Calgary Analytics

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

Includes a free online app!

Calgary Analytics

Heat Exchangers

Heat exchangers are critical components in many industries including oil & gas, chemical and power generation.

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

Wall thickness of the tubes decrease over time due to corrosion.

Thickness readings provide an estimate of the remaining life. The thinnest tube is the “weakest link” and determines the remaining life of the heat exchanger.

Calgary Analytics

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.

Can statistics come to the rescue?

Calgary Analytics

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 thickness value (i.e. thinnest tube in the whole heat exchanger).

Calgary Analytics

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

I built a web application that does EVA using the R open source software, based on the ASME conference paper results (Wang, 2006).

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

Calgary Analytics

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.

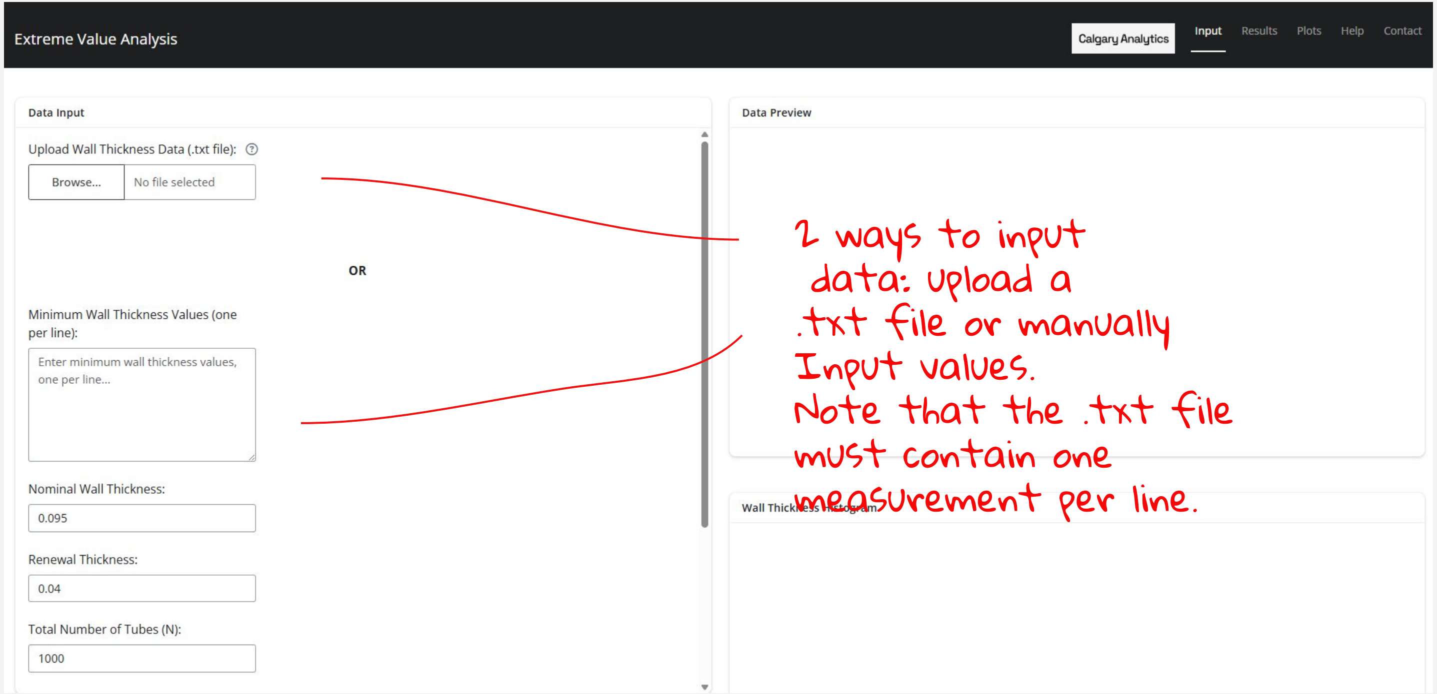
If there is any evidence to suggest that corrosion behaviour might be different in different areas (eg: top vs bottom, inlet vs outlet), then stratification must be employed. Each strata should be analyzed separately.

