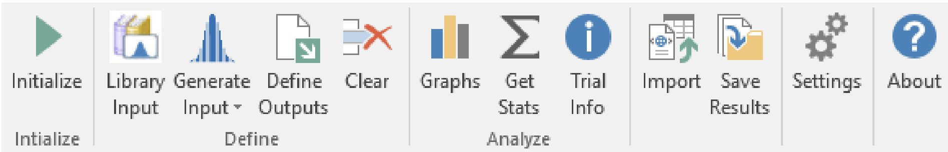

SIPmath™ Modeler Tools for Excel

REFERENCE MANUAL

by

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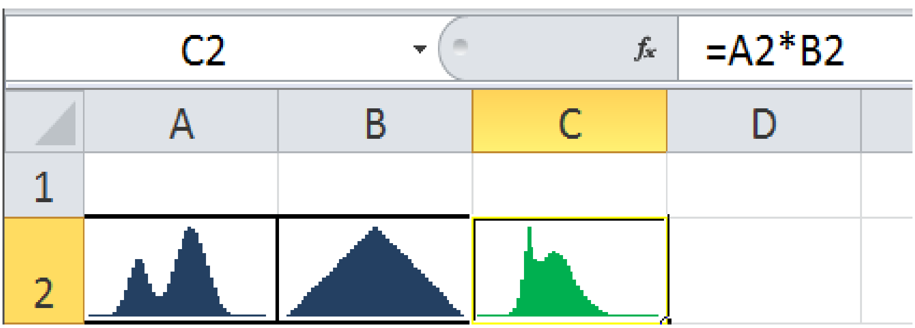
SIPmath Modeler Tools Version 3.1

Reference Build: 3.1.54



Compatibility: Excel 2010-2016 for Windows, Excel 2016 for Mac

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Supporting Files:

SIPmath Modeler Tools 3.1.xlam

Assets Library.xlsx

1 INTRODUCTION

The SIPmath Modeler Tools for Excel (the **Tools**) facilitate the development of stochastic spreadsheet applications, making use of the native Data Table function[i]. Model inputs can be based on SIP Libraries or dynamic random number generation.

Once created, **Tools** applications do not require the add-in to run. The **Tools** work with current Microsoft Excel versions on Windows and Mac OS. Although any of the functions of the **Tools** may be performed manually in Excel, the **Tools** significantly reduce the work needed to design and develop stochastic models.

Probability Management is a decision support framework for dealing with uncertainties much in the same way that traditional data management deals with regular spreadsheet numbers[ii],[iii].It is based on four principles:

1 **Communicating Distributions as Data**

Normally, spreadsheets allow each cell to store only a single value. Thus, when estimating uncertainties, spreadsheets show just one number, typically a single "average" future scenario. This leads to a set of systematic errors known collectively as the *Flaw of Averages*,[iv] which explains why so many projects are behind schedule, beyond budget, and below projection.

The SIPmath Modeler Tools enable Excel to model thousands of potential futures simultaneously, so that we can make better decisions in the face of uncertain future prices, demand, project duration, etc.

These potential futures are stored in *Stochastic Information Packets* or SIPs, which contain hundreds or thousands of simulated or historical outcomes of an uncertainty. That is, SIPs are arrays filled with realizations and optional metadata concerning the uncertainty in question. A central goal of ProbabilityManagement.org is to develop cross-platform standards for formatting SIP Libraries – repositories of reliable, auditable probability distributions.

2 Interactive Simulation

Microsoft Excel has become so powerful that worksheets may be vectorized; that is, formulas are applied to whole arrays instead of individual numbers. Expressions based on random number generators such as the `RAND()` formula, or pre-compiled distributions stored as SIPs, may be used in interactive simulations in an approach we call SIPmath. It can calculate output distributions based on tens of thousands of trials, and store them in SIPs, in the time it takes your finger to leave the `<Enter>` key.

SIPmath works in Microsoft Excel using only the `INDEX()` and Data Table function, so models created with the SIPMath Modeler Tools can be shared with people who do not have the Tools themselves.

3 Credibility of Uncertain Estimates

Many organizations do not comfortable with managers who express uncertainty. As a cure for this problem, the discipline of probability management suggests creating a Chief Probability Officer (CPO) role. The CPO takes responsibility for the integrity and provenance of the SIP Libraries used by an organization. This provides access to centralized, cross platform, standardized representations of uncertainty that yield repeatable and identical results for all authorized model users.

4 Coherence of relevant distributions

When there are multiple uncertainties associated with each other, it is important to make sure they stay *coherent*. For example, consider two SIPs of 1,000 trials, one representing the value of your house, and the other representing the payout of your fire insurance policy. If there is one chance in 1,000 that your house will burn down, then one element of the house value SIP is zero (total loss), while the other 999 take on its undamaged value. However, a SIP representing the fire insurance payout is clearly relevant to the house value SIP: it must have one positive element in which it pays up to the coverage terms, while the other 999 entries contain the negative value (your insurance premium). These two SIPs are said to be coherent if the realization of the value loss (fire) for the value SIP lines up (appears on the same trial) with the realization of payment in the insurance payout SIP. A coherent set of SIPs is also known as a Stochastic Library Unit with Relationships Preserved or SLURP.

If the house and fire insurance SIPs were not coherent, it would be like buying insurance on someone else’s house. There would be an event when the house has burned down (zero value) but insurance has not paid off, or the insurance pays off but the house doesn’t burn down.

2 SIPMATH OPERATING MODES

The SIPMath Modeler Tools is an Excel add-in that can be configured to run in one of the two major modes:

Generate Mode: Generate Mode is much like traditional Monte Carlo simulation except that the computations take place interactively with up to tens of thousands of trials taking place before your finger leaves the <Enter> key. The **Tools** make use of random number generators, including the built-in Excel `RAND()` function to derive model inputs.

In addition to the distributions contained in the file above, historical data may be resampled with a formula like

```
=INDEX(Data,RANDBETWEEN(1,N))
```

where N is the number of data elements.

Generate Mode is a quick way to get a sense of a stochastic process, or to generate SIP Library for cataloging and later use in Library mode. *Models in this mode are only auditable if the HDR generators are used instead of `RAND()` (see below).*

Generate Mode with HDR Numbers: The tools support a second random number generator that can be used in place of `RAND()`, referred to as *HDR (Hubbard Decision Research).* Unlike `RAND()`, `HDR()` returns seeded, repeatable pseudo random values. In general terms, HDR numbers have all the characteristics of random numbers except unpredictability; a given pair of inputs will always generate the same output. The HDR algorithm is somewhat experimental, but has passed preliminary tests of randomness and is very convenient for generating interactive auditable results using pure Excel formulas. It takes as input, a Variable ID, and PM_Index, the simulation counter that drives the Data Table, and in this way creates a virtual SIP on the fly, it does not require macros to run, as the tools insert the generating formula into the designated input cell.

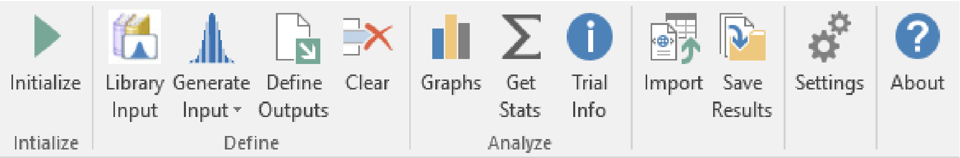
SIP Library Mode: In this mode, the inputs are drawn from a SIP Library, which may be stored within the model, or linked as an external file. This is the mode that currently provides the cross-platform auditability required by the discipline of probability management. From the perspective of the Excel user it adds a third dimension to your worksheet representing thousands of potential outcomes. You may scroll through this third dimension either with the View Trials tool or by changing the value of PM_Index on the PMTable sheet.

This is fundamentally different from earlier forms of Monte Carlo simulation in that SIPmath draws its values from prepared libraries of Stochastic Information Packets (SIPs). SIPs hold arrays of pre-computed trial values created by statistical or subject matter experts, using simulation or real-world data. SIPs also maintain data provenance, an audit trail, and reproducible results, and thus are suitable for informing robust business decisions.

As a result, if various SIPmath applications are based on the same set of coherent input SIPs, the results may be networked together. Thus, the results of complex stochastic models may be aggregated to form hierarchical model structures.

3 SIPMATH MODELER TOOLS OVERVIEW

To start working with the SIPMath package, open a new workbook with the `SIPMath.xlam` add-in installed. The Excel ribbon should include a *SIPmath Modeler Tools* tab. Select that tab and the Modeler Tools ribbon should appear·



The *Initialize* tool identifies the stochastic library containing the input SIPs in SIP Library mode, or specifies the number of trials to run in Generate Mode, and sets up the PMTable sheet on which the simulation data will be generated. This function will also reinitialize existing models and, in Generate Mode, allow the number of trials to be changed.

Once a Library has been Initialized, the *Library Input* tool identifies input cells and links them to one or more SIPs in the Library. This tool may also be used to add a library to a model created in Generate Mode, or additional Libraries to one created in Library Mode. Care must be taken when do this, as the number of trials will be changed to the PM_Trials range in the last loaded Library.

The *Generate Input* tool (see section 6.3) selects probability distributions and their parameters to generate one or more input cells. This tool is used primarily in Generate Mode, but may also be used to add inputs to models in Library Mode.

The *Define Outputs* tool identifies the model's output cells with a name, and feeds them to the data table. The result is a SIP for each output cell identified.

The *Clear* tool allows the modeler to remove inputs and outputs from the model. It clears the associated results from both the PMTable sheet and SIPmath Chart Data sheet.

The *Graphs* tool quickly creates histograms and cumulative probability distribution graphs for the output cells, once a simulation has been created. It can also create graphs from pre-existing arrays of data in Excel.

The *Get Stats* tool bulk is useful for returning statistics on multiple input or output SIPs. For example, suppose cell D10 is an output cell named "Portfolio01." To find the standard deviation of Portfolio01, you may enter =STDEV(Portfolio01) directly into a cell, or enter =STDEV(D10) into the cell and then click on the Get Stats button. This is particularly useful for generating statistics for ranges of output cells. Note that for some statistical functions, such as STDEV, the cell will display an error message until the formula is converted with Get Stats.

The *Trial Info* tool works only when using the HDR generators or in SIP Library modes to step through the input SIP values one trial at a time, or displays optional metadata such as the average or specified percentile if stored in the SIP.

The *Import* tool (Windows only) allows the modeler to import SIP Library files stored in XML or CSV format and store them in Excel format.

The *Save Results* tool allows the modeler to convert a model's simulated data and optional metadata on the PMTable sheet to an Excel format SIP Library.

The *Settings* Excel Calculations must be set to Automatic for interactive simulation. This tool sets Automatic warnings and Calculation options, sets the default number of Bins for charts, and activates the Crystal Ball or @Risk interface if they are installed.

The *About* tool displays version and copyright information.

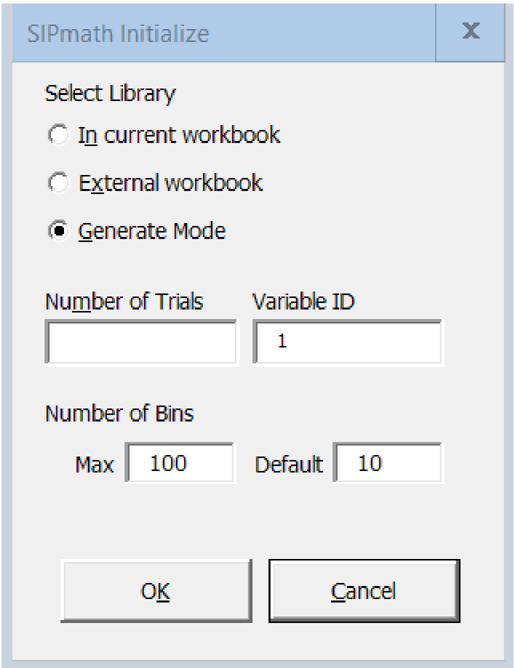
Note: It is a good idea to save your work before initializing SIPMath.

