



Simply Smart Software



DiscoverSim™  
Discovery through Simulation

# DiscoverSim™ Getting Started Guide

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**DiscoverSim™ Feature List  
Summary, Installation Notes,  
System Requirements and Getting  
Help**

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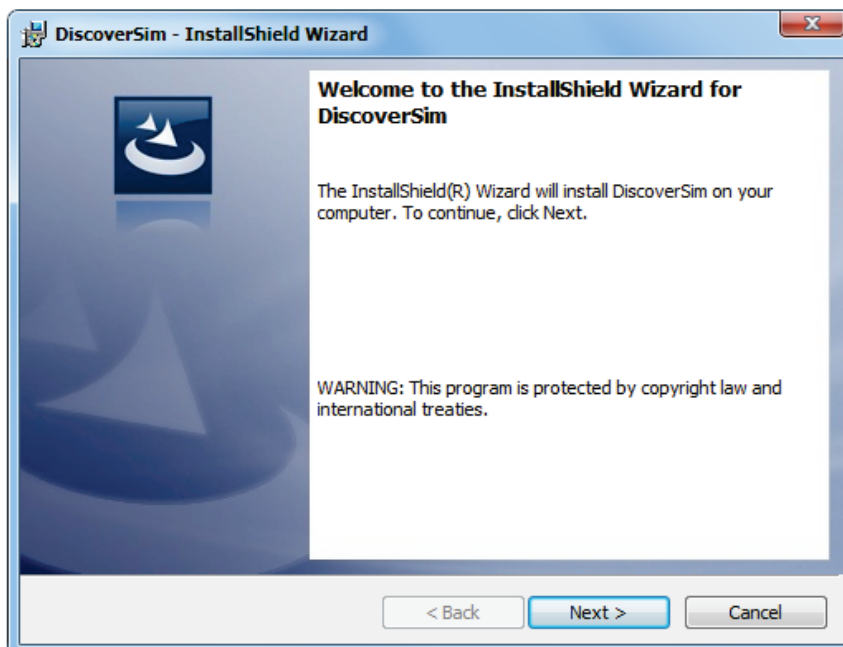
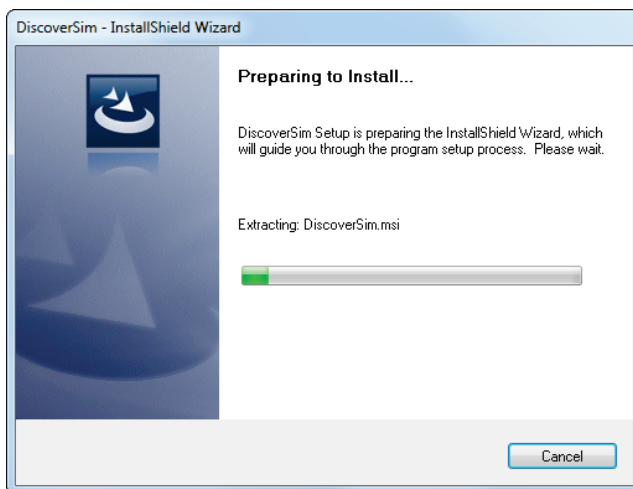


## **DiscoverSim™ Version 1.0 Feature List Summary**

- Excel add-in for Monte Carlo Simulation and Optimization
- Uses Six Sigma Language: Specify Inputs (X's) and Outputs (Y's)
- Batch Distribution Fitting
- Specify Input Correlations
- Excel Formula Interpreter for Accelerated Calculations
- 53 Continuous Distributions, 10 Discrete Distributions
- Sensitivity Analysis based on correlation or stepwise regression (includes quadratic terms)
- Optimization with Input Control Values:
  - Dividing Rectangles (DIRECT) Global Optimization
  - Genetic Algorithm (GA) Global Optimization
  - Sequential Quadratic Programming (SQP) for Fast Local Optimization
  - Powerful hybrid of the above 3 methods
  - Specify linear and nonlinear constraints
  - Stochastic Optimization – minimize dpm or maximize Ppk
  - Multiple Response Optimization using Desirability, Weighted Sum or Deviation from Target

## Installation Notes

1. **This installation procedure requires that you have Administrator rights to install the software on your computer. Also, please ensure that you have the latest Microsoft Office service pack by using Windows Update before installing DiscoverSim.**
2. Please uninstall any earlier versions of DiscoverSim.
3. Download DiscoverSim from the link that is provided. Double-click on the file **DiscoverSim\_Setup.exe**. The setup file will launch the installation of DiscoverSim. Click on the “Next” button to begin the installation.

