

# Estimating Remaining Life of Heat Exchangers using Extreme Value Analysis (EVA)

Includes a free online app!

## Heat Exchangers

Heat exchangers are integral to operations in oil & gas, chemical and power generation industries.

A typical shell and tube heat exchanger can house anywhere between a few hundred tubes to more than 5000 tubes.

The wall thickness of these tubes diminishes over time due to corrosion.

Thickness readings offer an estimate of the remaining life. The thinnest tube represents the “weakest link” and dictates the remaining life of the heat exchanger.

## Measuring Wall Thickness

Wall thickness of heat exchanger tubes are typically measured using the Internal Rotary Inspection System (IRIS) method.

It is an ultrasonic non-destructive method, and is able to detect corrosion and pitting on the tube surface along with thickness measurements.

This method requires the tubes to be thoroughly cleaned before inspection. It also requires a constant water supply as a couplant.

IRIS can be very time consuming, especially when there are thousands of tubes to inspect, delaying restart after a shutdown.

Can statistics come to the rescue?

## Extreme Value Analysis

Extreme Value Analysis (EVA) is a statistical method that can be used to estimate the wall thickness of the thinnest tube in a heat exchanger based on measurements from a sample of tubes (20 to 30 tubes).

Wang (2006) presented a paper at a conference of The American Society of Mechanical Engineers (ASME) demonstrating this type of analysis.

Wall thickness measurements from a sample of tubes are taken and the minimum thickness from each tube is recorded.

A Gumbel distribution is then fit to the recorded values and extrapolation is used to estimate the most extreme value (i.e. thinnest tube in the entire heat exchanger).

## Extreme Value Analysis

Technical details regarding model parameter estimation, uncertainty quantification and goodness-of-fit assessments can be found in the Appendix to this document.

EVA is available in commercial Integrity Management System (IMS) softwares (Cenosco, 2025).

I built a web application that can perform EVA using the R open source software, based on the work by Wang (2006).

The rest of this document demonstrates how to use this online application to perform EVA for a heat exchanger remaining life calculation.

## Selecting Tubes to Sample

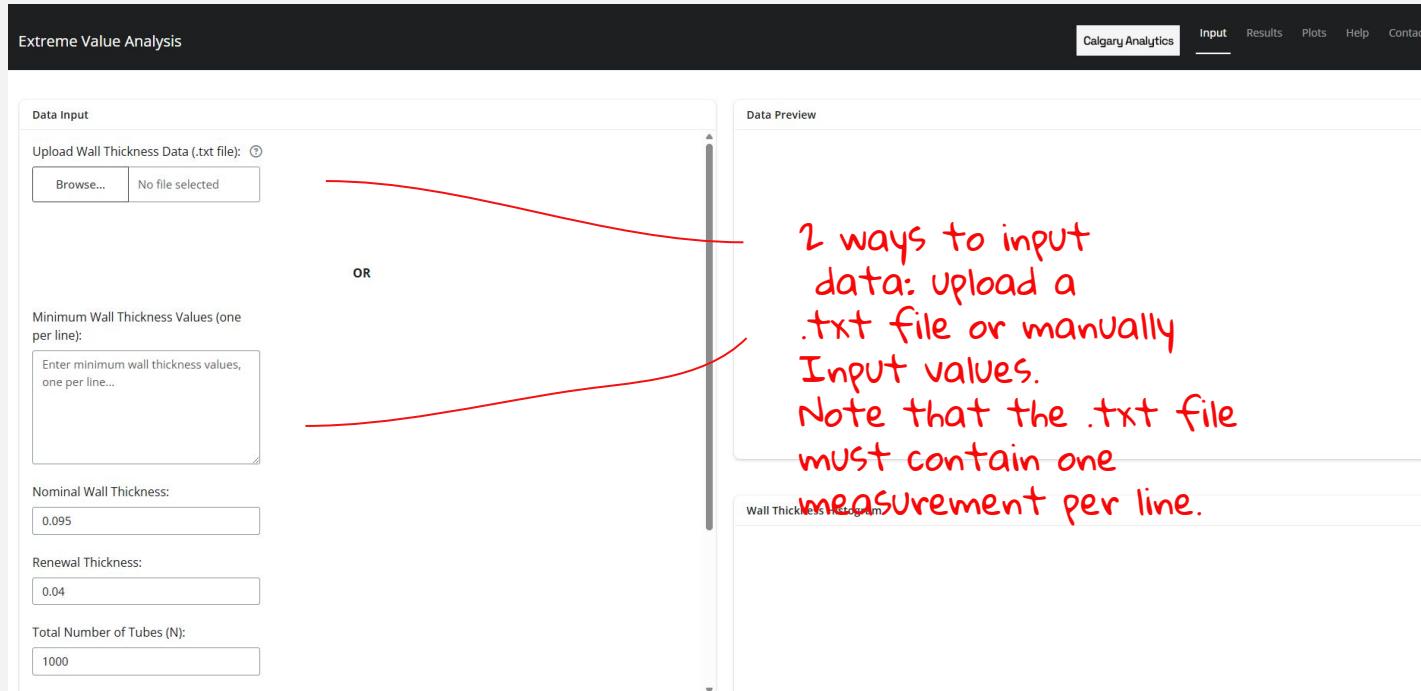
The sample of tubes selected for measurement must be representative of the population of tubes in the heat exchanger. There should be no bias towards any one particular part of the exchanger i.e. convenience sampling.