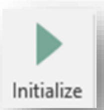
Due to the differences in versions and platforms of Excel, some action sequences may make Excel unstable; if this happens, please make sure the problem is repeatable and submit a bug report with a list software versions and user actions to Support@ProbabilityManagement.org.

4 EXERCISE: MODEL IN GENERATE MODE

SIPMath operates in two main modes: *Generate* and *SIP Library*. If `RAND()` is used in Generate Mode the model will produce different results every time it is run. Use HDR generators for repeatable results.

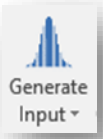
Let's say we are interested in finding the distribution of the sum of three uncertain variables. Such a distribution is easy to simulate with the SIPmath Modeler Tools in just a few steps:





Step 1. Initialize in Generate Mode

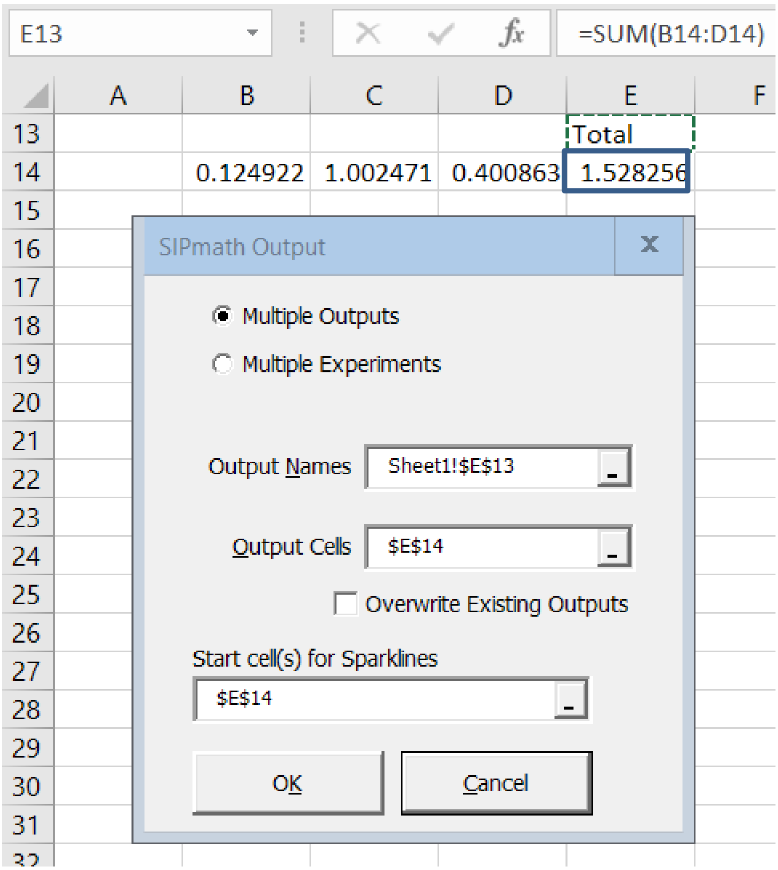
Click the *Initialize* tool, choose *Generate Mode*, type the desired number of trials, and click OK. This will set up the PMTable and SIPmath Chart Data sheets in your workbook.

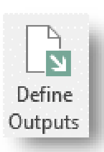


Step 2. Generate Random Inputs. Select the cells you want to use as input cells and click the *Generate Input* tool.

This drops down a list of distribution choices. Select the distribution you want. This will bring up a dialog that's specific to the parameters needed to calculate your selected distribution (see section 6.3).

Step 3. Using Excel formulas create the cell you wish to output. In this case we sum the three random variables in cells B14:D14 at step 2, and give it the name "Total".

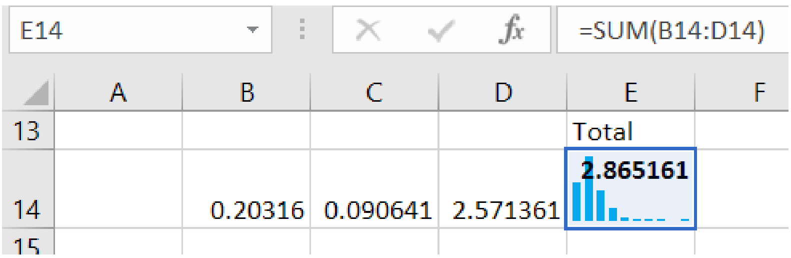




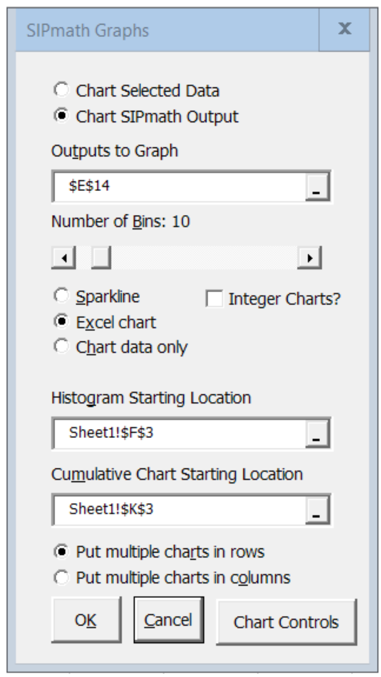
Step 4. With the cursor in output cell (E14) select *Define Outputs* on the ribbon and specify the name (cell E13). If there are multiple output cells (several random variables to study), they can be entered together in the normal Excel

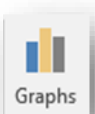
fashion (as continuous ranges or lists). Names should also follow Excel conventions and include only letters, underscores and numbers and not overlap with built-in identifiers or cell addresses.

After you click on OK, the Tools will convert the text found in cell E13 into a range name and use cell E14 to feed consecutive trials into data table on the PMTable sheet. It also places a Sparkline graph in a specified cell E14 if this option was specified during initialization.



At this point, the simulation is complete and the spreadsheet now has 1,000 samples (or whatever you defined in step 1) of the sum of the three random variables stored as a range named “Total” on the PMTable sheet. Now try changing the parameters of the distributions in B14:D14 or the formula in cell E14 to instantly run a new simulation.



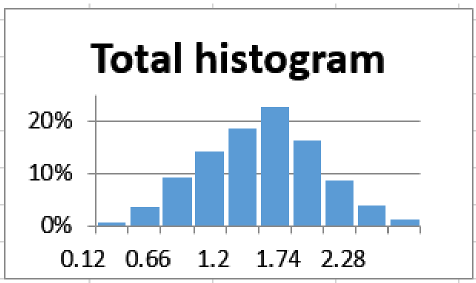


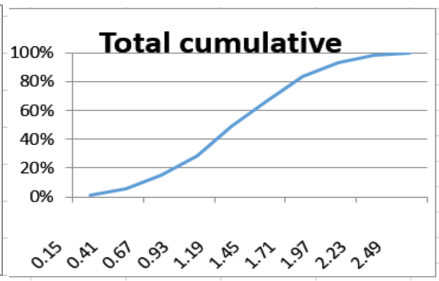
Step 5. Graphs

To create histograms or cumulative graphs as either sparklines or regular Excel graphs, select the simulation output cell (E14) and click the Graphs button.

In this example we will specify both an Excel histogram and cumulative graph in cells F3 and K3 Respectively.

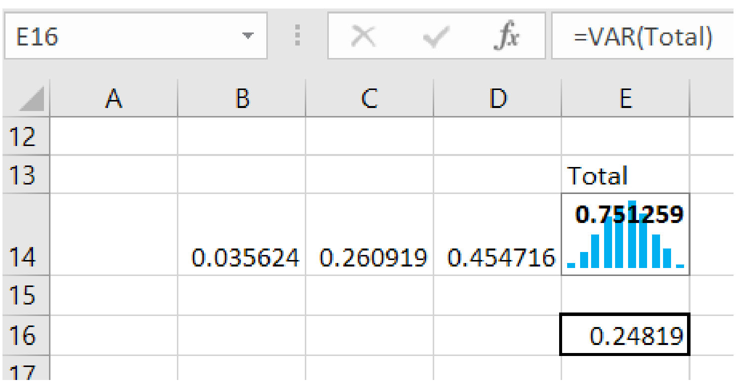
The number of decimal places displayed in the graph, the offset of the horizontal axis, and the cumulative curve direction may be specified in the SIPmath Chart Data worksheet.



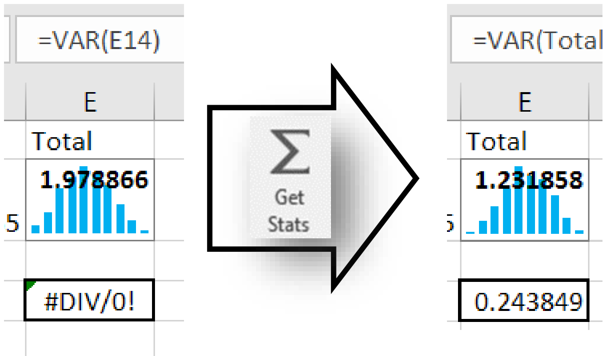


Step 6. Statistics

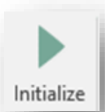
We can use the built-in Excel functions like `Var()` to estimate various statistics of the resulting distribution by referring to its range name:



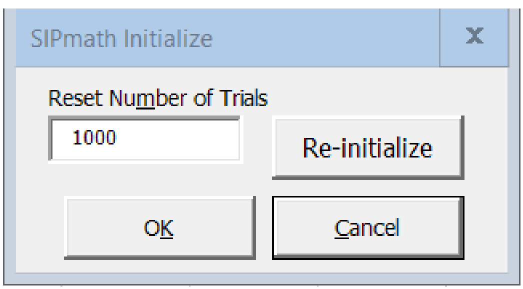
Alternately you may apply the statistical formula to the output cell address and then press the Get Stats button.



This is particularly useful when copying statistical formulas across a range of output cells.



Step7. Re-initializing



If you want to run a larger number of trials, press the *Initialize* button again.

5 EXERCISE: MODEL IN SIP LIBRARY MODE

5.1 INITIALIZE

We will now demonstrate how to build a SIP Library Mode application using Excel and the *SIPmath Modeler Tools*. You can either start with an existing model and add distributions to it, or as we describe, start with a blank workbook, and build a model with input and output distributions.

We are going to build a financial portfolio simulation so that we can compare the expected risks and returns for a variety of investment portfolio choices. We will present these as a graph plotting the mean against the variance of the return for each portfolio.

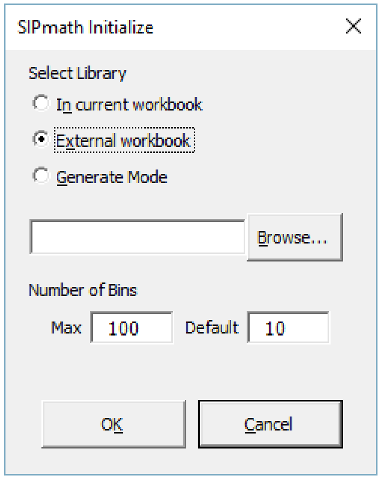
In financial circles, variance is a proxy for risk, so better portfolios have higher return and lower variance. Risk and return are trade-offs, so the best portfolio depends on your risk attitude. That’s why you need a picture.

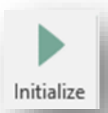
We will simulate five different portfolios and be able to compare their risk/return characteristics while making changes to their mix of assets.