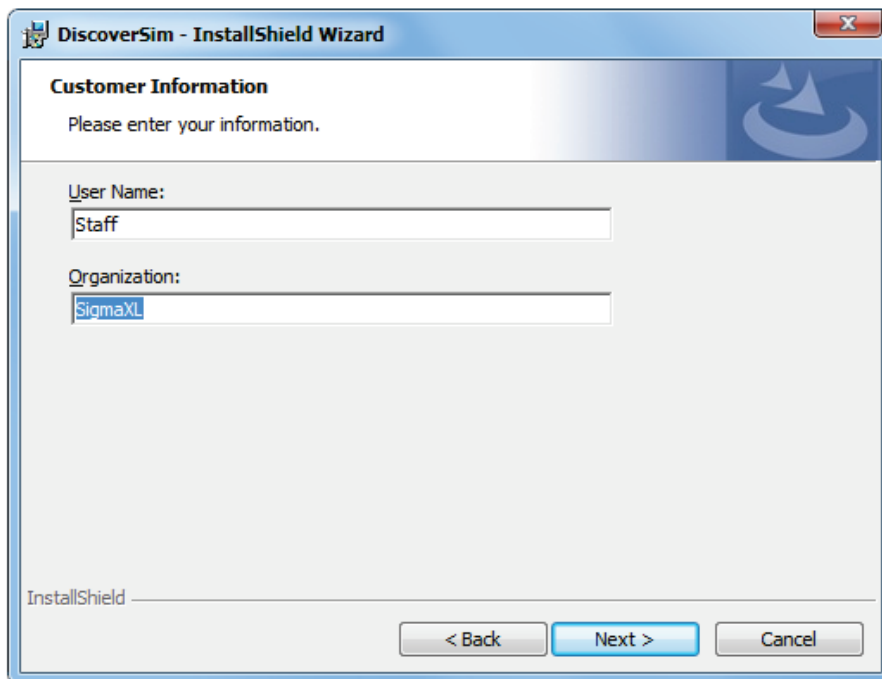




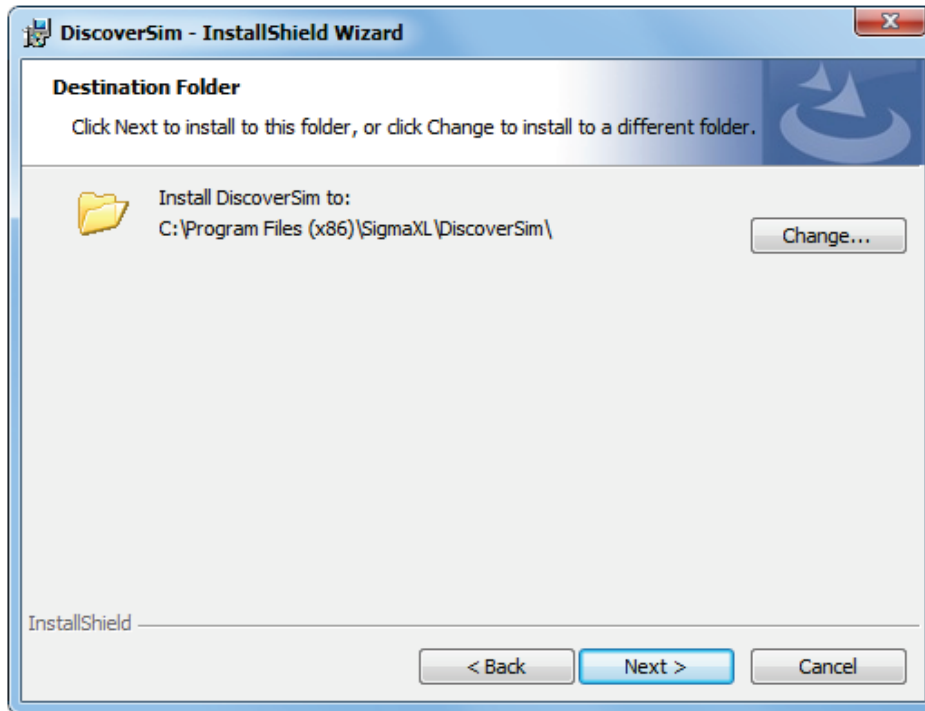
4. Read the License Agreement and select the option “I accept the terms of the license agreement” to continue.



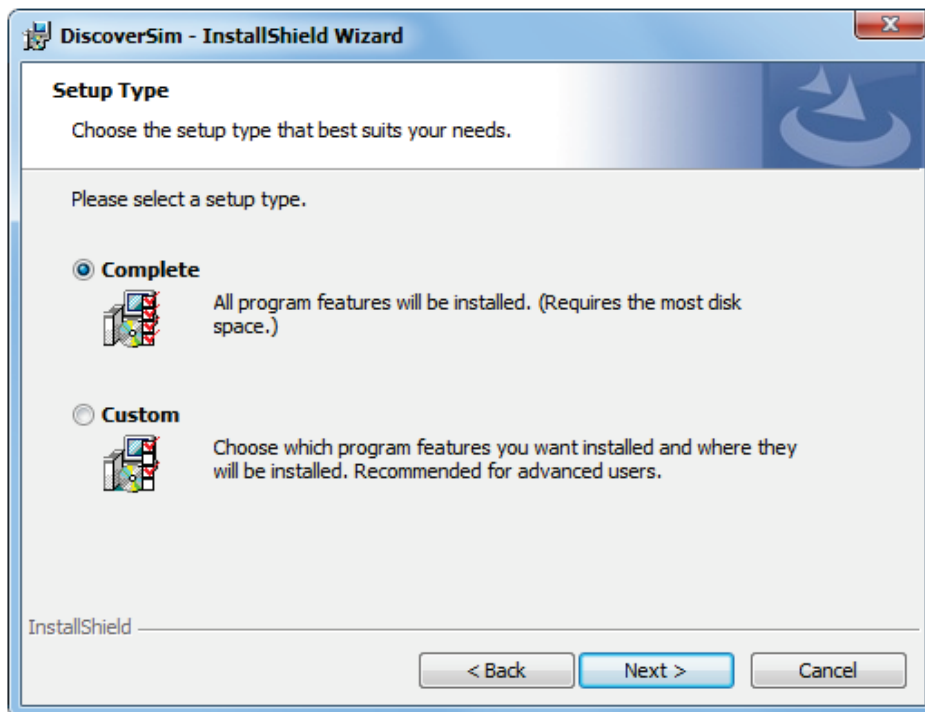
5. Fill in the User Name and Organization fields. Click on the “Next” button to continue.