If there is any evidence to suggest that corrosion behaviour might be different in different areas (eg: top vs bottom, inlet vs outlet), then stratification must be employed. Each strata should be analyzed separately.

It is important that the selected sample of tubes for EVA come from a homogenous population for unbiased results.

Selecting tubes from a non-homogenous population can lead to misleading conclusions.

## EVA Online App



Extreme Value Analysis

Calgary Analytics    Input    Results    Plots    Help    Contact

Data Input

Upload Wall Thickness Data (.txt file): [?](#)

OR

Minimum Wall Thickness Values (one per line):

Nominal Wall Thickness:

Renewal Thickness:

Total Number of Tubes (N):

Data Preview

Wall Thickness Histogram

2 ways to input data: upload a .txt file or manually Input values. Note that the .txt file must contain one measurement per line.

## EVA Online App

The screenshot displays the EVA Online App interface. On the left, a form for 'Extreme Value Analysis' is shown with fields for Nominal Wall Thickness (0.095), Renewal Thickness (0.04), Total Number of Tubes (1000), Start of Operation (2024-10-15), and Inspection Date (2025-10-15). A red annotation with a curved arrow points from the 'Renewal Thickness' field to the 'Wall Thickness' histogram on the right, stating: 'Data preview and histogram cards are auto populated after data upload/entry.' A blue 'Run Analysis' button is at the bottom of the form. On the right, a 'Calgary Analytics' navigation bar is at the top, followed by tabs for Input, Results, Plots, Help, and Contact. The 'Input' tab is selected. Below the tabs is a table showing 10 entries of data, with a vertical scroll bar. The table has columns for Index, Wall Thickness, and Nominal Thickness. The data is as follows:

Index	Wall Thickness	Nominal Thickness
1	0.064	
2	0.061	
3	0.066	
4	0.061	
5	0.064	
6		
7		
8		
9		
10		

Below the table, it says 'Showing 1 to 10 of 20 entries' with buttons for Previous, 1, 2, and Next. On the right, a 'Wall Thickness Histogram' is shown with a red dashed vertical line at the Nominal Thickness. The histogram has a frequency of 5 for the first bin (0.058-0.060) and 4 for the second bin (0.060-0.062). The x-axis is 'Minimum Wall Thickness' from 0.06 to 0.09, and the y-axis is 'Frequency' from 0 to 5. Text on the right says 'Tubes sampled: 20' and 'Total tubes: 1000'.

## EVA Online App

The screenshot shows the EVA Online App interface. On the left, there is a form for 'Extreme Value Analysis' with the following input fields:

- Nominal Wall Thickness: 0.095
- Renewal Thickness: 0.04
- Total Number of Tubes (N): 1000
- Start of Operation: 2024-10-15
- Inspection Date: 2025-10-15

Below these fields is a blue 'Run Analysis' button. To the right of the form is a table titled 'Wall Thickness' showing data for 20 entries. The table includes columns for Index, Wall Thickness, and a vertical scroll bar. The data is as follows:

Index	Wall Thickness
1	0.064
2	0.061
3	0.066
4	0.061
5	0.064
...	...
10	0.064
15	0.061
20	0.064

Below the table, it says 'Showing 1 to 10 of 20 entries' and has 'Previous' and 'Next' buttons. The page number '1' is highlighted in blue. To the right of the table is a histogram titled 'Wall Thickness Histogram' with the following data:

Minimum Wall Thickness	Frequency
0.058	2
0.060	5
0.062	5
0.064	4
0.066	4

Text on the histogram indicates 'Tubes sampled: 20' and 'Total tubes: 1000'. A vertical red dashed line is labeled 'Nominal Thickness' at approximately 0.065. At the bottom left of the histogram, it says 'Run Analysis'.