Typically, we would start by developing a determinist model, then test and debug it before adding stochastic inputs and outputs. In this case, the model is pretty simple, so we will start with the inputs and work your way to the outputs and graphical presentation.

Start by opening a blank workbook in Excel. In our example we renamed “Sheet1” to “Model”. Give the file a name of your choice.

The first thing we need is a source of data about assets we can invest in. The data you want is probability distributions of their annual returns. In a real-world application, these would come from a *Stochastic Library* maintained by a financial organization with the appropriate credentials. Since this is just an exercise, we will use the Assets Library.xlsx workbook that comes with the SIPmath Modeler Tools.





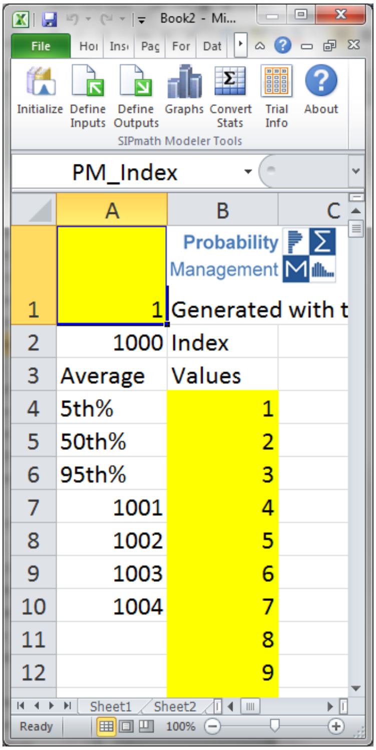
To get a stochastic library, use the *Initialize* tool on the ribbon. You are then prompted to open a stochastic library file.

Instead of linking your model to an external Library file, you have the option to use a stochastic library within the current workbook. This is used for creating self-contained models (not linked to other files) for convenient distribution as a single Excel file. To do this you may either open a library or copy a worksheet from a desired library to the application workbook with the sheet Move or Copy command in Excel, then choose In current workbook.

For this exercise, click on “Browse” and pick the file named *Assets Library.xlsx* that came with the **Tools**.

When you click OK, the *Initialize* function will perform several tasks that you need not understand at this stage, but which may be important as you perform more advanced modeling.

1. Opens the library file.
2. Creates a “PMTable” sheet.
3. Names cell A1 of the PMTable sheet PM_Index, and add links to Meta Data such as Average, 5th Percentile, etc., which are stored in the SIP Library.
4. Creates a SIPmath Chart Data sheet.



Cell A1 of the PMTable sheet will be the Column Input Cell of the Data Table that will run the simulation.

5.2 Input Distributions

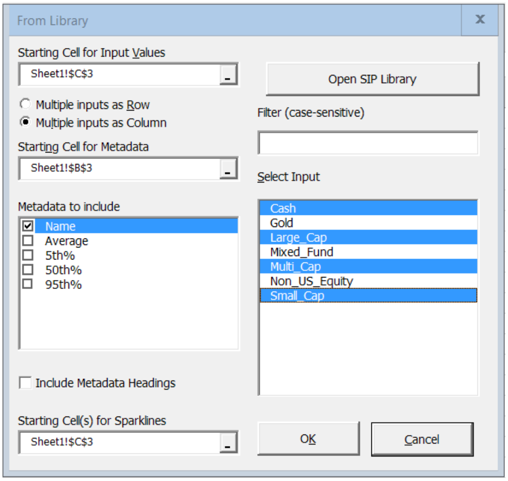
The next task is to set up the input variables, which get linked to the distributions from the library and PM_Index cell.

For this we will use the *Library Input* tool. We need to specify where to put the input cells for the distributions we’ll be using. In this case we’ll put the names (optionally) in a column starting at B3 and the values in a column starting at C3.

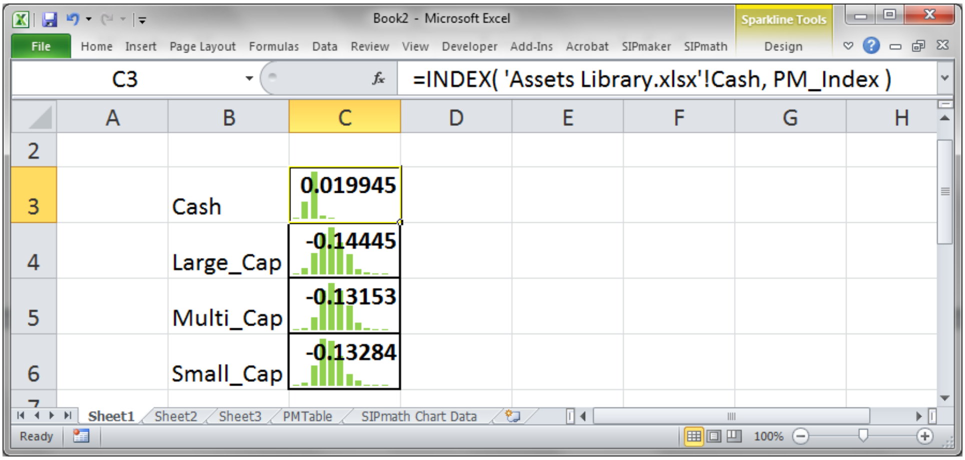
On the Model sheet, select cell C3 and click *Library Input* on the SIPmath ribbon. In the dialog that comes up, with the cursor in the “Starting Cell for Input Names” field, select cell B3. Make sure the “Multiple inputs as

Column" radio button is ticked. Finally, select some assets to use in the portfolios. Use the Shift and Ctrl keys in the usual ways to select multiple entries from the list.

Here we have chosen `Cash`, `Large_Cap`, `Multi_Cap`&`Small_Cap`. Because we opted to create Sparkline graphs for Inputs and Outputs, they are also created at this time.

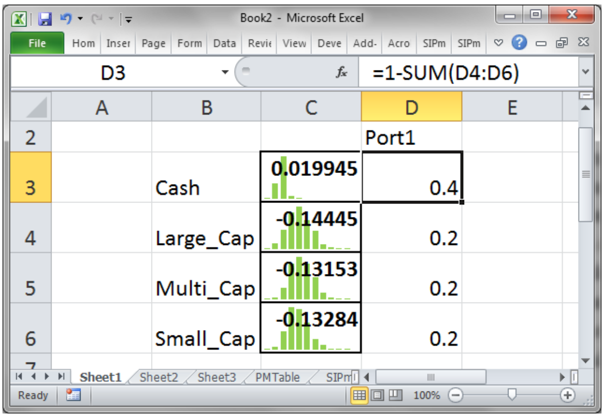


When you click OK, *Define Inputs* will put the names of the assets you chose into a column below B3 and the index formulas that access the SIPs in a column below C3. The numbers in column C are the first trial of each asset distribution. Because we opted to create Sparkline graphs for Inputs and Outputs, they are also created at this time. Note that the Sparklines could also have been place in any other cells in the worksheet, for example those containing the names.

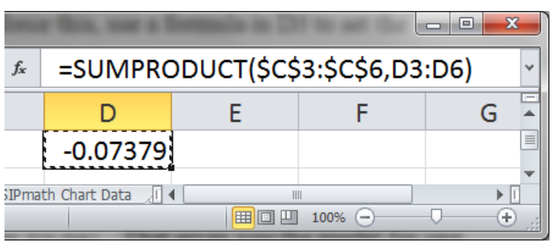


Warning If you use range names in your formulas instead of cell addresses, you'll need to have different names for the model input cells versus the corresponding input SIPs. That is, cell C3 may not be named Cash, because that name is already taken by the Cash SIP range.

5.3 The Model



The model will consist of a few portfolios and their calculated returns. Define a portfolio in column D with its name in D2 and a weight for each asset. The weights must add up to 1.0 because you want them to be the fraction of total investment allocated to each asset. To enforce this, use a formula in D3 to set the Cash weight so that the portfolio sum is 1.0.



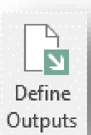
Then, to calculate the return from this portfolio, multiply each asset's return by its weight and add up all the results. Excel's `SUMPRODUCT()` function achieves this in one operation in ell D7.

That gives us the model for one portfolio. Note that $ appear on C3:C6 in the formula but not on D3:D6). This will ensure that when we create multiple portfolios, they will all be pointing at the same inputs. We will make four more portfolios now. Select D2 through to D7 and drag/copy them over to column H. Excel will automatically increment the name “Port1” as it copies and it will adjust the formula for each column. Now, change the portfolio weights so that each portfolio is different. You should have something like this:

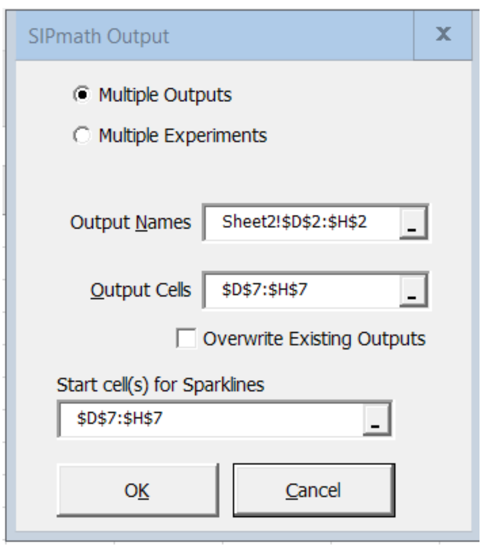
		Port1	Port2	Port3	Port4	Port5
Cash	0.019945	1	0.6	0.3	0	0
Large_Cap	-0.14445	0	0.2	0.2	0.4	0
Multi_Cap	-0.13153	0	0.2	0.3	0.4	0
Small_Cap	-0.13284	0	0	0.2	0.2	1
		0.019945	-0.04323	-0.08893	-0.13696	-0.13284

The formulas in column C hook the model to the input distributions, and now you need to hook it up to the data table and to create the interactive simulation.

5.4 THE OUTPUT DISTRIBUTIONS



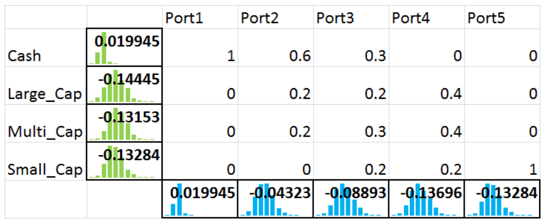
For this we’ll use the *Define Outputs* tool on the SIPmath ribbon. Select the cells with the model results, D7:H7 and click *Define Outputs*. In the dialog box that comes up, set the Output Names field to D2:H2 by selecting



the cells containing “Port1” to “Port5” while the cursor is in the Names field.

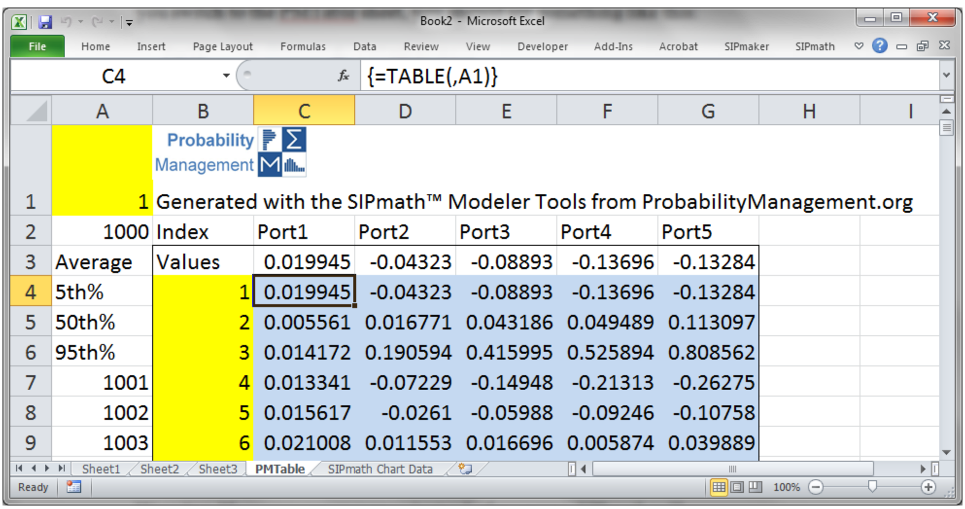
When you click OK, the simulation is set up and run, with Sparklines appearing in the output cells as opted for during initialization. At this point if you change any of the weights of the portfolios, the model will instantly run another 1,000 trials.