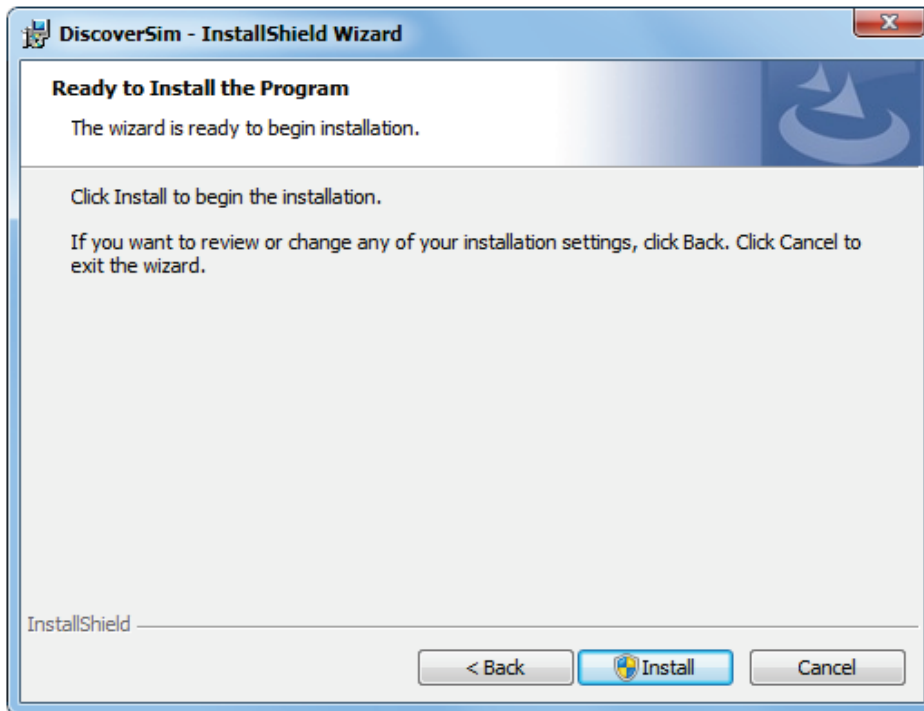
6. You will be given the option to specify DiscoverSim's installation directory. Click on the "Next" button to continue.



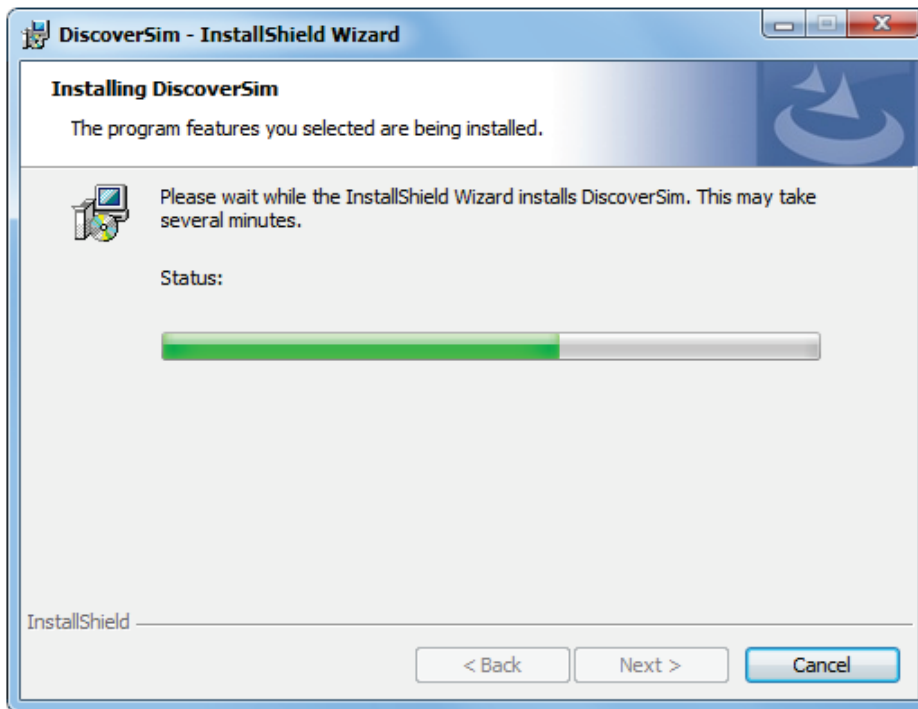
7. Select a setup type. **The default setting "Complete" is recommended.** Click on the "Next" button to continue.