**Renewal thickness is the minimum acceptable wall thickness for heat exchanger operation**

**Ensure rest of the data is input correctly.**

## EVA Online App

Extreme Value Analysis

Calgary Analytics    Input    Results    Plots    Help    Contact

Nominal Wall Thickness: 0.095

Renewal Thickness: 0.04

Total Number of Tubes (N): 1000

Start of Operation: 2024-10-15

Inspection Date: 2025-10-15

Run Analysis

Start of operation and inspection date is required for corrosion rate and remaining life calculation.

Index	Wall. Thickness
1	0.064
2	0.061
3	0.066
4	0.061
5	0.064

Showing 1 to 10 of 20 entries    Previous 1 2 Next

Wall Thickness Histogram

Frequency

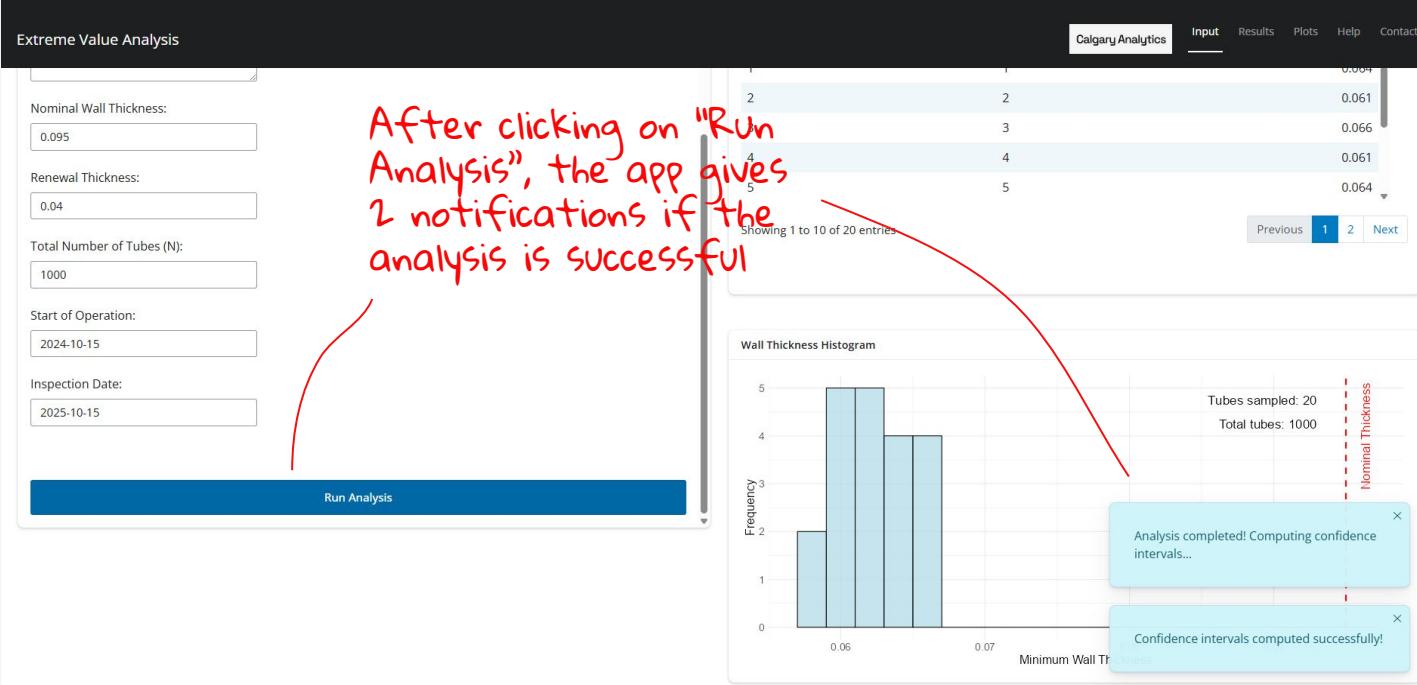
Minimum Wall Thickness

0.06    0.07    0.08    0.09

Tubes sampled: 20    Total tubes: 1000

Nominal Thickness

## EVA Online App



Extreme Value Analysis

Calgary Analytics    Input    Results    Plots    Help    Contact

Nominal Wall Thickness: 0.095

Renewal Thickness: 0.04

Total Number of Tubes (N): 1000

Start of Operation: 2024-10-15

Inspection Date: 2025-10-15

Run Analysis

Showing 1 to 10 of 20 entries

2 3 4 5

0.064 0.061 0.066 0.061 0.064

Previous 1 2 Next

Wall Thickness Histogram

Tubes sampled: 20    Total tubes: 1000

Frequency

0.06 0.07

0 1 2 3 4 5

Minimum Wall Thickness

Analysis completed! Computing confidence intervals...

Confidence intervals computed successfully!

After clicking on "Run Analysis", the app gives 2 notifications if the analysis is successful

A red arrow points from the text "After clicking on 'Run Analysis', the app gives 2 notifications if the analysis is successful" to the two notifications at the bottom right of the histogram.

## EVA Online App

The screenshot shows the EVA Online App interface with the following sections:

- Gumbel Distribution Fit:** Shows parameters: Location parameter: 0.031082, Scale parameter: 0.002301. Notes: Parameters estimated using maximum likelihood.
- Goodness of Fit Tests:** Shows results for Kolmogorov-Smirnov (p-value: 0.952) and Anderson-Darling (p-value: 0.915). Note: Higher p-values indicate a better fit.