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.

Calgary Analytics

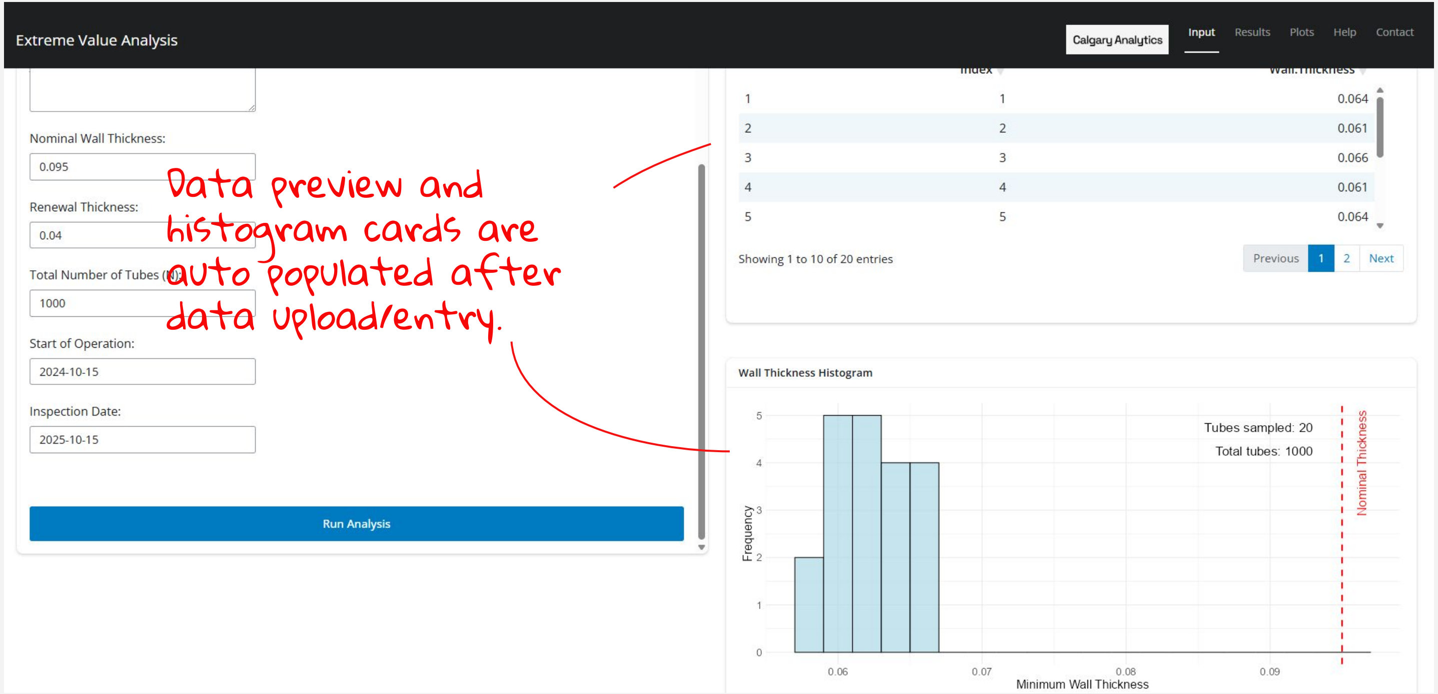
EVA Online App



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