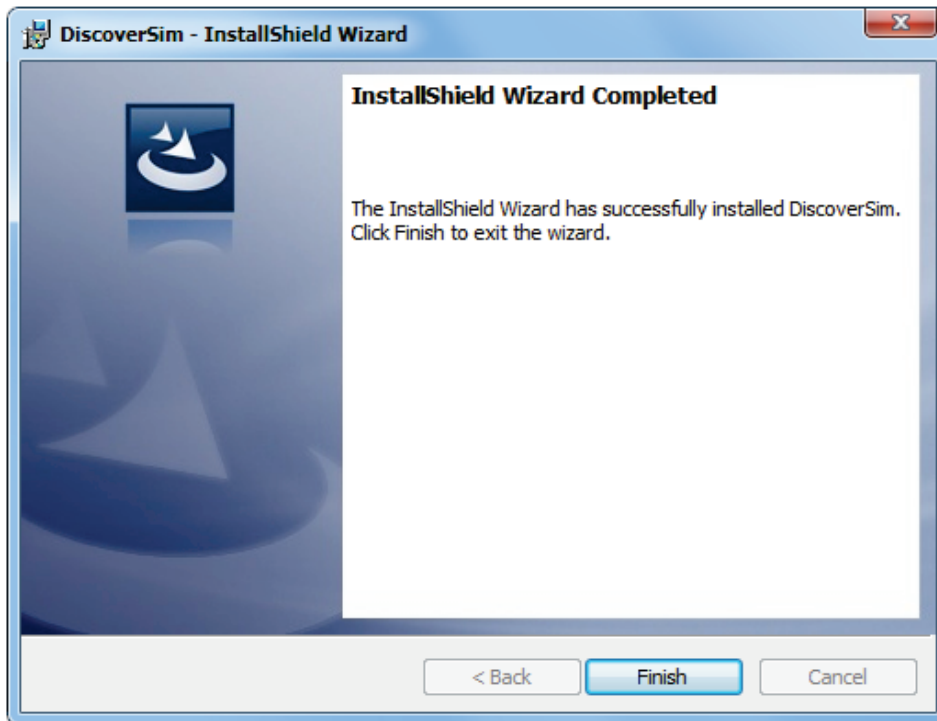
8. Press the “Install” button.



A progress bar window will appear as the files are transferred.



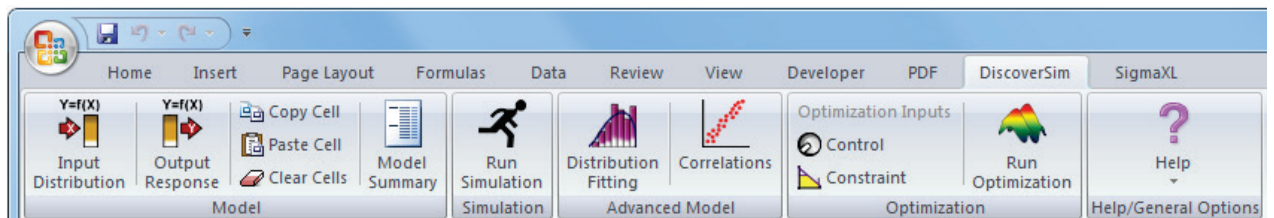
9. Press the “Finish” button.



10. To start DiscoverSim, double-click on the DiscoverSim desktop icon or click **Start > Programs > All Programs > SigmaXL > DiscoverSim**.



11. In Excel 2007 and 2010, the DiscoverSim Ribbon appears as shown below:



Note: SigmaXL is bundled with DiscoverSim, so the SigmaXL menu tab is also available. See the SigmaXL workbook for further details.

## **DiscoverSim™ System Requirements**

### **Minimum System Requirements:**

**Computer and processor:** 500 megahertz (MHz) processor or higher.

**Memory:** 512 megabytes (MB) of RAM or greater. 8 GB of RAM is recommended for large simulation runs (i.e., 1 million replications)

**Hard disk:** 160 MB of available hard-disk space.

**Drive:** CD-ROM or DVD drive.

**Display:** 1024x768 or higher resolution monitor.

**Operating system:** Microsoft Windows XP with Service Pack (SP) 2, or later operating system.

**Microsoft Excel version:** Excel 2007 and 32 bit Excel 2010 with latest service packs installed.

Administrative Rights to install software.

## **Getting Help and Product Registration**

To access the help system, please click **DiscoverSim > Help > Help**.

Technical support is available by phone at 1-866-475-2124 (toll-free in North America) or 1-416-236-5877 or e-mail [support@sigmaxl.com](mailto:support@sigmaxl.com).