- Minimum Wall Thickness Estimate:** Shows: Estimated Maximum Wall Loss for 1000 tubes: 0.047 units, Standard Error: 0.003. Handwritten note: **Estimated minimum wall thickness at 95% CI**. Estimated minimum wall thickness based on the lower bound of a 95% confidence level is 0.042 units.
- Corrosion Rate and Remaining Life Estimates:** Shows: Corrosion Rates (units/year): 99% 0.056, 95% 0.053, 90% 0.052, 80% 0.051. Remaining Life (years): 99% -0.01, 95% 0.03, 90% 0.05, 80% 0.08. N/A 2025-10-28, 2025-11-05, 2025-11-14. Note: Negative remaining life indicates that the estimated minimum wall thickness is less than the renewal thickness. Renewal Thickness: 0.04 units, Start of Operation: 2024-10-16, Inspection Date: 2025-10-16.

Handwritten annotations in red:

- Estimated minimum wall thickness at 95% CI** (pointing to the 95% confidence interval estimate in the results section).
- Estimated minimum wall thickness at other confidence levels** (pointing to the table of confidence interval estimates in the results section).
- Click "Results"** (pointing to the "Results" tab in the top navigation bar).

## EVA Online App

Click "Results"

The screenshot shows the EVA Online App interface with the "Results" tab selected. A red arrow points to the "Results" tab with the text "Click 'Results'".

**Gumbel Distribution Fit**

Location parameter: 0.031082  
Scale parameter: 0.002301

Parameters estimated using maximum likelihood.

**Minimum Wall Thickness Estimate**

Estimated Maximum Wall Loss for 1000 tubes: 0.047 units  
Standard Error: 0.003

Estimated minimum wall thickness based on the lower bound of a 95% confidence level is 0.042 units.

Minimum Wall Thickness Estimates:

	99%	95%	90%	80%
Lower Bound	0.039	0.042	0.043	0.044

Note: The estimates must only be used after considering the results of the goodness of fit

**Goodness of Fit Tests**

Test	P-value
Kolmogorov-Smirnov	0.952
Anderson-Darling	0.915

Higher p-values indicate a better fit. If the p-value is less than 0.05, we reject the null hypothesis (at the 5% alpha level) that the data follows a Gumbel distribution and conclude that the fit is not adequate.

