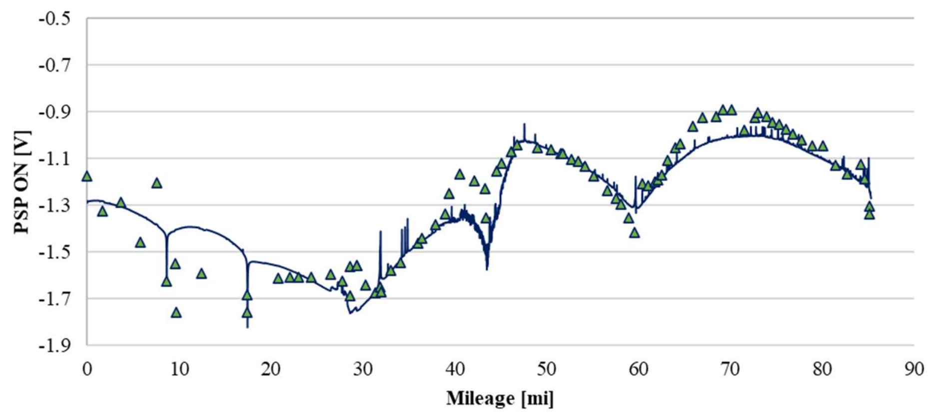


Figure 11 – comparison between simulated IR-free and measured OFF potentials at test stations

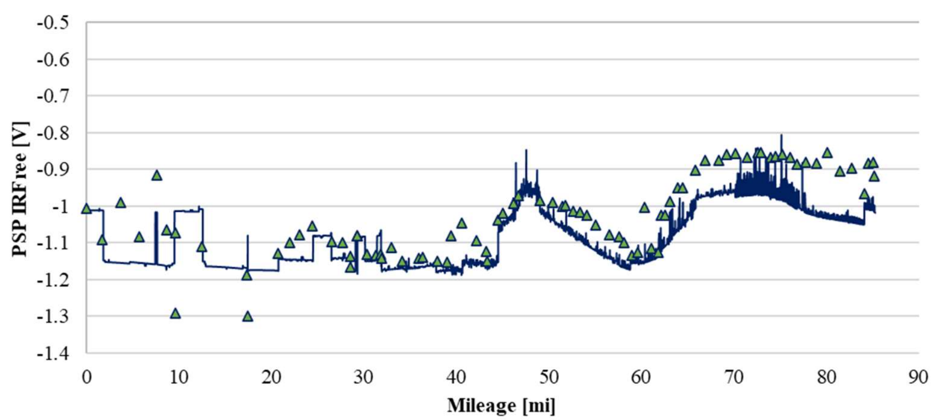
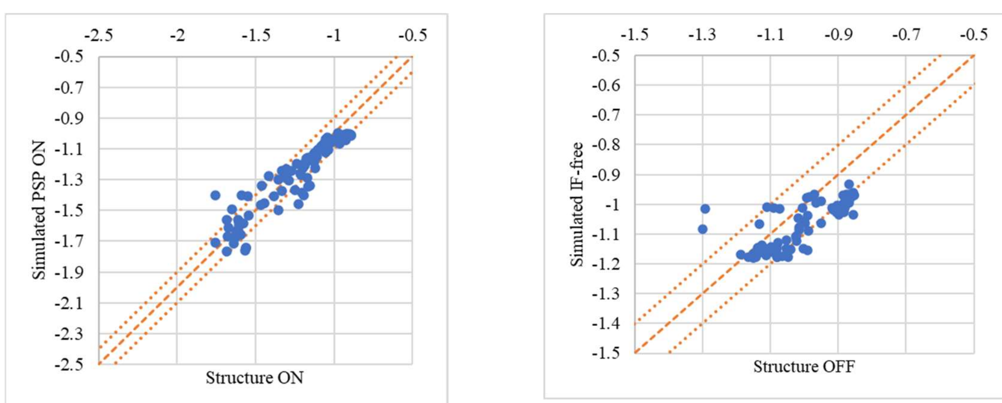
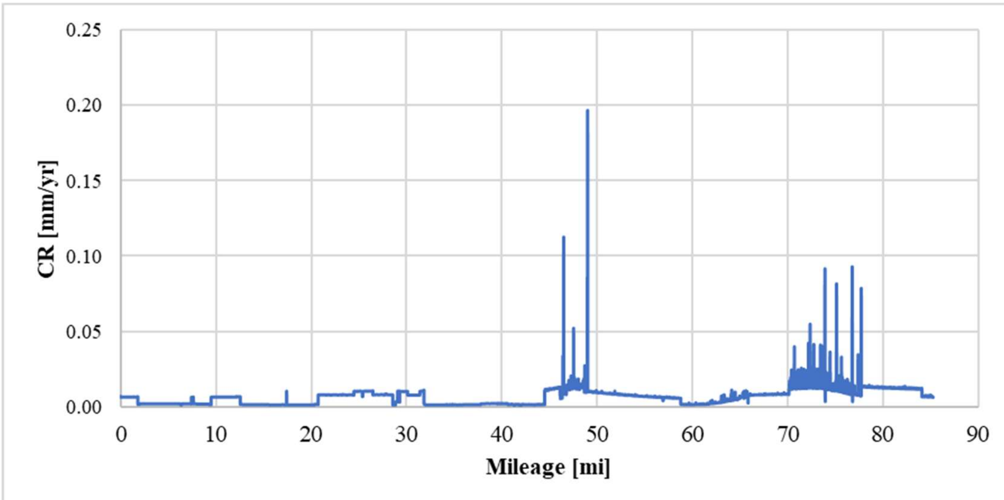