Please note that registered users obtain free technical support and upgrades for one year from date of purchase. Optional maintenance renewal is available for purchase prior to the anniversary date.

To register by web, simply click **DiscoverSim > Help > Register DiscoverSim**.

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# **Introduction to DiscoverSim™, Getting Started Tutorial and DiscoverSim™ Menu & Dialogs**

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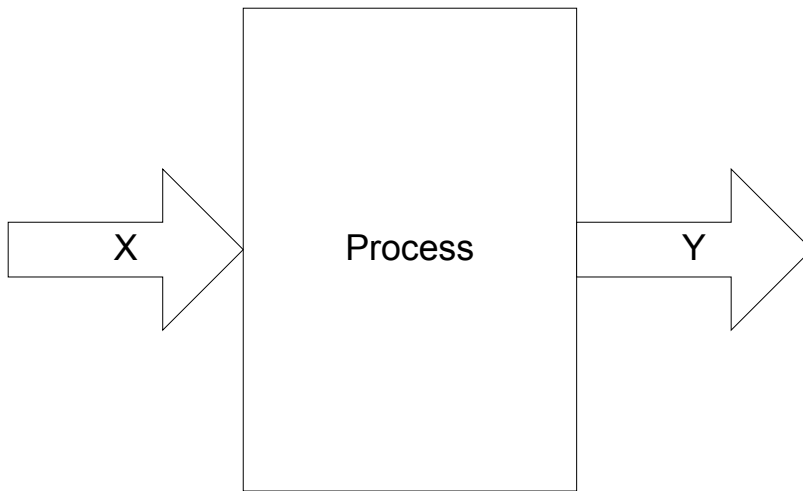




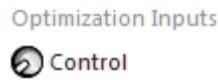
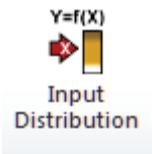
# Introduction to Monte Carlo Simulation and Optimization with DiscoverSim™

## The $Y=f(X)$ Model

DiscoverSim utilizes the “ $Y=f(X)$ ” model, where  $Y$  denotes a key process output response and  $X$  denotes a key process input. This is shown pictorially as:



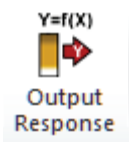
The DiscoverSim menu buttons to specify inputs are:



An input distribution is stochastic and includes random variation. It can be continuous or discrete. The most common continuous distribution is the normal distribution with parameters mean and standard deviation. DiscoverSim includes 53 continuous and 10 discrete distributions.

An input control is set to a constant value, but it can be varied like the temperature control knob of a thermostat and is used for optimization. An input control can be continuous or discrete.

The DiscoverSim menu button to specify an output response is:



A DiscoverSim model requires at least one input and one output. The output cell must contain an Excel formula that is a function of the inputs and references the cell address of the inputs or intermediate calculations including the inputs. The formula can be linear or non-linear and include Excel functions. The formula can reference other sheets within the workbook, but should not reference other workbooks.

The DiscoverSim Excel Formula Interpreter is used to dramatically accelerate the speed of calculations during simulation or optimization.

The  $Y = f(X)$  equation should be based on theory, process knowledge, or the prediction formula of a designed experiment or regression analysis. In Design for Six Sigma (DFSS), this is referred to as the “Transfer Function”. This prediction equation should be validated prior to use in DiscoverSim. As the eminent statistician George Box said, “All models are wrong, some are useful”, so while the model does not have to be exact, it should be a reasonable approximation of reality. The results of a DiscoverSim analysis should also be validated with further experimentation or use of prototypes.

### **Monte Carlo Simulation**

The  $Y = f(X)$  model gives us a starting point in the relationship between X and Y. After the  $Y = f(X)$  relationship has been validated, an important question that then needs to be answered is: “What does the distribution of Y look like when I cannot hold X constant, but have some uncertainty in X?” In other words, “How can I quantify my risk?”

Take an example of a sales forecast. Y is the predicted monthly sales, which is a sum of forecasts from five different product line sales managers. If each manager simply reports a single “most likely” estimate, the total predicted sales will also be a single “most likely” estimate. The problem with this approach is obvious; it does not take the uncertainty into account. So what then should be done? In addition to the most likely estimates, each sales manager could include best and worst case estimates. Alternatively, an estimate of the mean and standard deviation could be reported.

The challenge then becomes how to best take the uncertainty into account. One could simply sum the best and worst case values (or the +/-3 standard deviation values), and thus report the total range. This approach, however, is unsatisfactory because it does not take into account the very low likelihood that each line will simultaneously have a best case or worst case value. This would be akin to rolling 5 dice and getting 5 ones or 5 sixes.

