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## CML OPTIMIZATION: EFFECTIVE AND EFFICIENT COVERAGE AND PLACEMENT

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## INTRODUCTION

A best in class Mechanical Integrity (MI) program is comprised of numerous components, including Risk-Based Inspection (RBI), Integrity Operating Windows (IOWs), inspection strategies, and more. Inspection strategies, including Condition Monitoring Location (CML) selection, are critical in ensuring program effectiveness, as their results drive key decisions and continuous program improvement. Effective CML coverage and placement enables owner/operators to better understand and mitigate potential risks in a cost-effective manner. It also inspires confidence in the data used to make informed decisions, which ultimately maximizes the value of an MI program.

Consider a piping circuit subject to localized thinning requiring CML placement. One may choose to place spot UT CMLs on every single elbow, tee, and reducer, and one or more on each straight run, in an attempt to detect localized asset degradation (see **Figure 1**). Not only does this have a lower probability of confirming anticipated damage due to the selected inspection technique, but it may even cost more than a targeted inspection of likely locations by UT scan or profile RT.

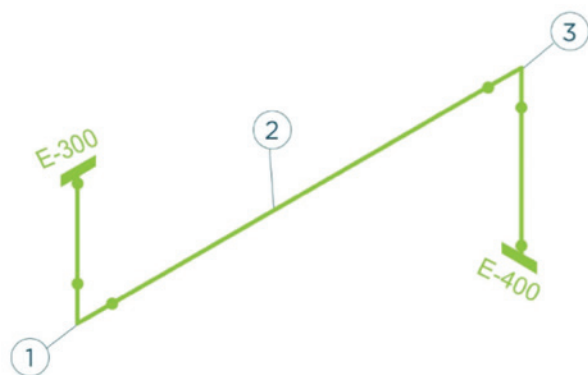
Conversely, consider a circuit primarily subject to generalized thinning, with CMLs placed on each fitting. In this case, an effective inspection technique for the anticipated damage type may provide a wealth of data to be analyzed, but is it actually necessary to gather this much information? How would one know when sufficient coverage has been achieved?

As the industry continues to grow and evolve, so should the standard approach to CML selection. Traditional qualitative approaches are simple to implement, but can be highly subjective in nature—considering the availability of data, as well as advances in engineering and technology, it is possible to supplement traditional approaches with quantitative engineering and statistical methods, improving confidence that CMLs are effectively and efficiently monitoring asset degradation.

## CML OPTIMIZATION

The next generation of CML selection is what we refer to as CML Optimization. Put simply, this approach is a marriage between inspection and engineering—a proactive approach designed to ensure plant resources are best utilized to perform effective inspections, balancing both theory and practicality.

A common misconception when discussing the topic of CML Optimization is that its sole purpose is to reduce CMLs to the fullest extent possible. CML Optimization is not a reduction technique, although reduction may be a welcome side effect. Depending on the current level of coverage for assets experiencing general thinning, it is possible to see overall spot UT reduction across a facility,



**Figure 1.** Piping with CMLs.

- *How many CMLs?* → *Overcome Inherent Variance in Data*
- *Where to place CMLs?* → *Capture Locations of Concern*
- *How to place CMLs?* → *Detect & Monitor Damage*

**Figure 2.** CML Optimization Goals.

with a decrease for some assets and an increase for others. These resources can then be reallocated towards effectively monitoring other damage types through advanced NDE techniques such as UT scanning, profile RT, phased array scanning, etc.

The ultimate goal of CML Optimization is to determine the appropriate number of CMLs placed in the correct locations for a specific asset, to find and better understand active damage mechanisms, while accurately predicting degradation rates and susceptibilities. This will provide sufficient information to enable more informed decisions regarding risk mitigation, while maintaining efficient usage of available resources (see **Figure 2**).

CML Optimization combines inspection history, corrosion expertise, and statistical analysis to provide inspectors with the information needed to confidently identify where a damage mechanism is likely to manifest itself. It also defines the optimal extent, location, and technique/s to find, characterize and quantify the damage. CML Optimization also places an emphasis on involving multiple personnel in the process for data acquisition, feedback, and validation.