The *Define Outputs* command creates named ranges in the data table for each portfolio, using the output names you selected.



		Port1	Port2	Port3	Port4	Port5
Cash	0.019945	1	0.6	0.3	0	0
Large_Cap	-0.14445	0	0.2	0.2	0.4	0
Multi_Cap	-0.13153	0	0.2	0.3	0.4	0
Small_Cap	-0.13284	0	0	0.2	0.2	1
		0.019945	-0.04323	-0.08893	-0.13696	-0.13284

Each of these will be an output column holding the results of a 1,000 trial simulation. If you switch to the PMTable sheet, you should see something like this:



	A	B	C	D	E	F	G
1	1	Generated with the SIPmath™ Modeler Tools from ProbabilityManagement.org					
2	1000	Index	Port1	Port2	Port3	Port4	Port5
3	Average	Values	0.019945	-0.04323	-0.08893	-0.13696	-0.13284
4	5th%	1	0.019945	-0.04323	-0.08893	-0.13696	-0.13284
5	50th%	2	0.005561	0.016771	0.043186	0.049489	0.113097
6	95th%	3	0.014172	0.190594	0.415995	0.525894	0.808562
7	1001	4	0.013341	-0.07229	-0.14948	-0.21313	-0.26275
8	1002	5	0.015617	-0.0261	-0.05988	-0.09246	-0.10758
9	1003	6	0.021008	0.011553	0.016696	0.005874	0.039889

The Data Table contains 5000 calculated numbers

5.5 PRESENTING THE RESULTS

As we showed in the Generate Mode exercise, you can you can create histograms and cumulative graphs of the output cells with the *Graphs* function. In this exercise we will focus on calculating and comparing the variance and average of each portfolio.

We could proceed by entering the following formulas for portfolio 1.

In cell D9, put `=VAR(Port1)`

In cell D10, put `=AVERAGE(Port1)`

But that would just set up portfolio 1, and the results could not be copied to the other portfolios because the range names would not translate.

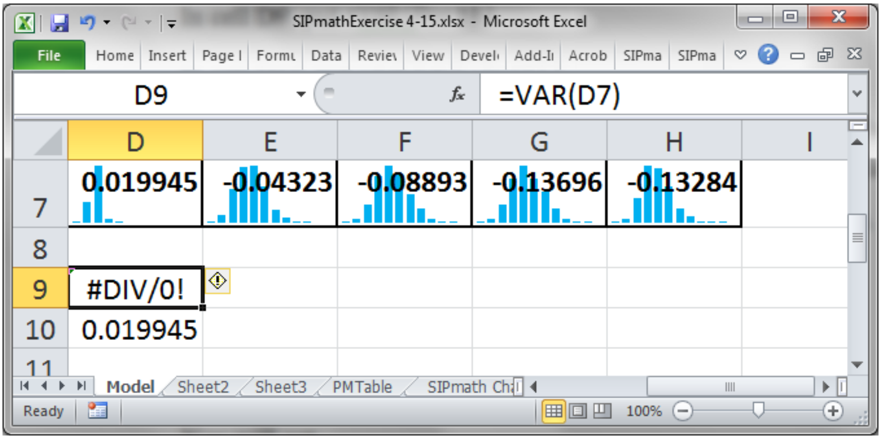
We solve this problem with the Convert Stats button as follows.

First:

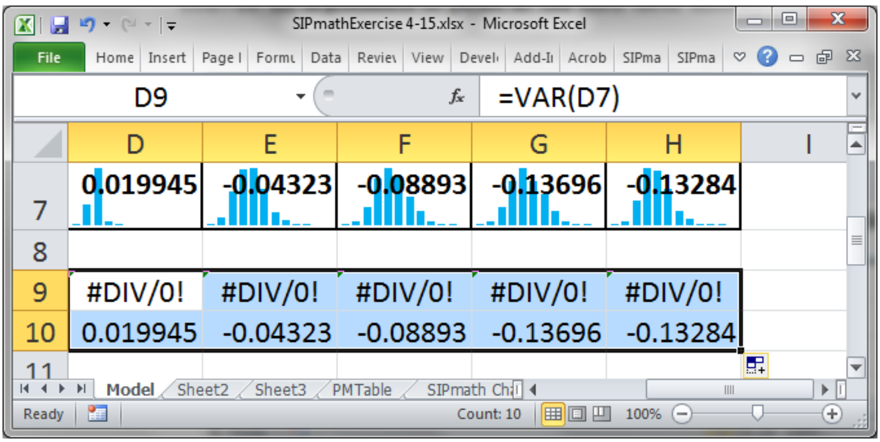
In cell D9, put `=VAR(D7)`

In cell D10, put `=AVERAGE(D7)`

You will get #DIV/0! in cell D9, but don’t worry about it, as we will convert all arguments to point to the output ranges in the data table shortly.



Next: copy cells D9 and D10 to E9 through H10.



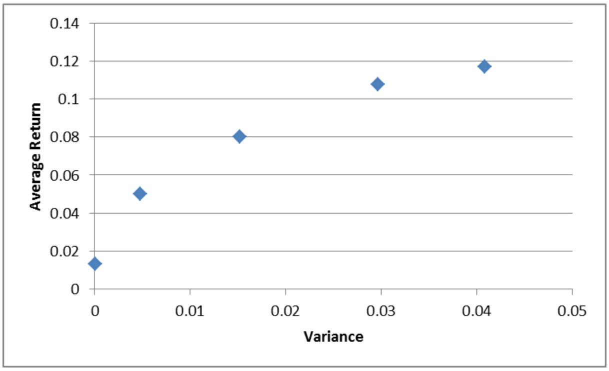
Finally, with all ten of the formulas selected, click on the Get Stats button, and they will be linked to the ranges on the PMTable sheet as shown.

NOTE: DO NOT USE =INDIRECT TO SOLVE THIS PROBLEM

In theory, the `Indirect()` formula could help in copying formulas, but it seriously degrades the speed of the Data Table.

Now we will use the averages and variances in a scatter plot so that they can be compared more easily.

Select D9:H10, the variances and averages. On the Excel ribbon, click *Insert / Charts / Scatter* and choose the style with no lines. With a little bit of decorating, you should end up with a similar result:

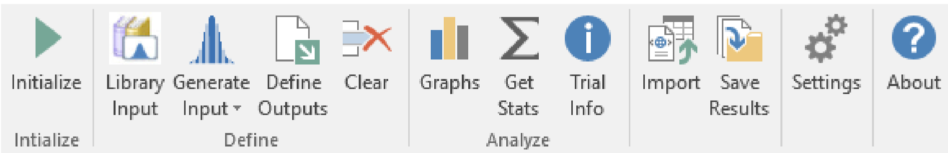


The scatterplot vertical axis is expected return and the horizontal axis is variance. Up and to the left is better: higher return, lower risk. As you can see as you change portfolios, 'better' has a lot to do with how big a return you want and how much risk you can tolerate. Now, as you change the portfolio weights, you will see the dots move around in the graph to reflect the risk and return for those weights.

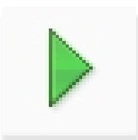
5.6 Running Your model Without the tools

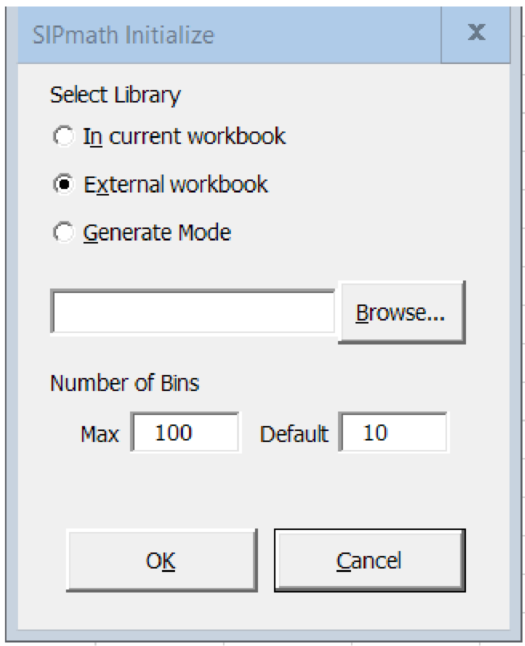
One of the important design parameters for the SIPmath Modeler Tools is that the application must work without the SIPmath add-in installed. If you used a library in the current workbook (or created a model in Generate Mode), all you need to do is open your application. Thus, SIPMath-generated spreadsheets are easy to share.

6 THE SIPMATH RIBBON DETAILS



6.1 INITIALIZE



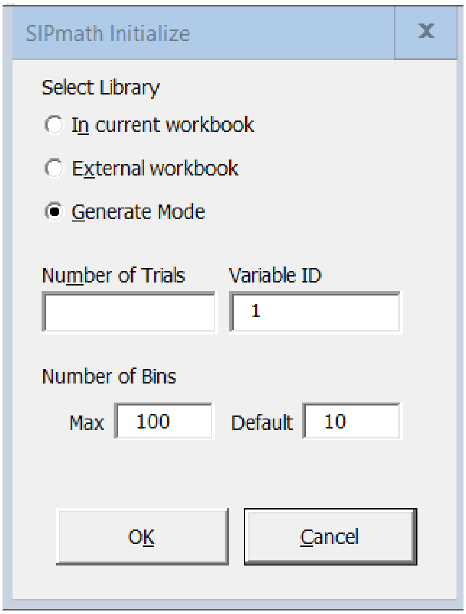


The *Initialize* tool must be used if the plan is to create a model in either SIP Library or Generate Mode.

In SIP Library mode, the *Initialize* tool dialog tells the SIPmath Modeler Tools where to find the distributions that will be used for input. They can be in the model workbook or an external workbook. To specify an external workbook, click “Browse”and use the file dialog to select the library file required.

The model will be linked to the library file through the use of `INDEX()` formulas, the second argument of which is PM_Index, a cell on the

PMTable sheet that does the simulation and records the iteration results. If you want to distribute a model widely you may want to place the library in the same workbook as the model. This can be accomplished by opening an existing library, right clicking on the sheet tab then using the “Copy” command to copy it to the desired workbook.



If Generate Mode is selected, initialization provides an input field for the number of trials to simulate. The variable `PM_Trials`, containing the number of trials, is set as a defined name.

The Number of Bins fields allow you to specify how many bins will be used to create the sparkline histograms.

Reinitializing

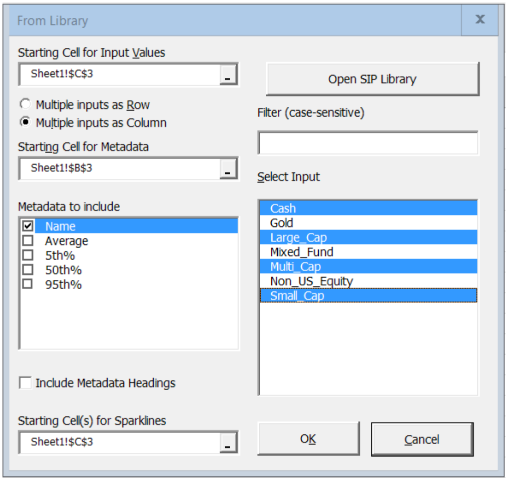
Clicking the Intialize button on an existing model will give you the option to reinitialize the model or, in Generate Mode, change the number of trials.

