# Tolerance analysis tool

## Background

This tool performance a Monte Carlo simulation to analyze dimension distribution.

Three main types of objects make up the analysis:

1. **Dimension** – A single value representing the size of a dimension. For example, the size of a hole, the length of a shaft, the thickness of a plate.
2. **Stackup** – A summation of dimensions whose overall value is controlled. For example, a stack of plates might have the total height control. A shaft and sleeve might have a controlled overall radius so it can fit in a hole.
3. **Product** – A collection of stackups. If one stackup fails, the entire product fails.

When the simulation runs, **instances** of dimensions are created by randomly sampling from a probability distribution. These are summed to create instances of stackups, whose overall values are checked against its limits. If an instance of a stackup fails, then the corresponding product instance also fails.

## Running the Analysis

To begin, information is entered in the *Main* sheet. Only the white cells should be modified. Any gray cell is either locked or is filled in automatically by the program. Ensure that the rows are filled out continuously. Any data below an empty row will be ignored.

1. Define dimensions by filling out the columns D to I. Each dimension occupies one row. The numbers in the C column represent the ID number of each dimension.
   1. **Name** (text) – The name of the dimension
   2. **Nominal** (number) – The nominal value of the dimension. This value can be negative.
   3. **Tolerance** (number) – The bilateral tolerance value around the nominal value. A dimension with nominal 1 and tolerance 0.1 would be marked on a drawing as 1 ± 0.1.
   4. **Accuracy** (number) – Required field representing the number of standard deviations between the mean and the upper or lower limit. For example, if the accuracy is 3 and the tolerance is 0.3 then the probability distribution is constructed such that the standard deviation is 0.1. Typically, a value of 3 is used.
   5. **Distribution** (text) – The name of the distribution to use. If this field is left blank, a normal distribution is used. The following distributions are supported:
      1. **normal** –The default normal distribution
      2. **fit** – A special setting where the program fits a distribution to empirical data. More detail is found in the Fitting Empirical Data section.
   6. **Mean shift** (number) – This optional field adds a shift to the mean. This is used to account for variability in manufacturing processes. For example, a 3D printed hole tends to be undersized. If this field is left blank, zero is used.
2. Define stackups by filling out the columns J to M. Each stackup occupies one row. The numbers in the C column represent the ID number of each stackup.
   1. **Name** (text) – The name of the stackup.
   2. **Dimensions** (text) – A reference to the dimensions that make up the stackup. The format is the ID number of each dimension, separated by a comma. For example, if three dimensions are defined, “0,1,2” is a valid dimension reference.
   3. **Lower** (number) – The lower bound of the stacked dimension.
   4. **Upper** (number) – The upper bound of the stacked dimension.

The remaining fields are outputs from the program.

* 1. **Nominal** (number) – The sum of all the nominal values of the dimensions that make up the stackup.
  2. **Passed %** (number) – The percentage of stackup instances that are within the bounds.
  3. **Under %** (number) – The percentage of stackup instances that are below the lower bound.
  4. **Over %** (number) – The percentage of stackup instances that are above the upper bound.

1. Define products by filling out the columns R and S. If any of the stackups in a product fails, the entire product fails. Each product occupies one row.
   1. **Name** (number) – The name of the product.
   2. **Stackups** (text) – A reference to the stackups that make up the product. This has the same format as the Dimensions column but refer to stackups instead. If three stackups are defined, then “0,1,2” is a valid stackup reference.

Column T is an output from the program.

* 1. **Passed %** (number) – The percentage of product instances where all of its stackups have passed.

Once all desired dimensions, stackups, and products have been defined, the analysis is ready to be run. In cell B5, the number of samples in the Monte Carlo simulation can be specified. Typically, a sample size above 100,000 is enough for fairly accurate results. The checkbox in A6 can be checked if you want to save the generated samples in the *Dimension samples* sheet. This will slow down the program. Press *Generate Samples* to start the analysis. After the analysis is completed, columns N to Q and column T will be populated with results.

## Fitting Empirical Data

If you have obtained actual measurements of a dimension, the tool can fit a distribution and generate more accurate samples. With more measurements, the better the fit.

1. Go to the row of the dimension you have measurements for. In column H, change the distribution to “**fit**”.
2. Go to the *Dimension Data* sheet. Fill in the experimental data under the columns corresponding to the correct dimensions, starting on row 6.
3. On row 5, fill in the number of bins to use when fitting the data. 200 seems to be a good value.
4. Go back to the *Main* sheet and press *Fit Data.* After this complete, rows 2 to 3 in the *Dimension Data* sheet should be populated.
5. Press *Generate Samples* to start the analysis.

Note that *Fit Data* will only need to be done when new empirical measurements are added. As long as rows 2 to 3 in the *Dimension Data* sheet is populated, the **fit** distribution can be used.

## Plotting Results

The tool can also plot results from the analysis as histograms. Though Excel can be used to create graphs, the tool’s plots are more interactive, and allow easy comparison of different dimensions. Note that to use the plotting functions, samples be saved. Make sure *Generate Samples* was run with cell A6 ticked so there are samples to plot.

1. Fill cell B9 with the number of bins to use in histogram plots.
2. Fill cell B11 and B16 with the dimensions and stackups you want to plot. The format is similar to columns K and S, ID numbers separated by commas.
3. On rows 12-14 and 17-19, select the desired plot type.
   1. **Single figure and plot** – All histograms are plotted in a single figure with shared axes. This allows easy comparison of distributions.
   2. **Single figure, multiple plots** – The histograms are plotted in a single figure but arranged vertically, each with its own y-axis. They share the same x-axis. This is useful when comparing distributions that would overlap if plotted with shared axes.
   3. **Multiple figures** – Each histogram is plotted in its own figure, with its own axes. If plotting many dimensions/stackups, then many windows will be opened.
4. Press *Generate Plots* to show the figures. Note that no other action can be taken until all windows have been closed.