**Corrosion Rate and Remaining Life Estimates**

Corrosion Rates (units/year):

99%	95%	90%	80%
0.056	0.053	0.052	0.051

Remaining Life (years):

99%	95%	90%	80%
-0.01	0.03	0.05	0.08
N/A	2025-10-28	2025-11-05	2025-11-14

Negative remaining life indicates that the estimated minimum wall thickness is less than the renewal thickness.

Renewal Thickness: 0.04 units  
Start of Operation: 2024-10-16  
Inspection Date: 2025-10-16

## EVA Online App

Extreme Value Analysis

Gumbel Distribution Fit

Location parameter: 0.031082  
Scale parameter: 0.002301

Parameters estimated using maximum likelihood.

Check p-values of the GOF tests

Goodness of Fit Tests

Test	P-value
Kolmogorov-Smirnov	0.952
Anderson-Darling	0.915

Higher p-values indicate a better fit. If the p-value is less than 0.05, we reject the null hypothesis (at the 5% alpha level) that the data follows a Gumbel distribution and conclude that the fit is not adequate.

Calgary Analytics    Input    **Results**    Plots    Help    Contact

Minimum Wall Thickness Estimate

Estimated Maximum Wall Loss for 1000 tubes: 0.047 units  
Standard Error: 0.003

Estimated minimum wall thickness based on the lower bound of a 95% confidence level is 0.042 units.

Minimum Wall Thickness Estimates:

99%	95%	90%	80%	
Lower Bound	0.039	0.042	0.043	0.044

Note: The estimates must only be used after considering the results of the goodness of fit

Corrosion rates and remaining life

Corrosion Rate and Remaining Life Estimates

Corrosion Rates (units/year):

99%	95%	90%	80%
0.056	0.053	0.052	0.051

Remaining Life (years):

99%	95%	90%	80%
-0.01	0.03	0.05	0.08
N/A	2025-10-28	2025-11-05	2025-11-14

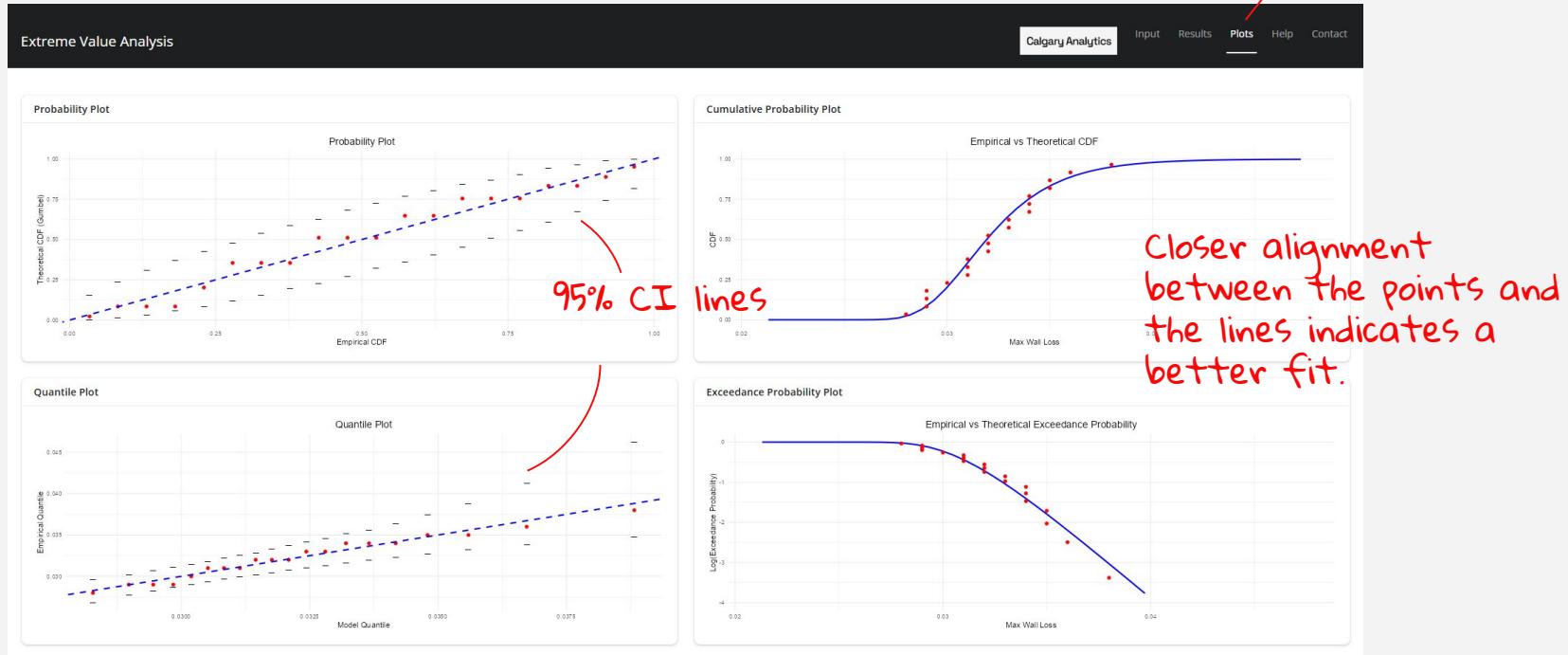
Negative remaining life indicates that the estimated minimum wall thickness is less than the renewal thickness.