Calgary Analytics

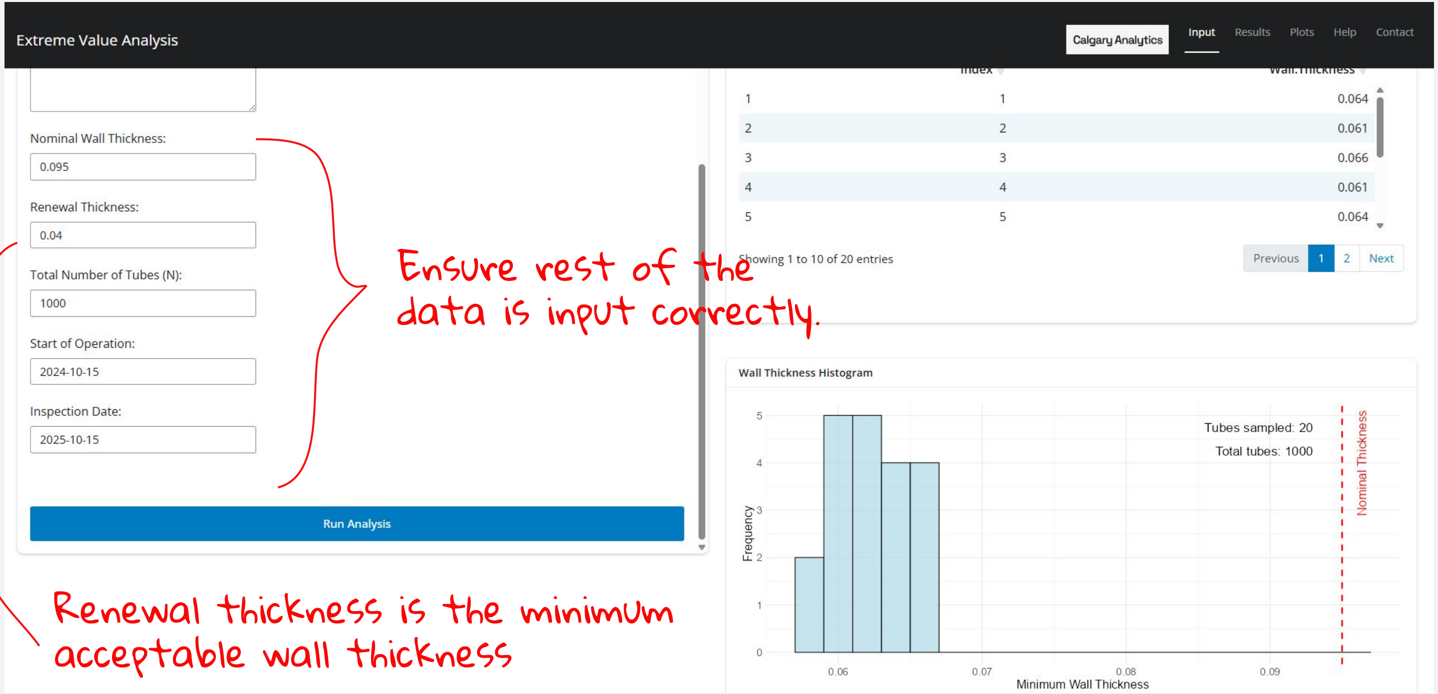
EVA Online App



Data preview and histogram cards are auto populated after data upload/entry.