Throughout this optimization process, CML placement is guided by understanding and analyzing the environment and anticipated (and/or data-proven) degradation, in addition to consideration of accessibility. By effectively utilizing this data, one is able to minimize monitoring redundancies by identifying which points are adding value and which ones are not. Thus, CML Optimization provides value by refocusing inspection resources to find

| Materials of Construction               | Inspection History Review                     | Anticipated Mechanisms                       |
|---|---|--|
| Review drawings and equipment documents | Confirm anticipated environments are accurate | Damage mechanism morphology                  |
| Operating conditions and process data   | Insight into risk drivers                     | Identify most susceptible regions for damage |

Figure 3. Example Data and Results of a Corrosion Model.

degradation where it is likely to occur and removing unnecessary CMLs that do not add value. In this manner, available resources can be better distributed by providing greater coverage on higher-risk locations or assets, and lower, but still effective, coverage for lower-risk areas.

### METHODOLOGY OVERVIEW

The CML Optimization process is composed of five key steps and includes activities that many owner/operators are likely already implementing as they continue to develop their MI programs. The process is relatively straightforward, and each facility can determine the level of rigor to employ at each step in the process based on their unique needs and program strategy.

#### 5-Step CML Optimization Process:

1. Generate Corrosion Model (Or leverage existing if available)
2. Perform Data Optimization and Determine Appropriate CML Coverage
3. Determine CML Placement
4. Identify Practical Limitations (but do not let ease of access drive the locations)
5. Update MI Program Components and Establish Evergreening

### CORROSION MODEL GENERATION

The first step in the CML optimization process is to generate an accurate corrosion model. All factors influencing an asset's degradation environment should be analyzed—such as the materials of construction, process fluid, temperatures, flow effects, and inspection history—to determine anticipated damage mechanisms, as well as the potential extent of said damage (see Figure 3). Not only does a corrosion model enable the CML Optimization process, but it also adds value to an MI program employing Risk-Based Inspection (RBI) and/or Integrity Operating Windows (IOWs).

### PERFORM DATA OPTIMIZATION AND DETERMINE APPROPRIATE CML COVERAGE

Once the corrosion model has been generated, one can then

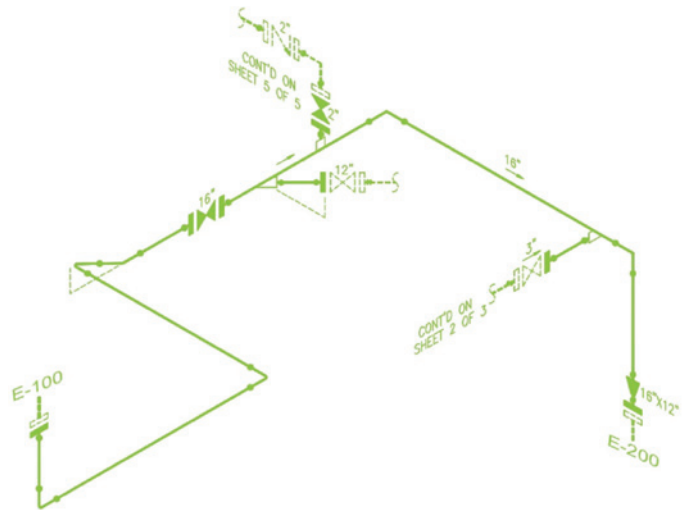


Figure 4. Complex Piping Circuit.

move into the data optimization phase to determine appropriate CML coverage. To accomplish this, three primary steps should be followed:

1. Determine the Level of Complexity per Asset
2. Determine the Level of Criticality per Asset
3. Review Inspection History

#### Determining Complexity

To determine an asset's complexity, one must understand the potentially unique degradation environments experienced by an asset—which ultimately drives the forms of degradation, as well as their rates and susceptibilities. In other words, it is important to understand how physical asset characteristics could create or exacerbate degradation. This involves reviewing the asset's overall number of components, component types, number and types of flow changes, asset dimensions, geometrical orientation, and any other factor contributing to asset degradation (see Figure 4).