Renewal Thickness: 0.04 units  
Start of Operation: 2024-10-16  
Inspection Date: 2025-10-16

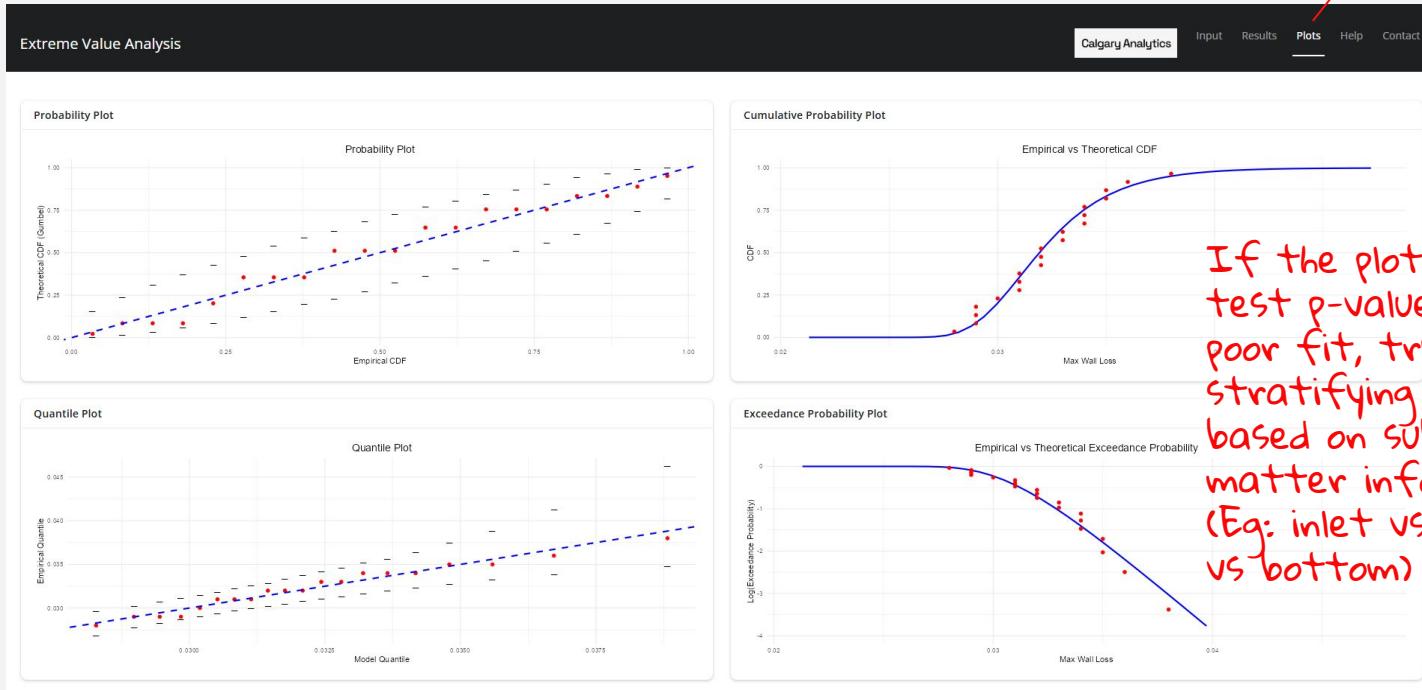
Click "Results"

End-of-life date is calculated from the inspection date onwards.