Figure 12 – unity plots for ON (left) and OFF/IRF potentials at test stations



The IR-free potential is linked to the current density arriving at the coating defect as dictated by the polarization curve. The larger the coating defect (and lower the coating resistance), the more corrosive the soil (higher current demand) the less protected the pipeline will be. The computed current density on the coating defect is then converted to an instantaneous corrosion rate as shown in Figure 13. The corrosion rate is higher the vintage coating (coal tar enamel) present from MP40 onwards (Figure 2). The maximum instantaneous corrosion rate is 16.7 µm/yr. Note that this is the pitting corrosion rate.

Figure 13 – instantaneous corrosion rate (simulated) along pipeline



3.4 Modeling exploitation

Different what-if scenarios were investigated to understand the effectiveness of the cathodic protection system and to anticipate on eventual events that may impact the corrosion rate on the pipeline.

The rectifier current output of the last seven years was utilized to compute the instantaneous corrosion rate. In Figure 14 the instantaneous corrosion rate varies from survey to survey year but the most segments remains critical. In the years 2014, 2015 and 2016 the corrosion rate increased around MP36. The corrosion growth rate (CGR) is calculated by multiplying the instantaneous pitting corrosion rate with the time interval between two consecutive surveys, and by dividing the accumulated metal loss by the total time period between the first and last survey. The computed corrosion growth rate could not only be compared with the one obtained by the next ILI run, but allows to anticipate much before severe corrosion attack is detected.

Figure 14 – evolution of the simulated instantaneous corrosion rate along the pipeline