6.2 Library Inputs

For use in the SIP Library mode only.

Use the *Library Input* tool to tell the SIPmath Modeler Tools which distributions to use from the library chosen during initialization, and which cells the model will use to get input trial values.

Use the Select Input dialog to select the SIPs you want linked to your model.



The Filter box can facilitate your search when you have a large number of variables. Use the shift and control keys in the usual way to select multiple SIPs. Click OK when you're done.

You may optionally specify cells into which to put the SIP names and other metadata (e.g. Average). Select the metadata you want included in the output in the Metadata to Include box.

The values in the cells are from the SIPs in the library, usually the first trial. The PM_Index default value is 1, but you may view any value with the Trial Info button.

If you look at the formulas under the values, you'll see that the tool has set them to something like

```
=INDEX( Library01.xlsx!Distribution3, PM_Index )
```

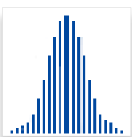
Where Library01.xlsx is the library file name, Distribution3 is the distribution name and PM_Index selects the element in the distribution's range.

Unless you cleared the Starting Cell for Sparklines field, you will see that a light green sparkline histogram has been placed in the cell with the

`INDEX`() formula, and the cell has a black border drawn around it. An example is shown below.

Cash	Gold	Large_Cap	Mixed_Fund	Multi_Cap	Non_US_Equity	Small_Cap
0.019945362	-0.001127084	-0.144446604	-0.144579575	-0.131532497	-0.157626654	-0.132836872

6.3 Generate Input



The famous mathematician and father of the modern computer, John von Neumann, said *"Anyone who attempts to generate random numbers by deterministic means is, of course, living in a state of sin."* This did not mean that he thought it could not be done, in fact his first computer launched the field of Monte Carlo simulation. However, generating such numbers is not straight forward, and some 70 years after the advent of Monte Carlo simulation this is still an active research area. As described below, the SIPmath Tools provide internal random number generation as well as the option to use SIPs of random numbers generated from any external source.

The distributions currently supported are listed below.

1. Uniform
2. Beta
3. Binomial
4. Chi-Square
5. Exponential
6. F
7. Gamma

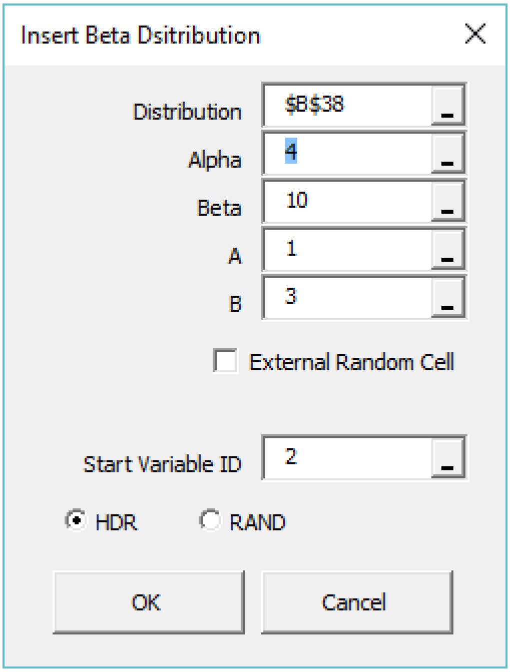
8. Lognormal
9. Normal
10. Poisson
11. Triangular
12. T
13. Weibull
14. Correlated Uniform
15. Correlated Normal

All the distribution functions in the SIPmath Modeler Tools are driven by Uniform random numbers between 0 and 1. These are referred to as U(0,1) variables. The Tools offer three options for U(0,1)s to drive your simulations.

1) The Native Excel `RAND()` function.
   This computes results the fastest, but does not provide replicable results.
2) The HDR Generator
   A Random Access Pseudo-Random Number Generator from Hubbard Decision Research (the HDR Generator). This is an evolving family of simple generators that use pure Excel formulas to provide repeatable results in an interactive simulation environment. Each instance of an HDR U(0,1) must have a unique Variable ID to avoid correlated results. The version of the HDR used in the tools has passed some basic random number tests, but should not be considered to be a “pedigreed” generator. However, this is the suggested approach for convenient everyday modeling. Because the modular nature of SIPmath, you may always go back and replace your U(0,1)s at a later date.
3) Your own favorite generator.
   By creating SIP Libraries from of your favorite generator, you may use U(0,1)s of any sort. For example, you may use any pedigreed random number generator, or even numbers generated from atmospheric noise by Random.org. Such SIPs are entered in your

model through the Library Input command, which creates an index into the specified SIP.

6.3.1 SAMPLE DISTRIBUTION DIALOG:



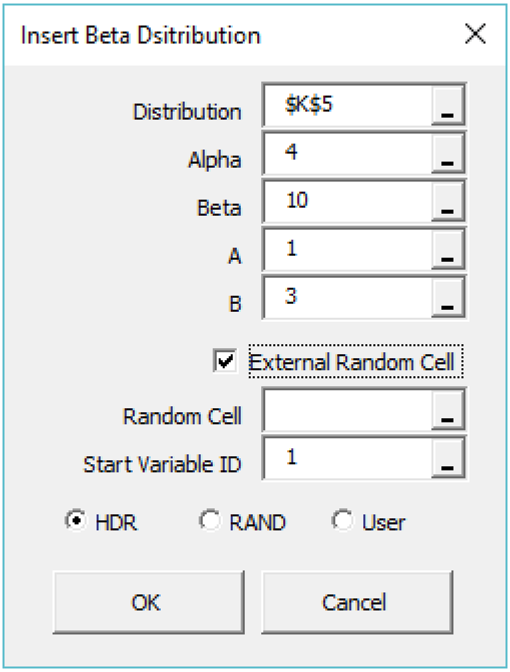
Distribution: Enter the cell or range of cells where you want the formula for the chosen distribution to appear. A range must be either a single row or a single column.

Alpha, **Beta**, **A, B**: These parameters determine the pattern of results computed by the formula. They may be entered either as constant values, single cells, or a range of cells. In the latter case, the range must be the same size and shape as the Distribution range. Note that every distribution has its own set of input values.

External Random Cell: check this box if you want to either correlate your distribution with other distributions or specify your own U(0,1)s to drive the Distribution formula. The External cell (or range of cells) will be used as 'random' inputs to the formula. For instance, a Normal distribution in cell A1 might be computed as

=NORMINV(A2, 0, 1), where A2 would be the External Random Cell containing a random uniform.

Leave the box unchecked if you want the Distribution formula to use a 'random' value computed inside the formula (RAND or HDR only). For instance, a Normal distribution in cell A1 might be computed as =NORMINV(`RAND()`, 0, 1)



Checking the box shows the Random Cell field, below; unchecking it will hide the Random Cell field.

Random Cell: If External Random Cell is checked, enter a cell or range of cells that will contain the random values. If this is a range, it must have the same size and shape as the Distribution range.

HDR: Select this option to generate pseudo-random values with the Hubbard Decision Research generator. This causes the sequence of pseudo-random values to be repeated every time a model is calculated, allowing for repeatable and auditable results. External Random Cells will be filled with the HDR formula for generating pseudo-random values.

Start Variable ID: This is required when using the HDR generator. Enter a constant, a cell, or a range of cells that has a value to identify the variable ID for the HDR generator. If you use a range, it must have the same size and shape as the Distribution range.

RAND: Select this option to generate pseudo-random values with Excel's `RAND()` function. External Random Cells will be filled with `=RAND()` formulas.

User: Select this option to use your own source of external random values. If this option is chosen, the Random Cells specified will be left unchanged, so you can put whatever formula you prefer in the Random Cells. For example, by using the Library Input command to specify data from a known generator.

OK: Press this button to fill the Distribution range with formulas to compute the chosen distribution.

Cancel: Press this button to close the dialog without doing anything.

The example above shows the dialog for the Beta distribution. The other dialogs, except for the Poisson, Triangular, and Correlated distributions (marked by [1]) are very similar, differing only in that the input values **Alpha**, **Beta**, **A** and **B** will have different names, and not all dialogs have 4 inputs.

Distribution	Input variables			
Uniform	<none>			
Beta	Alpha	Beta	A	B
Binomial	Number of Trials	Chance of Success		
Chi-Square	Degrees of Freedom			

[11] These distributions require an External Random cell to hold the U(0,1).

Distribution	Input variables			
Exponential	Alpha			
F	Degrees Free 1	Degrees Free 2		
Gamma	Alpha	Beta		
Lognormal	50^{th} percentile	Top percentile rank	Top percentile value	
Normal	Mean	Standard Deviation		
Poisson *	Lambda			
Triangular *	Minimum	Most Likely	Maximum	
T	Alpha			
Weibull	Lambda	K		
Correlated Normal *	Mean	Covariance Matrix		
Correlated Uniform *	Correlation Matrix			

6.3.2 BRIEF DISTRIBUTION DESCRIPTIONS

The descriptions below are indications of where these distributions may be applied. We strongly recommend consulting a book on statistics or simulation before applying any of these in practice.

Uniform: every value between 0 and 1 is equally likely. Drives all other generators.

Beta: Used to model random variables limited to an interval. For example, the percentage of defective parts in a batch (between 0 and 100%).

Binomial: gives the number of successes in the given Number of Trials with the given Chance of Success. Can give any whole number from 0 to ∞. Note that, in Excel, ∞ is about 10^{15}.

Chi-Square: The chi-square distribution with K degrees of freedom is the distribution of the sum of the squares of K independent standard normal random variables. It can give any value from –∞ to ∞.

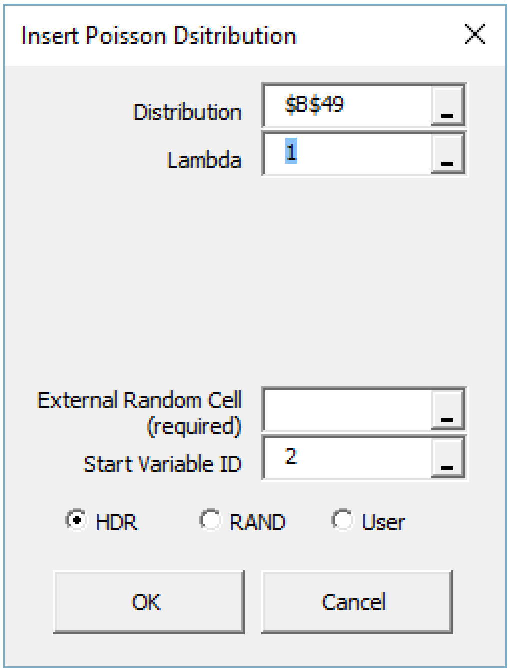
Exponential: gives the time between events, when the average time is alpha. Can give any value greater than or equal to 0

F: used in testing whether two data sets have the same degree of diversity. If U and V are chi-square distributions with degrees of freedom given by Degrees Free 1 and Degrees Free 2, then F is (U/Degrees Free 1)/(V/Degrees Free 2). Can give any value from 0 to ∞.

Gamma: gives the waiting time until alpha events have happened, when the average time between events is Beta. (Thus when Alpha=1, this is the same as the exponential distribution.) Alpha and Beta are (possibly fractional) values > 0.

Lognormal: the log of this distribution is a normal distribution. 50% of generated values fall below the 50^{th} percentile. The top percentile rank can be between 0.6 and 0.99. If this rank is (say) 0.75, then 75% of the generated values will fall below the top percentile value. Can give any value from 0 to ∞.