## EVA Online App



## EVA Online App



If the plots and GOF test p-values indicate a poor fit, try stratifying your data based on subject matter information. (Eg: inlet vs outlet, top vs bottom)

## Appendices

Appendix A: Model Parameter Estimation

Appendix B: Uncertainty Quantification

Appendix C: Goodness-of-Fit Assessment

Appendix D: Potential Improvements

Appendix E: References

Appendix F: Credits

## Appendix A: Parameter Estimation

Wall loss (nominal minus measured thickness) from each sampled tube is recorded.

The maximum wall loss readings from each sample is then fit to a Gumbel extreme value distribution.

The Cumulative Distribution Function (CDF) of a Gumbel Distribution is given by:

$$F(x) = \exp\left(-\exp\left(-\frac{x-\lambda}{\delta}\right)\right)$$

The parameters  $\lambda$  (location) and  $\delta$  (scale) can be estimated via maximum likelihood, method of moments or least squares estimation.

## Appendix A: Parameter Estimation

The EVA calculator uses maximum likelihood to estimate the parameters using the “evd” package in R.

Maximum likelihood tends to be more accurate, but is slightly more computationally intensive as compared to Method of Moments and Least Squares.

In the rare case that the maximum likelihood estimation fails to converge or the information matrix is singular, one can revert to other estimation methods.

Not currently implemented in the app

## Appendix A: Parameter Estimation

Once the parameters of the model are estimated, the maximum wall loss estimated using the “return level” method is given by:

$$x_N = \delta \cdot \left( -\ln \left( -\ln \left( \frac{N-1}{N} \right) \right) \right) + \lambda$$

Where  $N$  is the total number of tubes in the heat exchanger.

The confidence interval for the above quantile is obtained using the Expected Information matrix and the Delta method.

## Appendix B: Uncertainty Quantification

The ASME paper (Wang, 2006) uses the inverse of the Expected Fisher Information matrix as an estimate of the variance-covariance matrix.

The “evd” package in R uses the Observed Fisher Information matrix to estimate the variance-covariance matrix.

Both approaches are valid, but the EVA calculator uses the Expected Information matrix to stay consistent with the ASME paper (Wang, 2006).

## Appendix C: Goodness-of-Fit

Goodness of fit is assessed using two statistical tests - Kolmogorov-Smirnov and Anderson-Darling.

Null Hypothesis: The recorded data follows the specified distribution (i.e. Gumbel).

Alternate Hypothesis: The recorded data does not follow the specified distribution (i.e. Gumbel).

The EVA calculator shows the p-values for both the tests in the “Results” tab. Higher p-values indicate a better fit.

It is important not to rely only on the statistical tests. The diagnostic plots must also be assessed.

## Appendix C: Goodness-of-Fit

Diagnostic plots like the probability plot, quantile plot and the exceedance probability plots are displayed in the “Plots” tab.

These plots aid in visually assessing the quality of the fit. A good alignment between the points and the line indicates a good fit.

Additional details about these plots can be found in the IMS Handbook on the Cenosco (2025) website.

If the plots and the statistical tests indicate a bad fit, consider stratification.

## Appendix D: Potential Improvements

1. On the rare occasion that maximum likelihood estimation fails, method of moments or least squares estimation to be used. This feature is not currently implemented in the app and can be easily incorporated in the future.
2. Profile likelihood method is a more accurate method of calculating confidence intervals instead of the Wald interval (Meeker et al., 2022) or Student's t-based interval. The EVA calculator uses the Student's t-based CI. The downside to profile likelihood methods is that it can be computationally intensive.
3. If the Gumbel distribution is not a good fit, and stratification doesn't help, fitting other distributions (Nee et al., 2025) could be useful. This is not currently implemented in the app.

## Appendix E: References

Wang, W. D. (2006, July 23-27). *Extreme value analysis of heat exchanger tube inspection data* [Paper presentation]. 2006 ASME Pressure Vessels and Piping Division Conference, Vancouver, BC, Canada.

<https://doi.org/10.1115/PVP2006-ICPVT-11-93702>

Cenosco. (2025, January 29). *Extreme Value Analysis (EVA) overview*. Cenosco IMS Handbook.