#### Determining Criticality

In addition to establishing asset complexity, an asset's level of criticality should also be understood. This entails understanding how the asset is designed, how it operates, its operating conditions (e.g., temperature and pressure), process fluids, metallurgy,

and associated level of risk or other available measures of severity such as pipe class. Severity should be determined in order to escalate placement of CMLs on circuits that are more likely to fail by means of degradation, or that have a greater consequence of failure. Much of this information is obtained while developing the corrosion model, or is available in existing data management systems. The specifics of how this level of severity is determined are unique per facility, and should be reflective of existing MI practices.

### CML Base Coverage

Once an asset's levels of complexity and criticality have been identified, we can determine an appropriate CML Base Coverage, or the initial appropriate CML coverage prior to reviewing the Inspection History. This is also particularly useful when historical data is not available, not accurate, or if a facility has recently been constructed.

For general thinning mechanisms specifically, one can develop statistical requirements to meet both desired levels of coverage and confidence in the measured data. This can be achieved through easier to implement qualitative means (based on a percentage asset features), or by using various quantitative statistical sampling methods, which are useful for improving precision in determining CML coverage requirements. An asset's level of complexity may be used to drive the level of statistical sampling while the level of criticality may be used to drive the desired level of confidence. This scalable approach enables the aforementioned monitoring optimization in which higher risk or more complex assets, require additional monitoring, while lower risk or less complex assets, require less monitoring.

A similar, although less quantitative, process may be utilized for other damage morphologies, such as localized thinning or cracking, in order to determine the appropriate levels of coverage.

### Reviewing Inspection History and Data

**Historical Ultrasonic Thickness (UT) Data** Understanding an asset's general environment is important in determining recommended CML count and placement, but what about historical UT data? If historical data (vetted as accurate) indicates relatively uniform thinning and confirms the corrosion model assessment performed in the first step, then the number of CMLs may potentially be reduced due to potential data redundancy (pending verification). If the historical data indicates relatively non-uniform thinning, additional action should be considered, such as adjusting CML placement, increasing coverage, performing field verification, re-evaluating the corrosion model, verifying data accuracy, exploring alternative NDE monitoring, etc.

### UT Data Evaluation by Means of Statistical Algorithms

Conversely, should historical data always be trusted? Before utilizing historical data to make decisions regarding CML coverage and placement, there may be a need to assess said data to identify potentially erroneous readings or areas for additional verification. If there are concerns about the accuracy of the data, this can be accomplished by applying a series of statistical algorithms and decision trees employing logic rules to identify areas of potential concern (e.g., extreme statistical outliers, very close consecutive



Figure 5. Historical Data Assessment.

readings [date], and much more) (see **Figure 5**). Potentially erroneous readings may then be reviewed by a multi-disciplinary team to validate the results and determine an appropriate path forward (e.g., ignore reading, perform field verification, etc.).

Not only does this process improve the accuracy of the CML Optimization process, but accurate inspection data also enables a better understanding of asset degradation and improves the confidence in inspection and maintenance plans, as well as the RBI program, if implemented.

### Using Historical Data to Update CML Count

Once historical data has been reviewed and validated, it can be assessed to verify whether an asset or even a specific component is truly experiencing relatively uniform thinning or some other form such as localized thinning. This can be achieved using various statistical measures known as the Coefficient of Variation (COV) or Index of Dispersion (IOD), both of which are normalized indicators of data dispersion, or the degree of data scatter (see **Figure 6**).

$$\text{Index of Dispersion (IOD)} = \frac{\sigma_{CR}^2}{CR_{avg}}$$

$$\text{Coefficient of Variation (COV)} = \frac{\sigma_{CR}}{CR_{avg}}$$

Where:

$CR_{avg}$  = Average Corrosion Rate

$\sigma_{CR}$  = Standard Deviation of Asset or Circuit Corrosion Rates

Figure 6. Index of Dispersion and Coefficient of Variation Equations.