Normal: also called the bell shaped curve, or Gaussian distribution. Has the mean and standard deviation specified by the inputs. Can give any value from -∞ to ∞.



Poisson: the number of events, (such as arrivals of customers) in a given time interval, given an average arrival rate, Lambda.

Triangular: Often used when a distribution must be guessed at. The minimum, most likely, and maximum values are as specified in the inputs.

T: Also called Student's t-distribution. Similar to a Normal distribution, but more likely to have extreme values. The larger Alpha is, the closer this is to a Normal distribution.

Weibull: This can be interpreted as the time-to-failure of a process. If k > 1, the rate of failure increases with time. If k < 1, it decreases. K must be > 0. Lambda characterizes the average time to failure; about 63.2% of the values will be less than Lambda.

Correlated distributions: Creates sets of distributions which are correlated as specified by the user.

6.3.3 DISTRIBUTIONS REQUIRING EXTERNAL RANDOM CELLS

The Poisson, Triangular, Correlated Uniform and Correlated Normal distribution formulas require the use of a Random Cell. Those dialogs have no **External Random Cell** checkbox, merely an **External Random Cell** field.

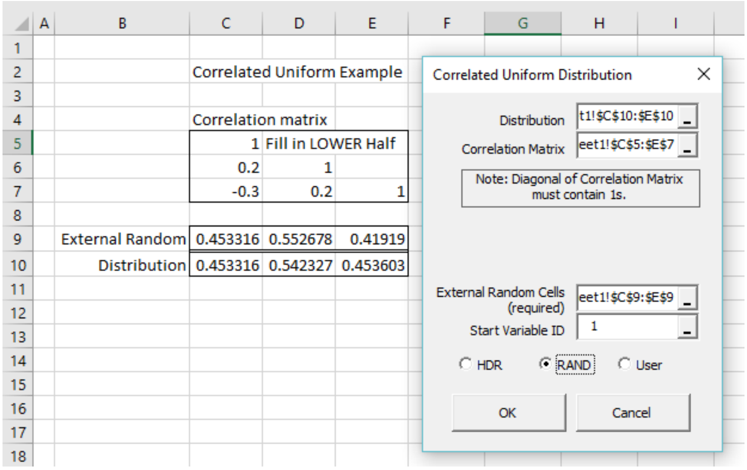
6.3.4 CORRELATED DISTRIBUTIONS

These distributions generate sets of Uniform or Normal pseudo-random values which have user-specified correlations. When these distributions are created, SIPmath adds a new worksheet to your model named SIPmath Cholesky Decomposition. This sheet contains intermediate formulas that are required to compute the correlated values.

6.3.4.1 Correlated Uniform Distribution

Distribution: Enter the range of cells (a row or column) where you want the correlated random values to appear.

Correlation Matrix is a square range of cells containing the correlations. The main diagonal of this matrix must contain the value 1. The correlations should be put below the main diagonal; values above the diagonal will be ignored. The range must have as many cells in its sides as there are cells in the Distribution range. For instance, if the Distribution range is four cells, the Correlation matrix must be a 4x4 range.

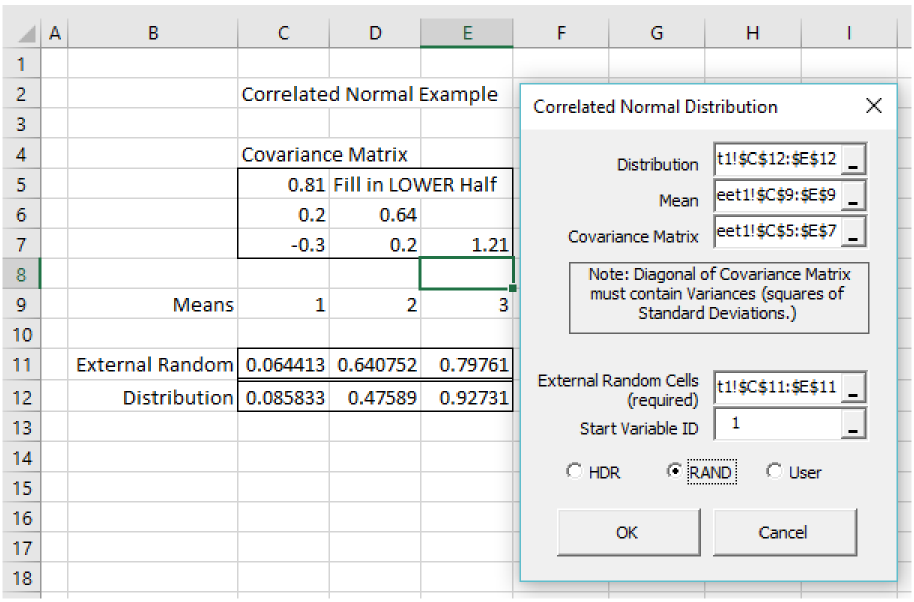


External Random Cells is a required range that is parallel to the Distribution range.

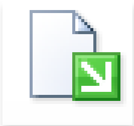
6.3.4.2 Correlated Normal Distribution

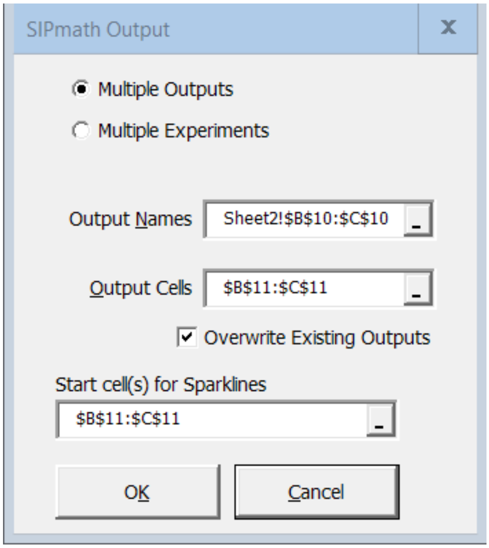
Mean: Enter the mean value of the normal distributions here, either as a single constant, or as a cell or cell range. If this is a range, it must have the same size and shape as the Distribution range.

Covariance Matrix is like the correlation matrix for correlated uniform distributions, except you use covariances and variance instead of correlations. Note, the variances are the squares of the standard deviations of the normals.



6.4 Define Outputs





Define Outputs is actually two different dialogs: *Multiple Outputs*, which is displayed in the examples, or *Multiple Experiments*, for "What If" analysis. The dialogs work the same way in both SIP Library and Generate Mode, but the Experiments setting is less informative in Generate Mode.

Multiple Outputs runs a single set of trials through one or more output cells, each of which will correspond to a column in the PMTable sheet. This dialog lets you specify names for the simulation result distributions and the cells containing the formulas to be simulated.

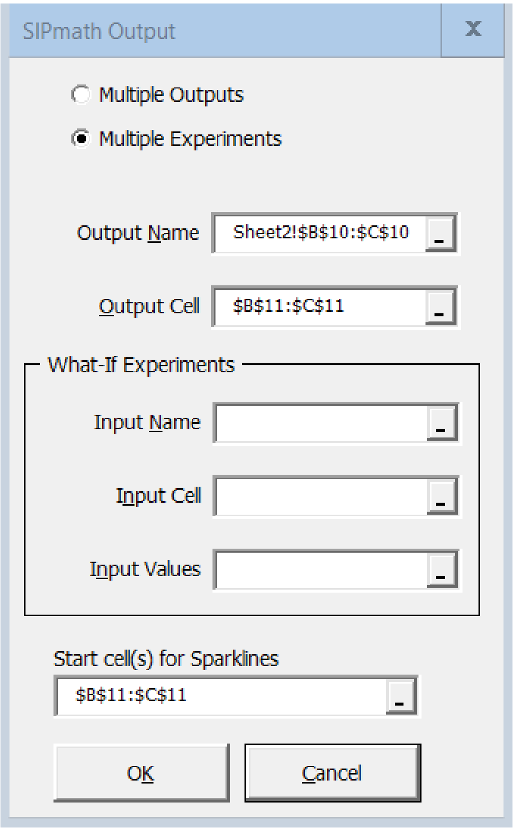
If you checked the "Create sparklines for Outputs" box in the *Initialize* dialog, then the cells with the output formulas will have a light blue sparkline histogram and a black border.

Define Outputs will put a named output column range in the data table for each cell and associated name that you specify. These names can then be used to refer to the output distributions for creating graphs and summary statistics using native Excel formulas anywhere in your model.

You may specify ranges of output cell. If you check "Overwrite Existing Outputs," a new table will be created; otherwise it will append your selections to the right of the current output columns. This means you don't have to specify all your outputs in one shot. Also, the output cells don't have to be contiguous and can be entered as Excel lists (comma-separated).

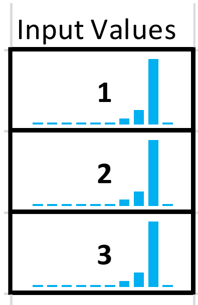
6.4.1 MULTIPLE EXPERIMENTS: WHAT-IF ANALYSIS

You get the second dialog by selecting “Multiple Experiments.” This is for “What If” experiments on a ***single*** output cell, in which you run a set of experimental parameter values through a numeric cell in your model and record the output distribution for each value. For example, you might simulate the cost of managing inventory under uncertain demand for 5 different stocking levels.



The output name and output value cells work the same way as in the previous case – specifying where to get the model results, and what name to give the output columns in the data table. The difference is that there will be an output column for each of the experimental values specified. So you’ll have one output cell but a different output distribution for each of the experiment input values.

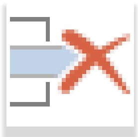
Note that the experiment input values are the values you want to test, not the same as the input distributions you specified in the “Define Inputs” dialog, which will still drive each simulation. The “What-If” values will drive multiple simulations and the output simulation columns are the distributions of the result of each experiment.



The importance of the names is that “Define Outputs” will concatenate the output name, experiment input name and experiment input values to give each output column in the data table a unique range name you can use for graphs and summaries. For example if the output name was “Cost”, the input name was “Stock”, and the input stocking levels were 10,15 and 20, then the names in the PMTable sheet would be: Cost_Stock_10, Cost_Stock_15, and Cost_Stock_20.

If you checked the “Create Sparklines for Outputs” box in the “Initialize” dialog, then a light blue sparkline with a black border will be created in each of the input value cells.

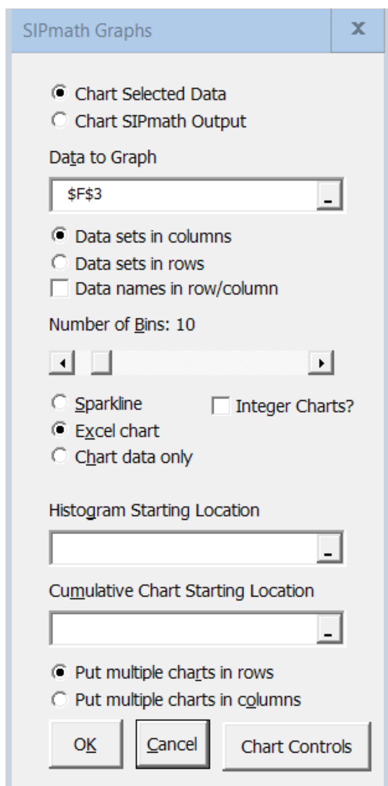
6.5 CLEAR



The *Clear* tool removes input and output formulas and formatting from the selected cells. It also removes any related chart data from the SIPmath Chart Data worksheet.