Calgary Analytics

EVA Online App



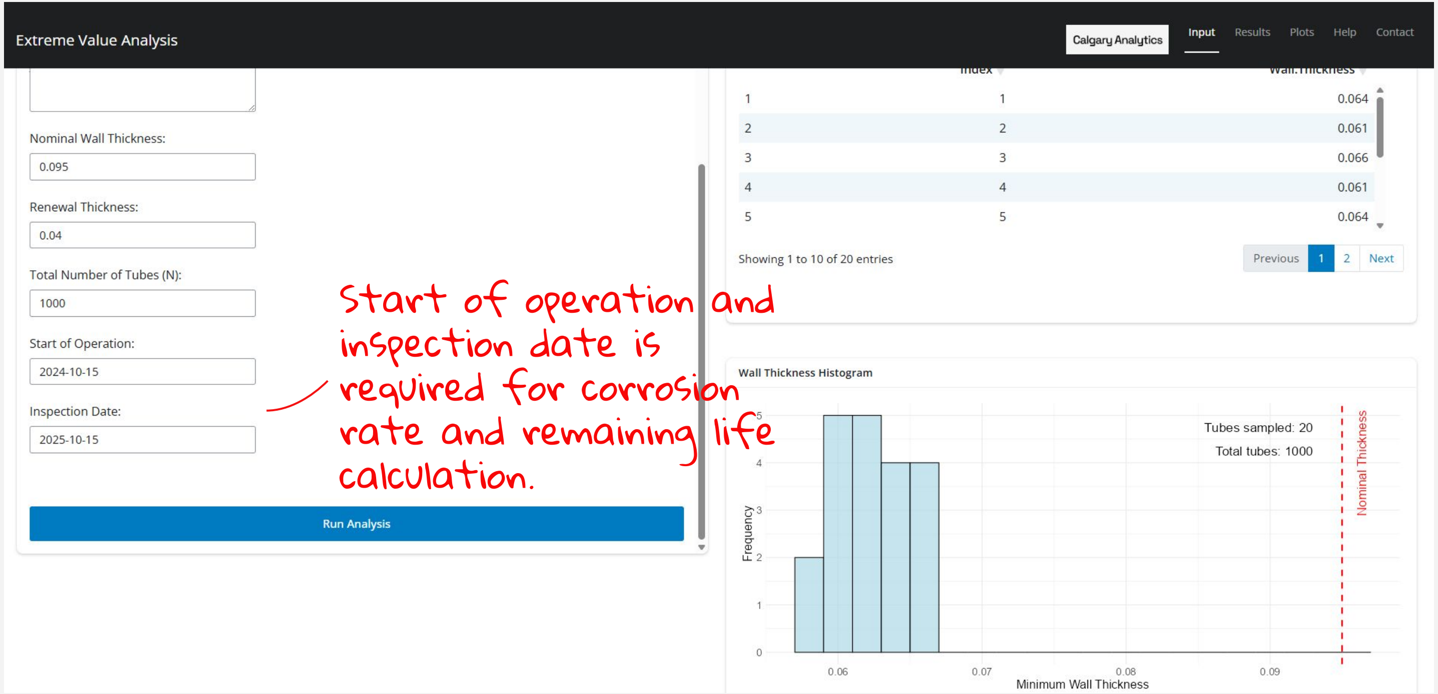
Ensure rest of the data is input correctly.