If each of the sales managers assume a normal distribution, the distribution for total sales will also be normal with:

$$\text{Total Mean} = \text{Mean}_1 + \dots + \text{Mean}_5$$

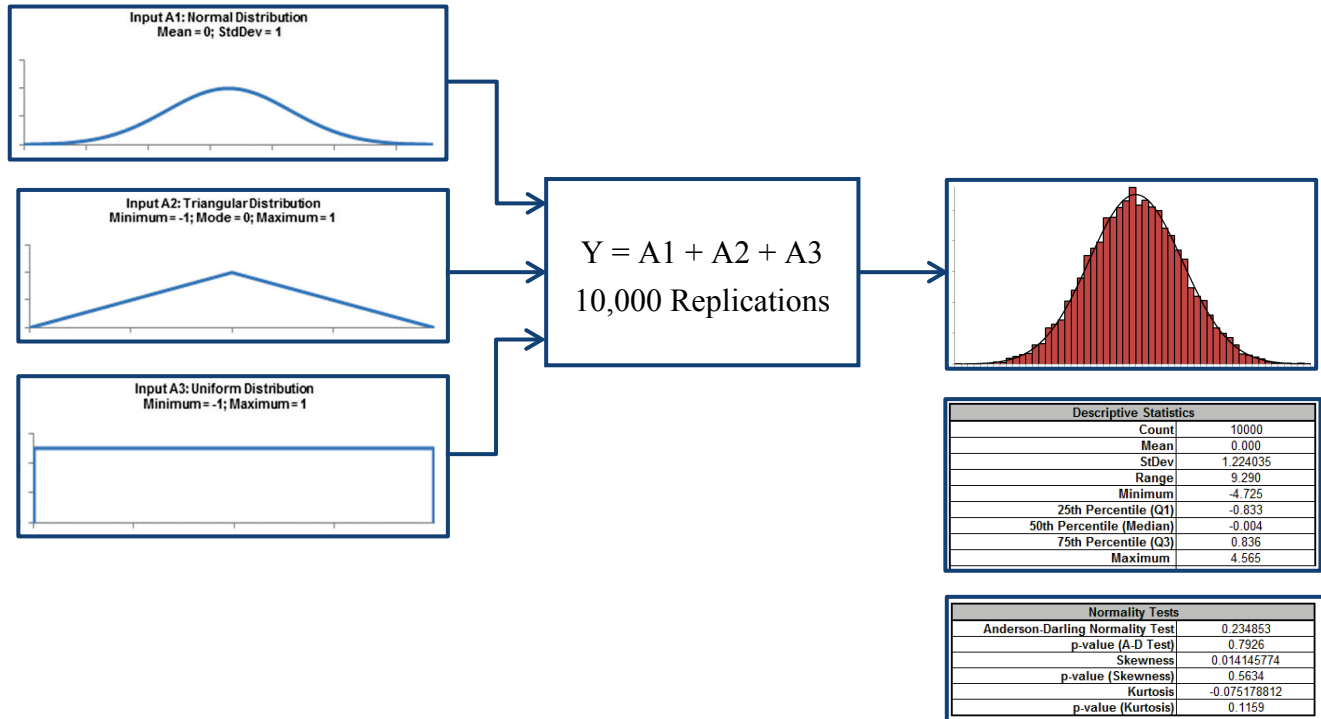
$$\text{Total StdDev} = \text{SQRT}((\text{StdDev}_1)^2 + \dots + (\text{StdDev}_5)^2).$$

If, however, some of the product lines have correlated sales, i.e., an increase in sales for product A also means an increase in sales for product B, then “things get complicated”. The StdDev formula given above does not hold because it assumes independence. Further complications arise if the sales managers need to use different distributions or if the total sales involve more than a simple sum. This is where Monte-Carlo simulation comes in to solve the complex problem of dealing with uncertainty by “brute force” using computational power.

The Monte Carlo method was coined in the 1940s by John von Neumann, Stanislaw Ulam and Nicholas Metropolis, while they were working on nuclear weapon projects in the Los Alamos National Laboratory. It was named in homage to Monte Carlo casino, a famous casino, where Ulam's uncle would often gamble away his money

(Ref: [http://en.wikipedia.org/wiki/Monte\\_Carlo\\_method](http://en.wikipedia.org/wiki/Monte_Carlo_method)).

The following diagram illustrates a simple Monte Carlo simulation using DiscoverSim with three different input distributions (X's also known as “Assumptions”):



A random draw is performed from each input distribution, Y is calculated, and the process is

repeated 10,000 times. The histogram and descriptive statistics show the simulation results. While not shown here, requirements (specification limits) can easily be added to Y to obtain probability of nonconformance.

Notice that even though input distributions A2 and A3 are not normal, the distribution for the total is normal. This is due to the central limit theorem. Of course, this will not always be the case when performing a Monte-Carlo simulation!

The areas of application for Monte-Carlo simulation are very wide, including Design for Six Sigma (DFSS), Tolerance Design, Project Management and Risk Management with common use in Engineering, Finance, Telecommunications and Oil & Gas Exploration.

The following books are recommended for further reading:

Savage, Sam (2009), *The Flaw of Averages: Why We Underestimate Risk in the Face of Uncertainty*, Hoboken, NJ, Wiley.

Sleeper, Andrew (2006), *Design for Six Sigma Statistics: 59 Tools for Diagnosing and Solving Problems in DFSS Initiatives*, NY, McGraw-Hill.