6.6 Graphs

The *Graphs* button lets you create histograms and cumulative graphs from either *pre-existing data ranges* or *SIPmath Output Cells*. For pre-existing data, select a range of values to be charted. You may either: 1) select that range before pressing the *Graphs* button, 2) type the range specification or name of the set in the Data field manually, or 3) click in the Data field and select the range to be charted. For this example, we have chosen a range called *Revenue Data*.



Graphs function makes a guess as to whether the data is grouped by columns or by rows, based on the shape of the selected region. If the guess is incorrect, you can correct it by clicking the appropriate radio button.

Graphs also guesses whether or not your data sets have names in a heading column or row. If you have data in headings, *Graphs* will use those names when creating range names to be used by charts. Otherwise, the range names will be based on the address of the selected data.

The “Number of Bins” slider sets the number of histogram bars or the number of points on the cumulative curve.

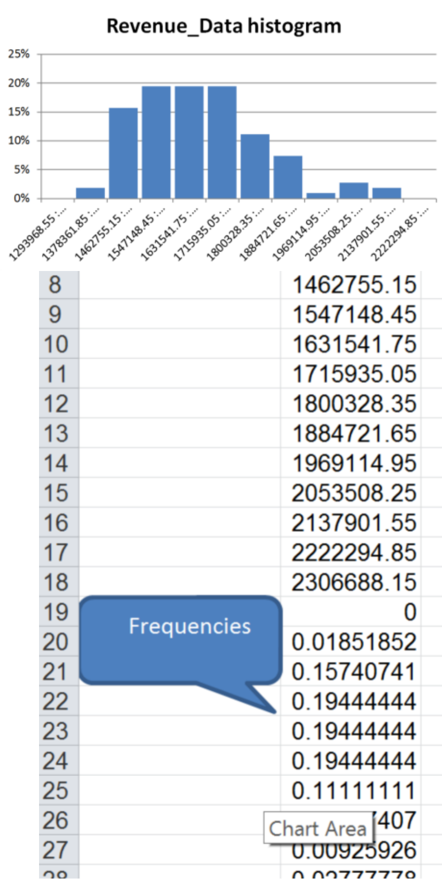
If you check the Integer Charts checkbox, *Graphs* will assume the data to be charted consists of integers (whole numbers only), such as 1, 2, 87, and −452. The number of bins will be automatically determined by *Graphs*, and the slider control will be greyed out when you check “Integer Charts.” The histogram will have one bar for each whole number between the smallest and largest whole number in the data. The bars will be labeled as whole numbers.

Note This option is not recommended if the range of data from smallest to largest value is more than 100.

If you select “Sparkline[2]” or “Excel Chart” the dialog will expand to ask you which graphs you want and where you’d like them put.

If you are charting more than one set of data, additional charts can be placed in a row to the right of the first chart, or in a column below the first chart. You can select which with the radio buttons.

Pressing OK will create the chart data and Sparkline or Excel chart, if any, in the specified location. Here’s what a chart might look like once created:



6.6.1 SIPMATH CHART DATA

When you initialize a model or click “Ok” to close the *Graphs* dialogue box under the Select Data option, a new worksheet will appear titled “SIPmath Chart Data.” Here is a screenshot of example chart data. Column A has been

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[2] In Excel 2010 or later.

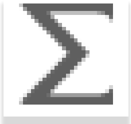
added to show what the numbers represent, the chart is created without labels.

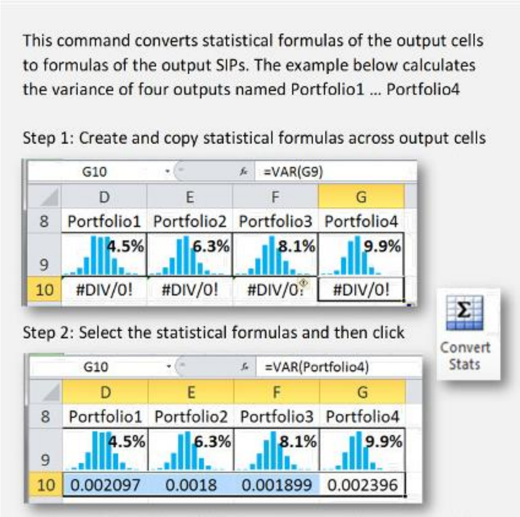
To make a chart, the *Graphs* tool must first set up a small table in the “SIPmath Chart Data” sheet with a row for each bin. The columns contain the bin and percentile values that, respectively, become the X and Y axis inputs to the histogram chart.

Data in this worksheet can be manually edited to change the way your output histogram on the other sheet looks. Bins can be manually edited, an offset can be applied, the number of decimal places allowed for class widths can be changed, and the histogram bar sizes (frequencies) can be altered.

Selecting “Chart Data Only” in the *Graphs* box will make the table without creating a chart. You can then use this to create your own charts using Excel’s *Insert Chart* tool. The ranges for the bins are suggestively named (e.g. Profit_bins, Profit_freq, assuming your data had a heading of “Profit”).

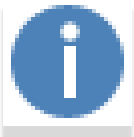
6.7 Get Stats



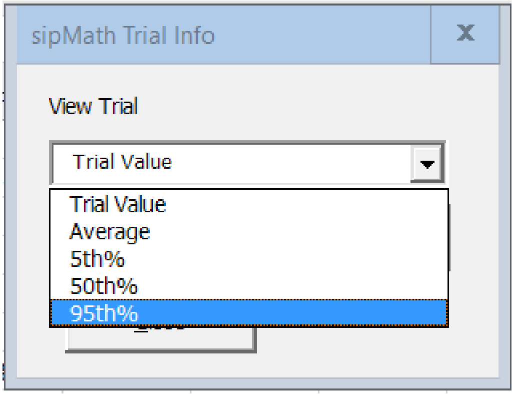


The *Get Stats* tool is designed to simplify the application of statistical formulas such as `Var()`, `Percentile()`, etc. to model outputs. Output variables are essentially SIPs (arrays of observed realizations), and must be referred to by the range names that were automatically created when they were defined (see *Define Outputs* above). See the example below. If you forget how to use this button, click on any cell without a formula and click the button. This explanation will appear:

6.8 TRIAL INFO



The *Trial Info* tool is only applicable in SIP Library mode. It lets you step through the simulation trials one at a time.

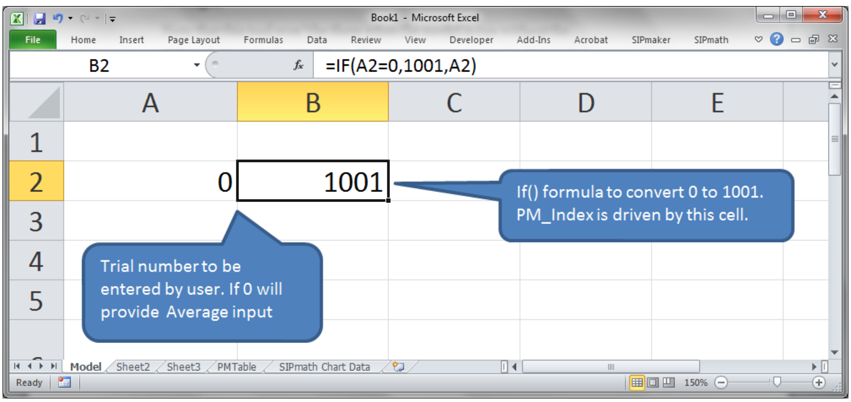


Wherever you set the trial number, you can see the corresponding trial values in the input cells and the corresponding result values in the output cells. *Trial Info* is actually incrementing the number in the PM_Index range on the PMTable sheet; this can be done manually.

If the SIP Library contains metadata extensions to the distributions, you can also use those to instantiate model parameters. Keep in mind that the choice is only for your inputs. For example, if you choose “Average”, you’ll see the outputs given average inputs, NOT average outputs.

If your spreadsheet model is non-linear, you will find an interesting difference between the *output* given *average* inputs and the *average output given input distributions*. This is due to Jensen's Inequality, commonly called the Flaw of Averages.

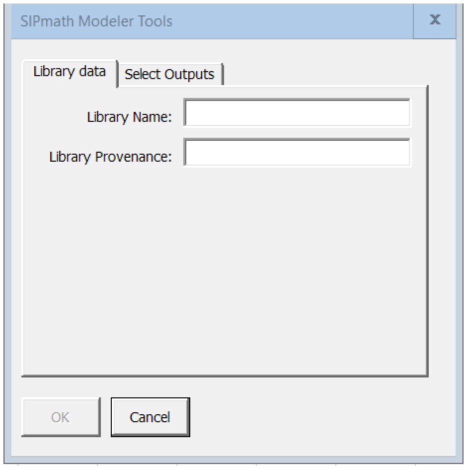
Note that this tool won't be there when the model is run without the SIPmath Modeler Tools add-in. If you want your user to be able to step through the trials, you'll need to let them change the PM_Index range and include a control to access the metadata at the ends of the SIPs if desired. Suppose, for example that the "Average" input is stored at location 1001. Then it is convenient to create two cells as follows to drive PM_Index.



6.9 Import

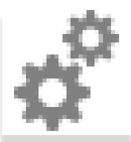
The *Import* tool allows the modeler to import SIP library files in XML or CSV format. Selecting *Import* brings up the Windows file open dialog to identify the file being imported. The tool creates another file (which should be a standard SIP/XML or SIP/CSV file) and unpacks the selected file into it. The file's *SLURP* worksheet holds the SIP metadata and SIP data in the standard Excel SIP library layout.

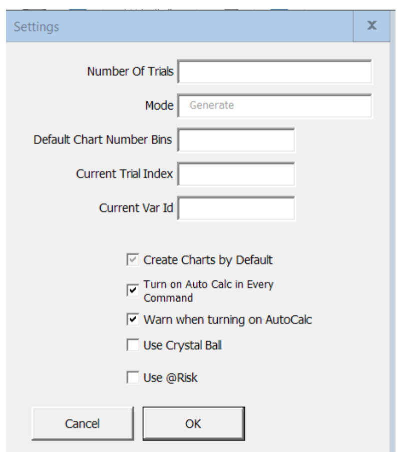
6.10 Save Results



The *Save Results* tool allows the modeler to export the model's data to an Excel SIP library workbook. Selecting *Save Results* brings up a dialog for specifying a worksheet name and selecting the SIPs to be exported. Use *Save As* to write the SIP Library file compatible with the format expected by the Library Input tool.

6.11 Settings





The *Settings* tool brings up a dialog for setting the tool's default values and behaviors.

6.12 ABOUT

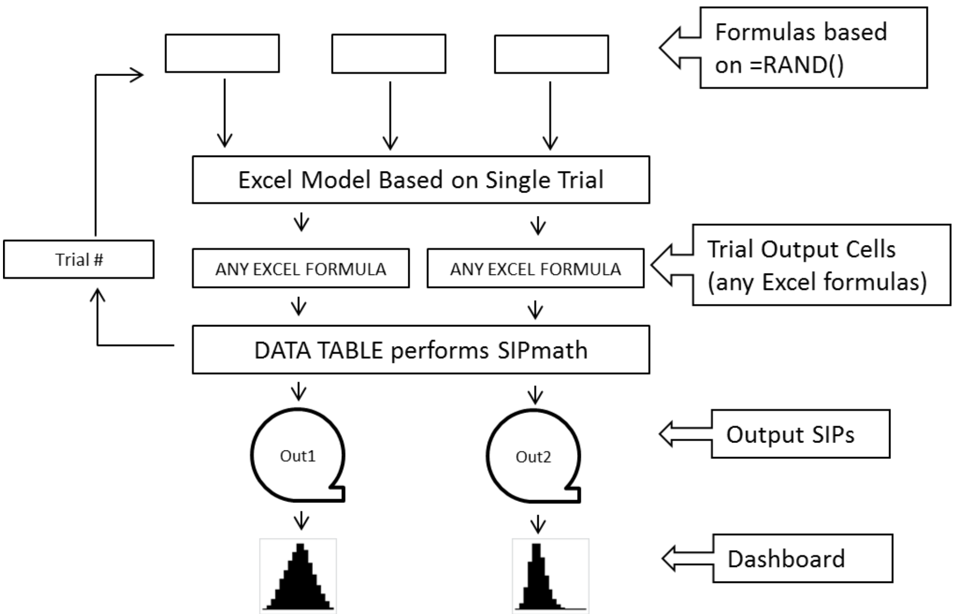
 The *About* tool brings up a box with information about the Modeler Tools.