If the data set is very tight, or has low dispersion (as depicted in the green curve in **Figure 7**), this is an indication that the asset, or specific component, is experiencing relatively uniform thinning. Degradation will never be perfectly uniform, but can be relatively similar within a specified margin.

The results of this assessment can also be used to determine monitoring redundancy; in other words, several CMLs for a given asset could be providing very similar information through repeated inspections, and thus, may be evaluated for discontinued monitoring. When potential redundancy is identified, the level of monitoring from the CML Base Coverage may be reduced

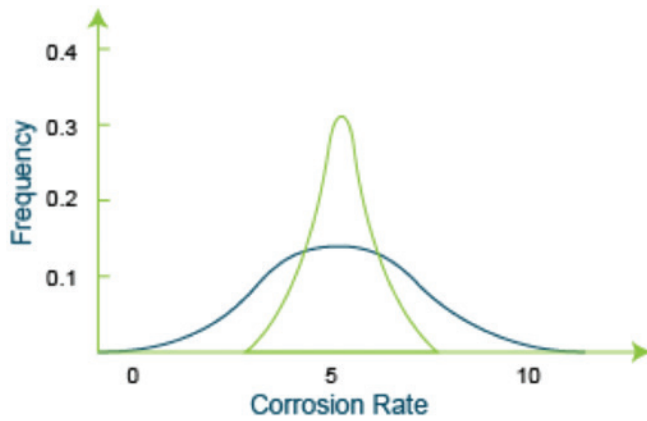


Figure 7. Data Sets with Varying Levels of Dispersion.

using mathematical algorithms—depending on the level of data dispersion—all while still maintaining a statistically significant portion of the original sample to accurately detect manifested damage and represent the asset’s degradation form and rates. Since this step in the process is very mathematical in nature, the results should be reviewed and validated by a knowledgeable, experienced multi-disciplinary team prior to implementing any form of CML reduction. Good judgment of knowledgeable and experienced facility personnel should hold more weight than the theoretical calculations.

### DETERMINE CML PLACEMENT

Once the appropriate levels of CML coverage have been determined, the next step in the CML Optimization process entails determining appropriate CML placement, including the appropriate inspection techniques. Below are a few questions to consider during this step:

- What are the environments present within the asset?
- What is the severity of each environment?
- What is the damage mechanism morphology?
- What is the risk, as determined by RBI assessments or anticipated corrosion rate/susceptibility?
- What effect will conditions, e.g. flow, upsets, intermittent operations, etc. have on anticipated environments?

Answering these questions and exploring other relevant factors regarding an asset’s degradation environment, will help guide the process of selecting CML locations and techniques to effectively detect damage, as well as ensure accuracy in the data gathered during inspections.

For example, consider the piping circuit in **Figure 8**. The anticipated forms of degradation identified in the corrosion model are General Corrosion for the main line and Under Deposit Corrosion on the deadlegs. Statistical analysis of the circuit’s historical data has shown uniform corrosion on the main lines, with several identified points of redundancy, as well as non-uniform corrosion on the deadlegs. The recommendations for CML coverage and placement are to reduce point UTs in the areas experiencing general thinning with low dispersion, and to adjust the monitoring