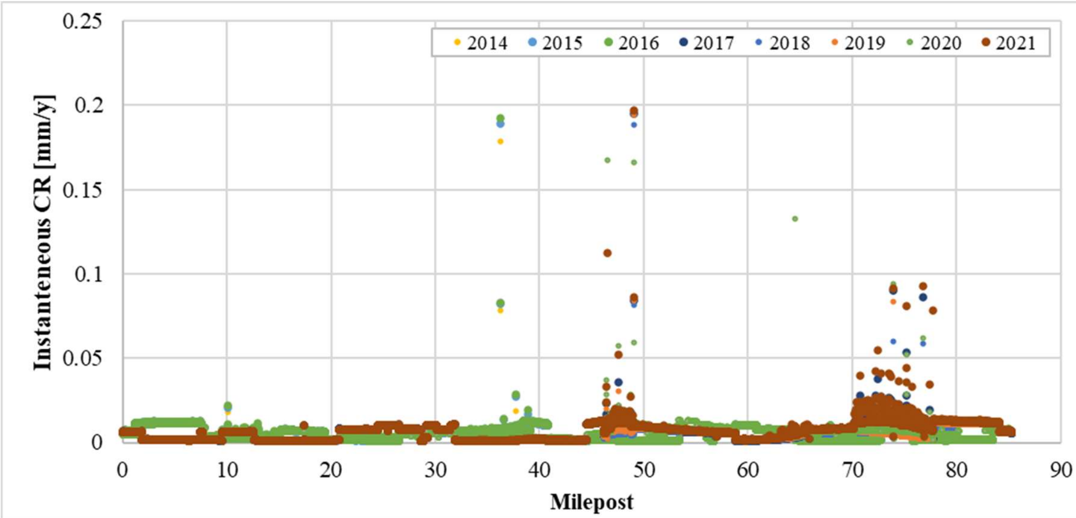
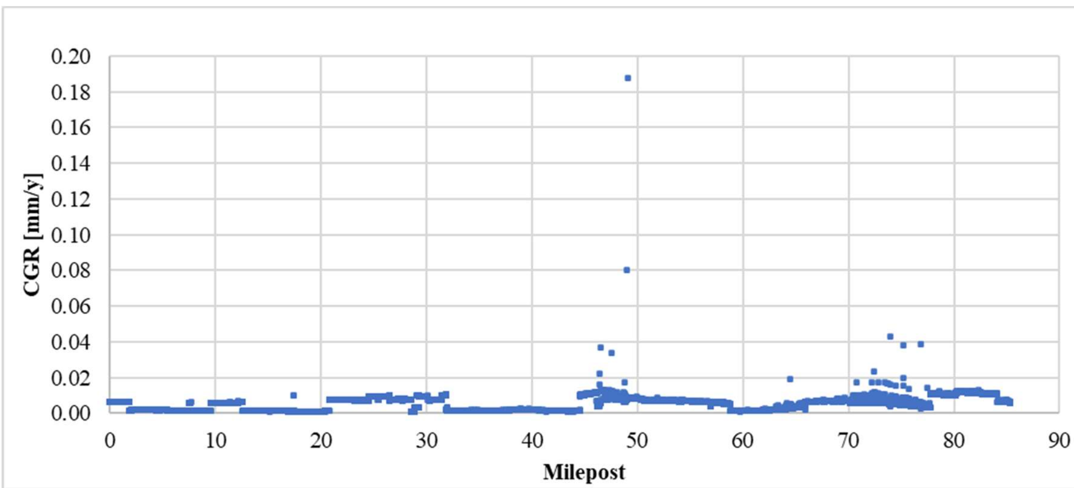


Figure 15 - calculated corrosion growth rate based on historical survey data



4 Conclusions

A digital twin model based on mechanistic modeling technology was built for a pipeline corridor (85mi or 136 mmi long) with foreign pipeline and high voltage powerline crossings. Conventional survey data (potential readings and rectifier outputs) and pipeline properties were utilized to calibrate the model such that it mimics the real-world conditions. Coating condition was determined from ILI anomaly size (length and width) and the soil data was extracted from public database sources and used to compute the soil resistivity and define the polarization curves along the pipeline. After imposing the known rectifier currents, the simulated-ON potentials are compared with the test station readings during the annual surveys. Some iterations on the coating resistance, unintended current losses at valve stations and current exchange with foreign pipelins were required to align the simulated with the measured potentials.

Once calibrated, the digital twin model is used to compute the current density and corrosion rates at coating defects which cannot be obtained with conventional overline survey techniques. Digital twins based on mechanistic modeling are a valuable tool for the integrated external corrosion management approach currently under development with the objective to understand, control and monitor the cathodic protection effectiveness of the pipeline network.

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