Renewal thickness is the minimum acceptable wall thickness

calgaryanalyticsltd.com

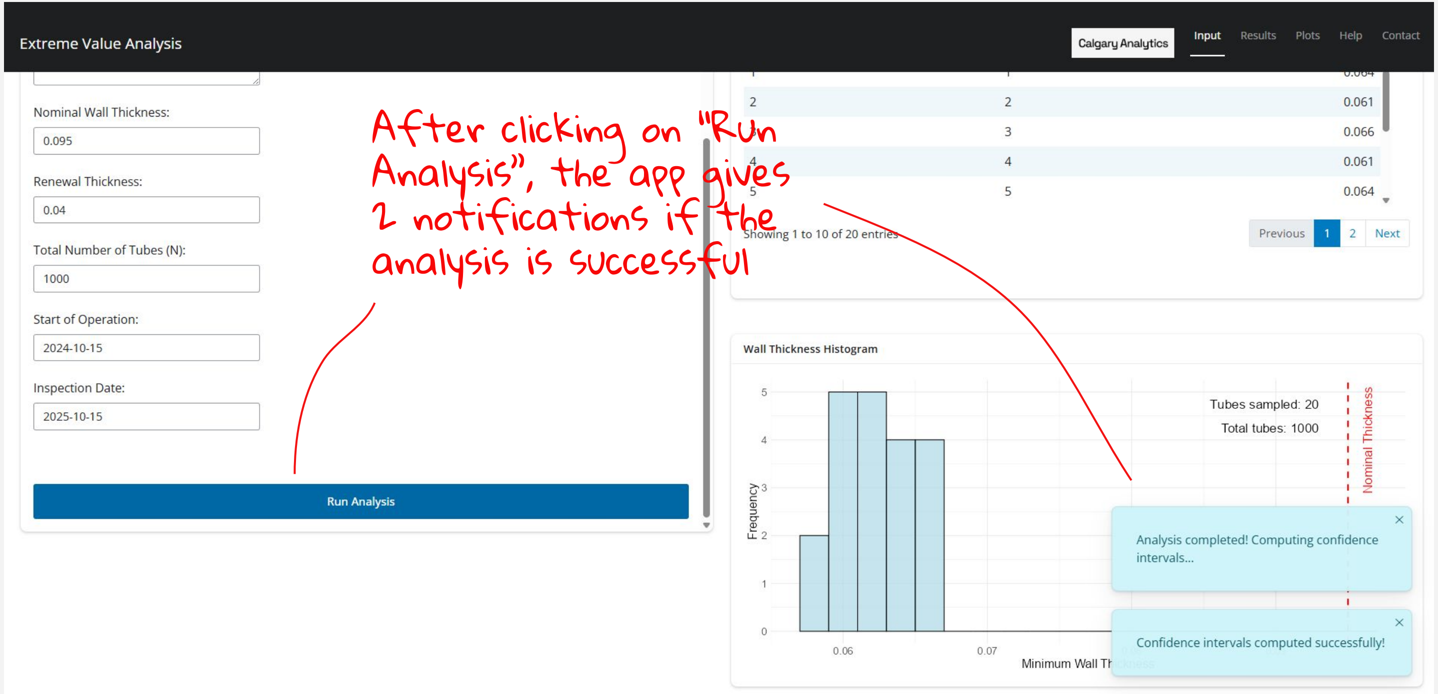
Calgary Analytics

EVA Online App



Calgary Analytics

EVA Online App

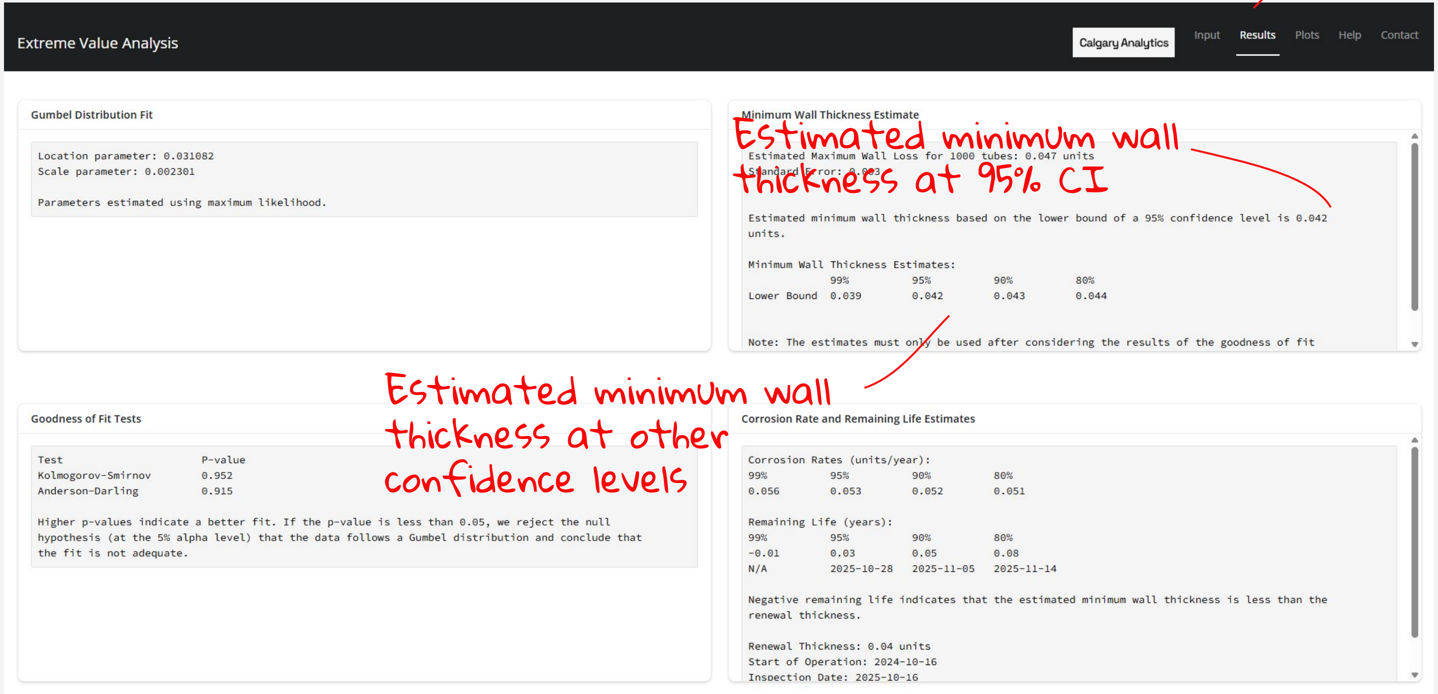


calgaryanalyticsltd.com

Calgary Analytics

EVA Online App

Click "Results"



Estimated minimum wall thickness at 95% CI