<https://ims-handbook.cenosco.com/docs/eva-overview>

Meeker, W. Q., Escobar, L. A., & Hahn, G. J. (2022). *Statistical methods for reliability data* (2nd ed.). Wiley.

Nee, A. T. A., Mokhtar, A. A., Latip, N. H. A., Faizul, F. N., & Azmi, N. H. (2025). Determining the cost-effective methods for heat exchanger maintenance using extreme value analysis (EVA). *PLATFORM - A Journal of Engineering*, 9(1), 20–25.

## Appendix F: Package Citations

The following R packages were used in building this EVA application.

1. Bengtsson H (2021). "A Unifying Framework for Parallel and Distributed Processing in R using Futures." *The R Journal*, 13(2), 208-227. doi:10.32614/RJ-2021-048 <https://doi.org/10.32614/RJ-2021-048>.
2. Chang W, Cheng J, Allaire J, Sievert C, Schloerke B, Xie Y, Allen J, McPherson J, Dipert A, Borges B (2024). *shiny: Web Application Framework for R*. R package version 1.10.0, <https://CRAN.R-project.org/package=shiny>.
3. Cheng J (2024). *promises: Abstractions for Promise-Based Asynchronous Programming*. R package version 1.3.2, <https://CRAN.R-project.org/package=promises>.
4. Faraway J, Marsaglia G, Marsaglia J, Baddeley A (2021). *goftest: Classical Goodness-of-Fit Tests for Univariate Distributions*. R package version 1.2-3, <https://CRAN.R-project.org/package=goftest>.
5. Grolemund G, Wickham H (2011). "Dates and Times Made Easy with lubridate." *Journal of Statistical Software*, 40(3), 1-25. <https://www.jstatsoft.org/v40/i03>.
6. Müller K, Wickham H (2023). *tibble: Simple Data Frames*. R package version 3.2.1, <https://CRAN.R-project.org/package=tibble>.
7. R Core Team (2024). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
8. Sievert C, Cheng J, Aden-Buie G (2024). *bslib: Custom 'Bootstrap' 'Sass' Themes for 'shiny' and 'markdown'*. R package version 0.8.0, <https://CRAN.R-project.org/package=bslib>.
9. Stephenson AG (2002). "evd: Extreme Value Distributions." *R News*, 2(2), 31-32. <https://CRAN.R-project.org/doc/Rnews/>.
10. Wickham H (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. ISBN 978-3-319-24277-4, <https://ggplot2.tidyverse.org>.
11. Wickham H (2023). *forcats: Tools for Working with Categorical Variables (Factors)*. R package version 1.0.0, <https://CRAN.R-project.org/package=forcats>.
12. Wickham H (2023). *stringr: Simple, Consistent Wrappers for Common String Operations*. R package version 1.5.1, <https://CRAN.R-project.org/package=stringr>.
13. Wickham H, Averick M, Bryan J, Chang W, McGowan LD, François R, Grolemund G, Hayes A, Henry L, Hester J, Kuhn M, Pedersen TL, Miller E, Bache SM, Müller K, Ooms J, Robinson D, Seidel DP, Spinu V, Takahashi K, Vaughan D, Wilke C, Woo K, Yutani H (2019). "Welcome to the tidyverse." *Journal of Open Source Software*, 4(43), 1686. doi:10.21105/joss.01686 <https://doi.org/10.21105/joss.01686>.
14. Wickham H, François R, Henry L, Müller K, Vaughan D (2023). *dplyr: A Grammar of Data Manipulation*. R package version 1.1.4, <https://CRAN.R-project.org/package=dplyr>.
15. Wickham H, Henry L (2023). *purrr: Functional Programming Tools*. R package version 1.0.2, <https://CRAN.R-project.org/package=purrr>.
16. Wickham H, Hester J, Bryan J (2024). *readr: Read Rectangular Text Data*. R package version 2.1.5, <https://CRAN.R-project.org/package=readr>.
17. Wickham H, Vaughan D, Girlich M (2024). *tidyR: Tidy Messy Data*. R package version 1.3.1, <https://CRAN.R-project.org/package=tidyR>.
18. Xie Y, Cheng J, Tan X (2024). *DT: A Wrapper of the JavaScript Library 'DataTables'*. R package version 0.33, <https://CRAN.R-project.org/package=DT>.

Calgary Analytics

End