## **Components of Uncertainty**

There are two components to uncertainty: one is the actual process variation, and the second is measurement error or error due to lack of knowledge. The contribution of the latter can be incorporated into a model, but for simplicity in our discussions and case studies, we will assume that the measurement error is negligible.

## Selecting a Distribution

Selecting the correct distribution is a critical step towards building a useful model.

The best choice for a distribution is one based on known theory, for example, the use of a Weibull Distribution for reliability modeling.

A common distribution choice is the Normal Distribution, but this assumption should be verified with data that passes a normality test with a minimum sample size of 30; preferably 100.

If data is available and the distribution is not normal, use DiscoverSim’s Distribution Fitting tool to find a best fit distribution. Alternatively, the Pearson Family Distribution allows you to simply specify Mean, StdDev, Skewness and Kurtosis.

In the absence of data or theory, commonly used distributions are: Uniform, Triangular and PERT. Uniform requires a Minimum and Maximum value, and assumes an equal probability over the range. This is commonly used in tolerance design. Triangular and PERT require a Minimum, Most Likely (Mode) and Maximum. PERT is similar to Triangular, but it adds a “bell shape” and is popular in project management.

The following table is a summary of all distributions in DiscoverSim (\*\* denotes with/without Threshold).

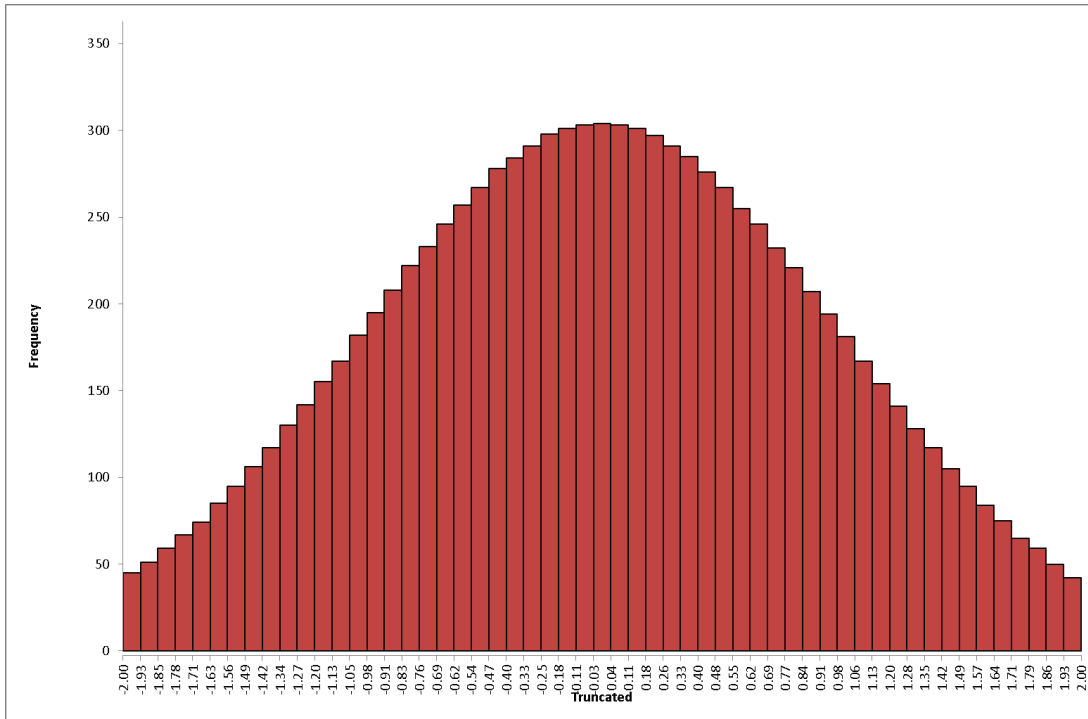
<b>Common Continuous:</b>	<b>Advanced Continuous:</b>	<b>Discrete:</b>
<ul style="list-style-type: none"> <li>• Normal</li> <li>• Triangular</li> <li>• Uniform</li> <li>• Pearson Family (specify Mean, StdDev, Skewness, Kurtosis)</li> <li>• Log Normal**</li> <li>• Exponential**</li> <li>• Weibull**</li> <li>• PERT</li> <li>• Custom Continuous</li> </ul>	<ul style="list-style-type: none"> <li>• Beta</li> <li>• Beta (4 Parameter)</li> <li>• Box-Cox**</li> <li>• Burr**</li> <li>• Cauchy</li> <li>• Chi-Squared**</li> <li>• Chi-Squared with Scale (3 Parameter)**</li> <li>• Error Function (ERF)</li> <li>• F**</li> <li>• F with Scale (4 Parameter)**</li> <li>• Fatigue Life**</li> <li>• Fisk**</li> <li>• Folded Normal</li> <li>• Frechet**</li> <li>• Gamma**</li> <li>• Generalized Error</li> <li>• Generalized Gamma**</li> </ul>	<ul style="list-style-type: none"> <li>• Bernoulli (Yes/No)</li> <li>• Binomial</li> <li>• Geometric</li> <li>• Hypergeometric</li> <li>• Logarithmic</li> <li>• Negative Binomial</li> <li>• Poisson</li> <li>• Step</li> <li>• Uniform (Discrete)</li> <li>• Custom Discrete</li> </ul>