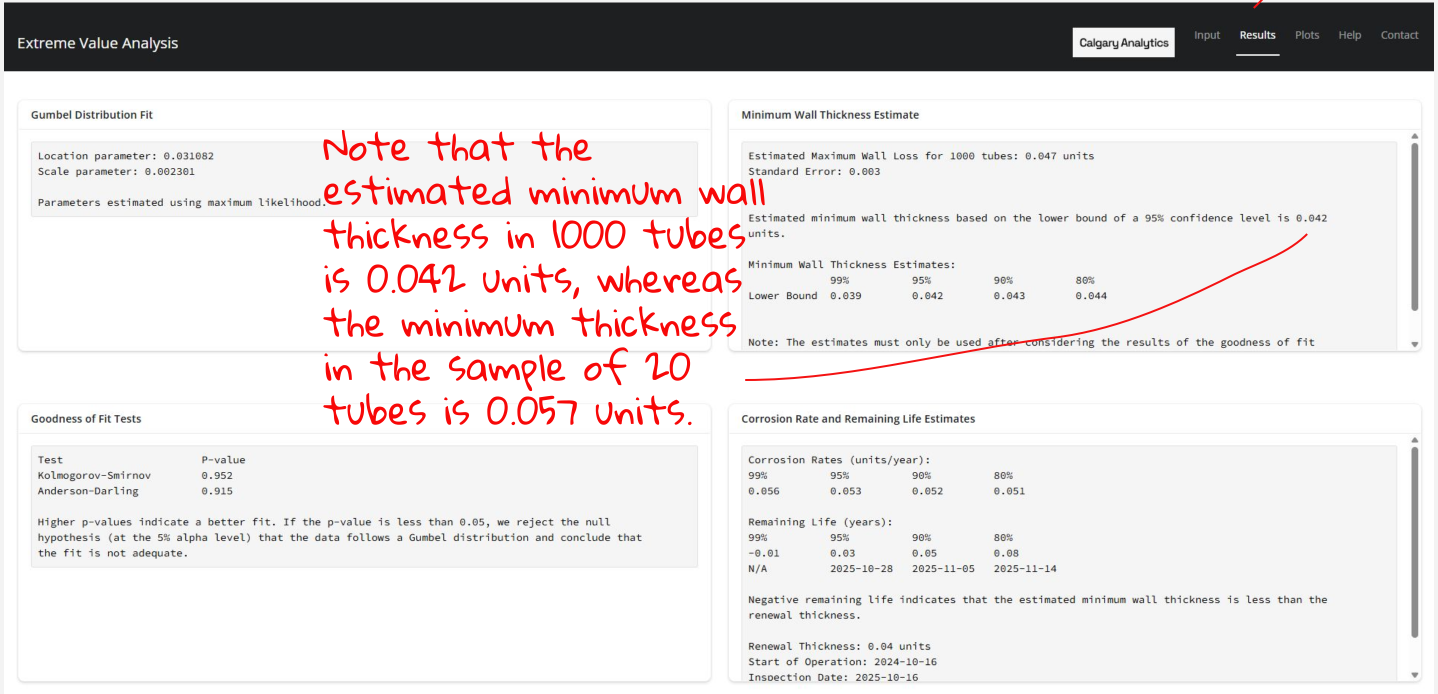
Estimated minimum wall thickness at other confidence levels

calgaryanalyticsltd.com

Calgary Analytics

EVA Online App

Click "Results"



Note that the estimated minimum wall thickness in 1000 tubes is 0.042 units, whereas the minimum thickness in the sample of 20 tubes is 0.057 units.