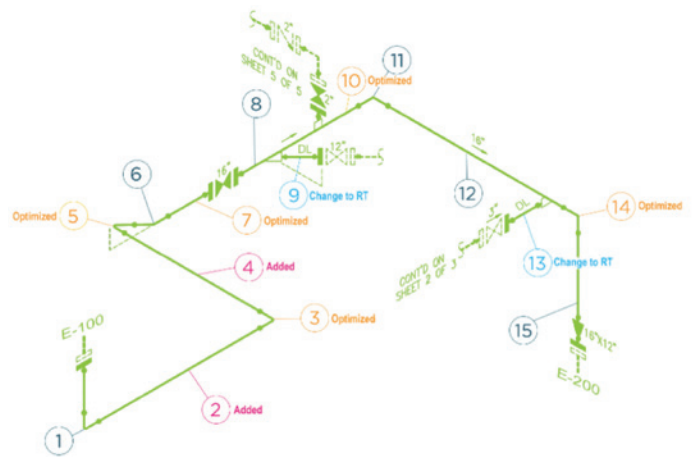
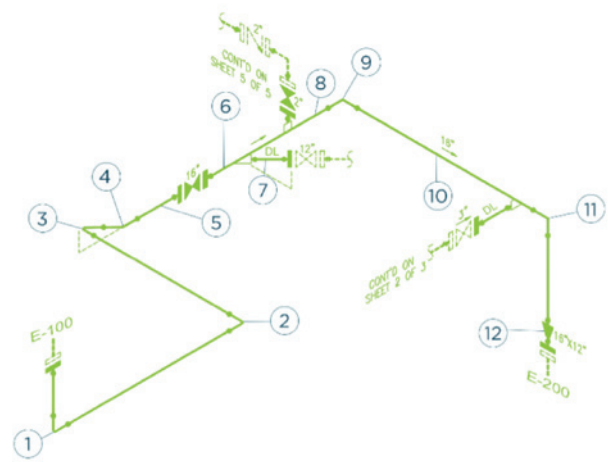
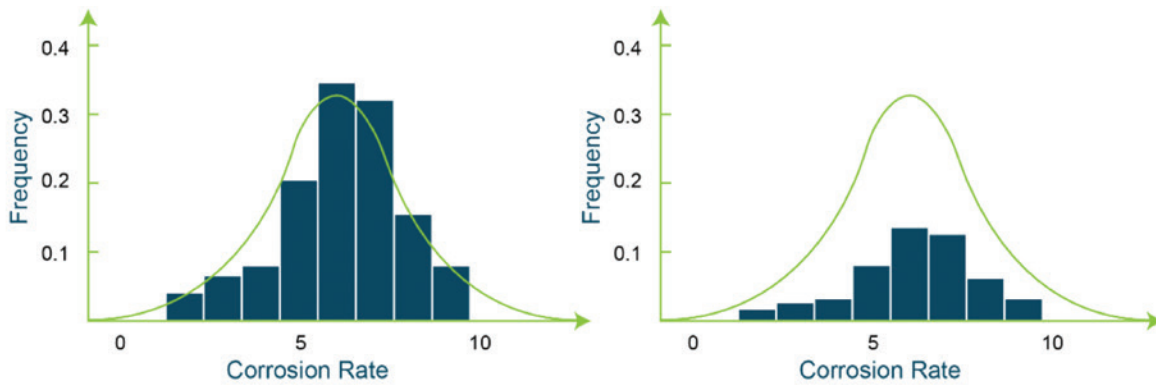


Figure 8. Example CML Count and Placement Plan Adjustment (Piping).

technique on the deadlegs to ensure localized corrosion is identified and appropriately monitored through more appropriate NDE such as profile radiography. The resources previously utilized performing redundant measurement on main lines can be better allocated to advanced NDE techniques, which can actually detect the anticipated localized corrosion on deadlegs. This adjustment enables both a more effective risk mitigation plan as well as a more efficient use of economic resources.

When evaluating where to focus monitoring efforts or minimize redundancy, one can again utilize statistical algorithms and decision trees to guide the selection process. Ultimately, this uses actual data, in addition to the previous analysis, to align the CML adjustments with the strategy of the MI program. This enables a shift in the monitoring profile (see **Figure 8**) to target the most likely points of failure (degradation rates, remaining thickness, etc.) or even maintain the current corrosion profile when identifying redundant points for discontinued monitoring. This can all be done while mathematically maintaining sufficient coverage, in addition to maintaining any other MI program requirements. These statistical methods, rather than more qualitative methods, are used to choose which CMLs to discontinue monitoring.

The methodology above may also be applied to equipment, particularly to evaluate trending history. While equipment tends to be adequately covered by CMLs per site procedures, optimization is



**Figure 9.** Corrosion Rate Monitoring Profile Before (left) and After (right) Optimizing Redundant CMLs.

still a valuable exercise in identifying correct techniques in different zones of corrosion and evaluating potential redundancy.