7 SIPMATH ARCHITECTURE

7.1 OVERVIEW

Generate Mode

When applied in random simulation mode, no SIP library is needed, and the input expressions are based on HDR or `RAND()` formulas as shown here.

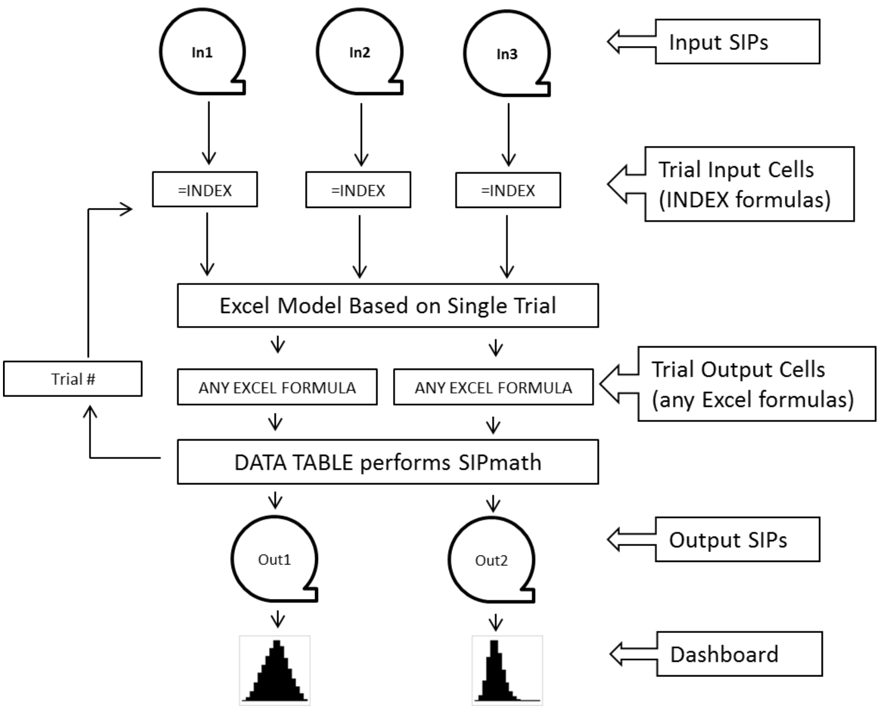


The Data Table function iterates the model through the trials of random inputs, calculates, and collects the results in arrays in the PMTable sheet. This is accomplished entirely with built-in commands and without using

VBA. So, once created, such models may be run in native Excel without the Tools.

The SIPmath Modeler Tools is a set of macros that facilitate the development of such models by automatically creating a data table, and assisting in setting up the inputs, outputs, graphs, etc. The model calculations are formulated as if the inputs and outputs are simple numerical cells in Excel. Then the Excel data table function causes the simulation to run the model for the number of iterations stored in the `PM_Trials` variable. Data Table computations are very efficient, and for medium sized models, thousands of calculations may be performed nearly instantaneously.

SIP Library Model



In SIP Library Mode the input formulas driven by the HDR or `RAND()` formula are replaced with `INDEX()` formulas that step the model through the trials of prepared input SIPs, and collect the results into output SIPs.

7.2 Stochastic Libraries

When not using Generate Mode, input distributions come from *SIP Libraries* – Excel worksheets containing SIPs and SLURPs (coherent sets of SIPs). There are some specifics that must be met for the SIPmath Modeler Tools to use them:

1. The SIPs can be in rows or in columns, but each one must be defined as a contiguous named range.
2. Optionally, there can be metadata appended to a SIP's trial values. (See below for metadata range naming rules.) These are useful for observing the results of your models under specified scenarios, such as average values of the inputs. If used, there must be a range named PM_Meta, containing the names of the metadata elements, and another named range PM_Meta_Index with the displacements to the metadata values. These displacements must be common to all the SIPs in the library. For example, assuming a 1,000 trials, the two ranges might appear as:

PM_Meta_Index	PM_Meta
1001	Average
1002	Median
1003	Minimum
1004	Maximum

These names can be used by the *Trial Info* dialog to let the modeler see model instances for specific trials. The named ranges for the input distributions do not include metadata. However, An additional range, with the same name as the SIP but with ".MD" appended to the name must include the `PM_Meta` elements so that *Trial Info* can use the range name with an `INDEX`() formula to find them. The values of the metadata are not calculated automatically, and must be specified when creating the library.

Important

1. Metadata elements are not included in input SIP defined ranges.
2. SIP data and Metadata are included in a defined range given the same name as the SIP but with ".MD" appended to the name.
3. Metadata values are data, not formulas, so if a SIP trial value is changed, the SIP's metadata must be recalculated. The SIP Standard says nothing, and the Tools do nothing, about disagreement between a SIP's trial values and its metadata.
4. The number of metadata elements are not included in the value of variable PM_TRIALS.

7.3 INPUT CELLS

Input cells are the interface between the input SIPs and the model.

In SIP Library mode, the interface between the model and the SIPs in the library is a pair of ranges – one for the SIP names and another for the SIP trial values as specified by the user in the *Library Input* tool. Each input distribution must have an input value cell and optionally one input name cell. The SIPmath Input tool will initialize the value cells with `INDEX()`

formulas pointing to the first trial in each SIP. As the data table increments PM_Index, these will evaluate to successive values from the corresponding input SIPs. The model refers to these cells to get its input data. In Generate Mode, the Index formulas are replaced with formulas using RAND() or HDR and the input cells do not require names.

7.4 Output Cells

Output cells interface between the model and the data table

With the *Define Outputs* tool, the modeler will specify one or more cells that will evaluate to the results of the model calculation for each trial. These results will be written into successive rows in the data table, collectively making up the output distributions. The use of this tool is the same in both modes. However, in Generate Mode, the output SIPs will change every time a calculation is performed or the F9 Key is pressed.

7.5 The Data Table

The data table steps through the input distributions and records the output distributions.

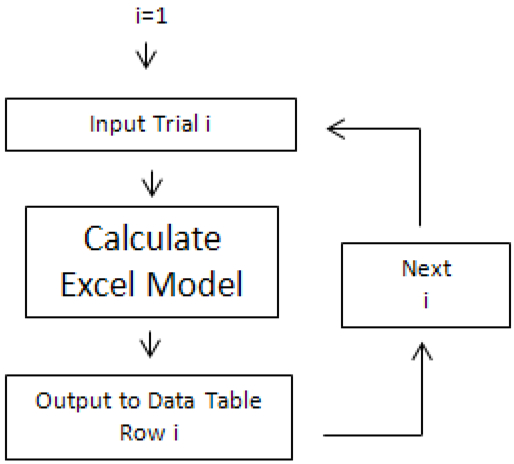
The Tools set up the data table on a worksheet called PMTable as part of the initialization. This includes defining PM_Index to be used as the trial number by the input cell formulas.

It also fills the leftmost column of the data table with a count from 1 to the total number of trials. These will be fed, one at a time, to PM_Index, which in turn will be used by the input cell formulas to select specific trials from the input distributions.

The *Define Outputs* tool completes the picture by setting up the output column or columns of the data table. It sets the formula driving the data table to a simple assignment that copies the model output cell.

7.6 The Process

A sheet recalculation event causes the data table to sequentially copy all the numbers from 1 to the number of trials into PM_Index. This results in re-evaluating the model for each of the trials in the stochastic library.



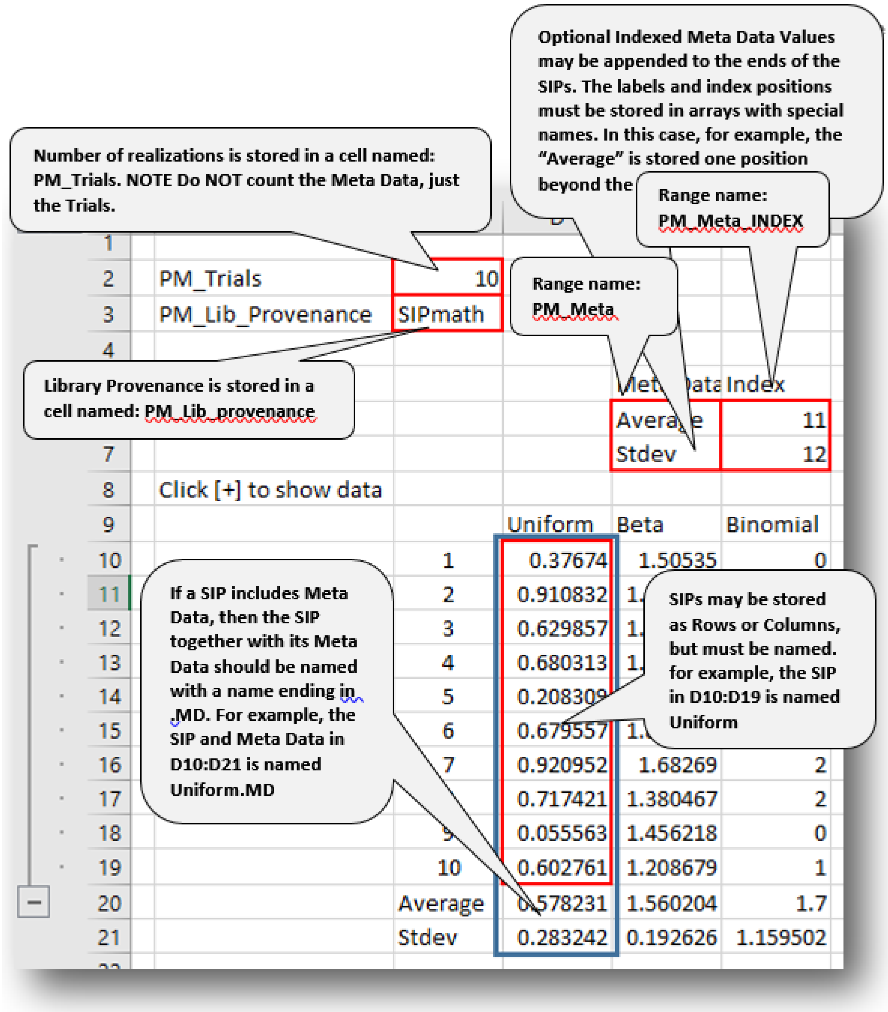
The Simulation Loop

The results appear in the corresponding rows of the output columns. Because these calculations are all internal to Excel they are much faster than they would be if the numbers were pasted into Excel by a macro.

The process ends when the desired number of trials is reached.

8 SIP LIBRARY SHEET FORMAT

Libraries are free-format, with information conveyed in Excel variable names & range names. Other Formats include XML and CSV.



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[i] Distribution Processing and the Arithmetic of Uncertainty, Sam Savage, November/December 2012, Analytics Magazine

[ii] Probability Management, Sam Savage, Stefan Scholtes and Daniel Zweidler, OR/MS Today, February 2006, Volume 33 Number 1

[iii] Probability Management 2.0, by Sam Savage and Melissa Kirmse, ORMS Today, October 2014

[iv] Sam L. Savage, The Flaw of Averages, Why we Underestimate Risk in the Face of Uncertainty, John Wiley 2009, 2012