Calgary Analytics

EVA Online App

Click "Results"

Extreme Value Analysis

Calgary Analytics   Input   Results   Plots   Help   Contact

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
```

Check p-values of the GOF tests

Corrosion rates and remaining life

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

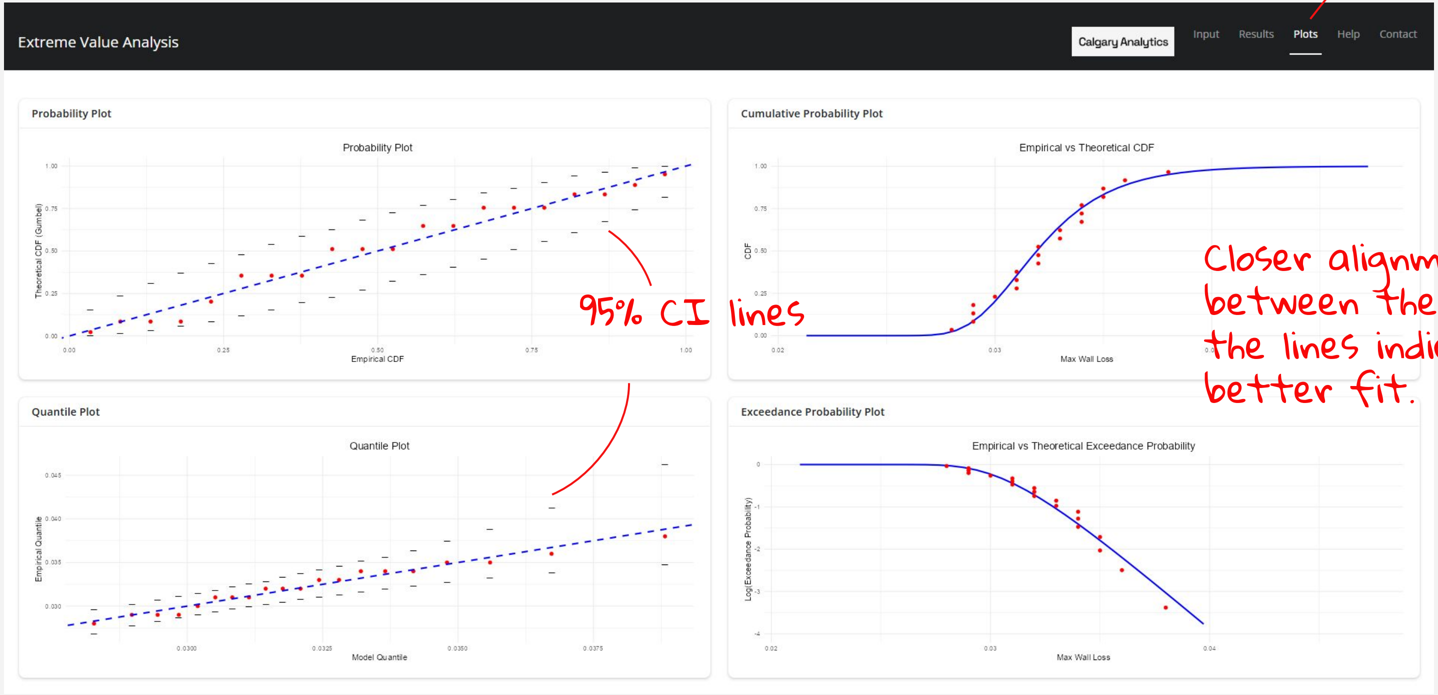
```
Corrosion Rates (units/year):
99%         95%         90%         80%
0.056       0.053       0.052       0.051