### IDENTIFY PRACTICAL LIMITATIONS

Up to this point, the CML Optimization process has been primarily theoretical, even with consultations with multi-disciplinary teams to validate and adjust data inputs and algorithm results. Once these exercises have been completed in an office setting, a facility must evaluate any practical limitations and determine if any additional adjustments are necessary with respect to field placement.

To define practical limitations, facilities should leverage established risk analyses, which will ultimately enable the evaluation of the cost of inspection versus the cost of failure. In other words, how much of a facility's financial resources can be allocated to each monitoring location? When placing locations in the field many implications should be considered, such as the following:

- Is scaffolding required?
- Does insulation need to be removed?
- Is this high-temperature service?
- Could an employee be exposed to significant risk?
- What is the risk reduction versus cost of inspection?

The process of weighing the cost of inspection against cost of failure (risk) should be considered by a multi-disciplinary team who can determine optimal balance between these factors. In addition to qualitative assessment, quantitative risk and economic optimization algorithms may also be employed.

### UPDATE MI PROGRAM COMPONENTS AND ESTABLISH EVERGREENING

Once final CML placement is complete, the final step in the CML Optimization process involves implementation, as well as ensuring robust processes are in place for evergreening, including activities such as:

1. Visually identifying new CMLs in the field
2. Updating inspection isometrics to reflect CML updates

3. Updating the Inspection Data Management System (IDMS) to reflect CML and Inspection Plan updates
4. Cleaning up Thickness Data in IDMS (validated by appropriate personnel)
  - It is recommended to archive deactivated readings. Deleting this data is not recommended for audit purposes and general good practice.
5. Verifying a strong Management of Change (MOC) process is in place to ensure the CML Optimization analysis remains valid and is appropriately reviewed if there are significant changes in facility design or operations

Once placement is complete and optimized CMLs are due for inspection, special emphasis should be placed on thickness reading quality. CMLs with erroneous thickness reading history which has been inactivated requires high quality readings moving forward, especially if less locations are being monitored. Regular audits of inspectors and technicians performing measurements should be implemented, as well as quick follow up on growths or large losses. In adopting this level of proactivity, readings found to be outside of expected ranges can either be verified or corrected prior to IDMS entry, resulting in more accurate corrosion rates and thus more effective risk mitigation.

### CONCLUSION

CML Optimization is a method in which CML placement is guided by environment and anticipated damage types, with respect to practical limitations, while involving high visibility to personnel outside of inspection. Through the combined efforts of the predictive modeling applied by engineering personnel to identify areas of likely damage, as well as the experience and knowledge of inspection personnel to reflect historical factors and current condition, an effective monitoring plan can be put in place on an asset by asset basis to reduce overall facility risk, minimize redundancy through optimized resource allocation, and maximize the value of each inspection performed. ■

For more information on this subject or the author, please email us at [inquiries@inspectioneering.com](mailto:inquiries@inspectioneering.com).



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### **BRIAN MARINO**

Brian Marino currently guides development of MI and RBI program implementation and refinement for PinnacleART. Brian has experience implementing these programs in the downstream refining, nitrogen plants (fertilizer) and storage facilities throughout the United States and Canada. Brian has also worked to implement CML Optimization and Smart CML Placement methodologies alongside these implementations. Brian obtained both his M.S. in Management and B.S. in Chemical Engineering, with a minor in Materials Science from Worcester Polytechnic Institute.

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### **RYAN MYERS**

Ryan Myers currently manages PinnacleART's major process improvement projects, internal software development, and the enhancement of complex external offerings. Ryan ensures the organization operates as efficiently and effectively as possible through the application of Lean Six Sigma, Kaizen, and 5S principles. He has experience implementing comprehensive MI and RBI programs in the oil and gas downstream, midstream, petrochemical and mining industries. Ryan has also led technical engineering development efforts for statistical reliability models, corrosion modeling software applications and CML optimization techniques. Ryan obtained his B.S. from The University of Texas in Mechanical Engineering, with a minor in Business Foundations.