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
```

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

Calgary Analytics

EVA Online App

Click "Plots"

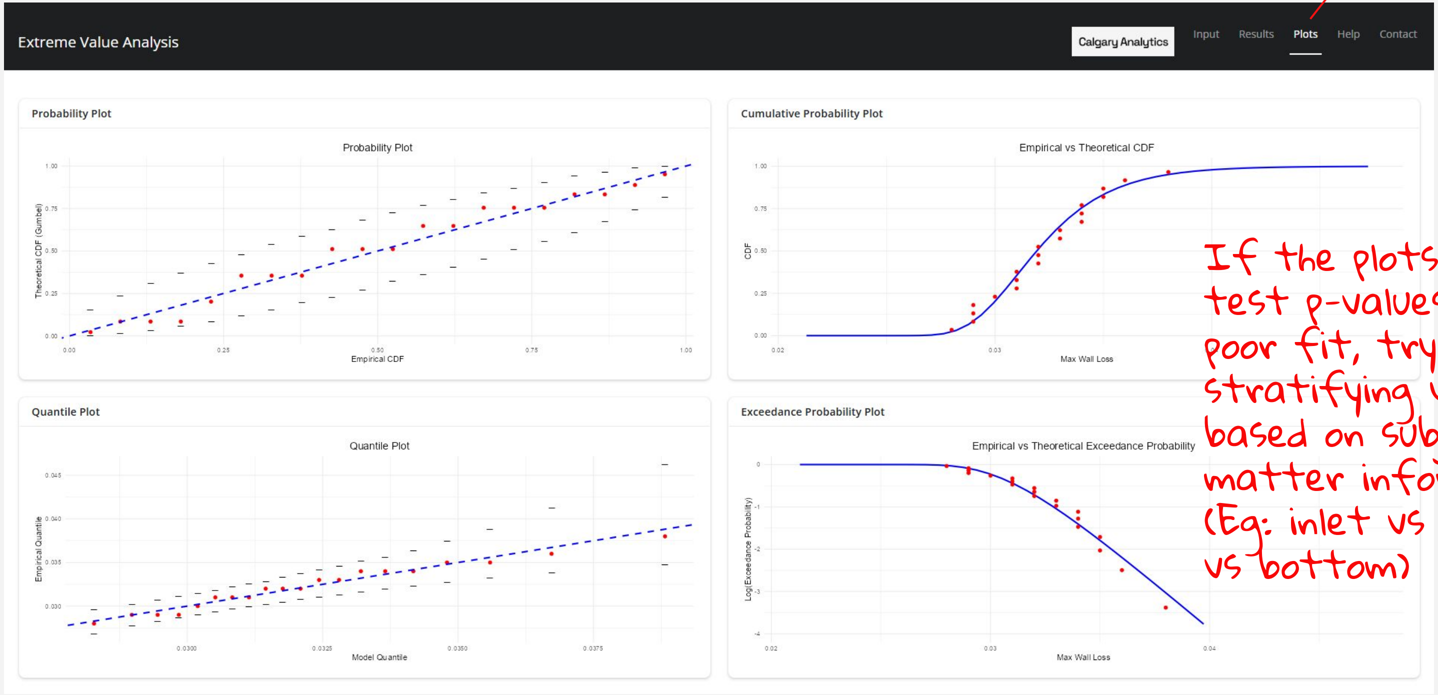


calgaryanalyticsltd.com

Calgary Analytics

EVA Online App

Click "Plots"



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)

calgaryanalyticsltd.com

Appendices

Calgary Analytics

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 λ (location) and δ (scale) can be estimated via maximum likelihood, method of moments or least squares estimation.

Calgary Analytics

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

Calgary Analytics

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:

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

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.

Calgary Analytics

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).

Calgary Analytics

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.

Calgary Analytics

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.

Calgary Analytics

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, 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 ‘rmarkdown’*. 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.

End