Common Continuous:	Advanced Continuous:	Discrete:
	<ul style="list-style-type: none"> <li>• Generalized Logistic</li> <li>• Generalized Pareto</li> <li>• Half Normal**</li> <li>• Inverse Gamma**</li> <li>• Inverse Gaussian</li> <li>• Johnson SB</li> <li>• Johnson SL</li> <li>• Johnson SU</li> <li>• Laplace</li> <li>• Largest Extreme Value</li> <li>• Levy</li> <li>• Logistic</li> <li>• Log Gamma**</li> <li>• Log Logistic**</li> <li>• Maxwell</li> <li>• Non-Central Chi-Squared**</li> <li>• Non-Central F**</li> <li>• Non-Central T</li> <li>• Pareto</li> <li>• Power</li> <li>• Rayleigh</li> <li>• Reciprocal</li> <li>• Skew Normal</li> <li>• Smallest Extreme Value</li> <li>• Student's T</li> <li>• Student's T with Location and Scale (3 Parameter)</li> <li>• Von Mises</li> </ul>	

## Specifying Truncation Values

DiscoverSim allows you to specify truncation values for any input distribution. For example, a truncated normal distribution would be appropriate if you have a component supplier that starts with a normal distribution, then rejects the parts that fail the lower and upper specification, and ships you the good parts.

The following histogram illustrates a truncated normal distribution (mean = 0, stdev = 1) with minimum = -2 and maximum = 2.

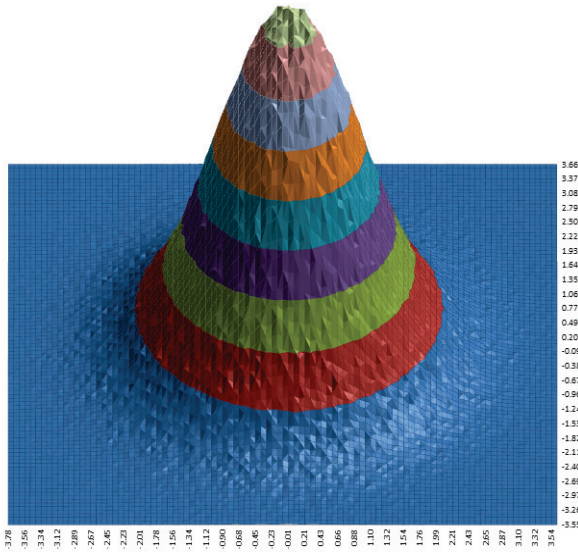


## Specifying Correlations

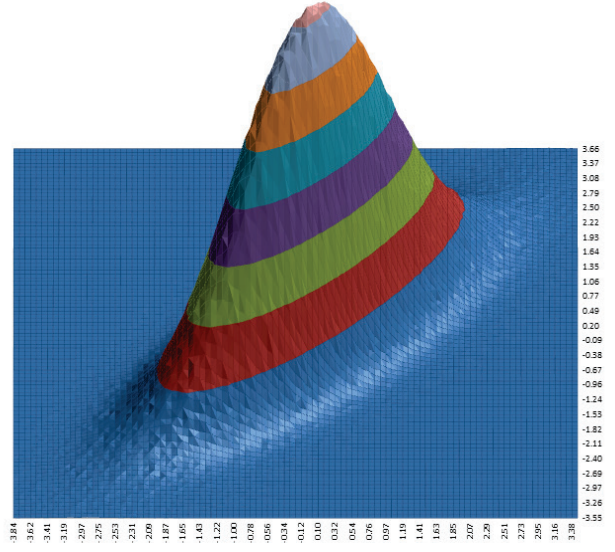
DiscoverSim allows you to specify correlations between any inputs. DiscoverSim utilizes correlation copulas to achieve the desired Spearman Rank correlation values.

The following surface plots illustrate how a correlation copula results in a change in the shape of a bivariate (2 input) distribution:

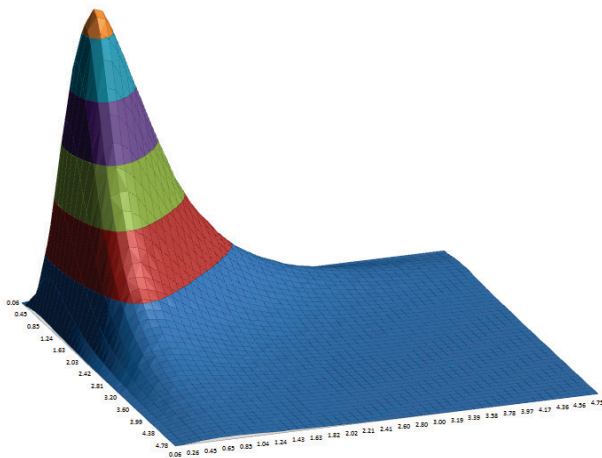
Surface Plot of Bivariate Normal Distribution



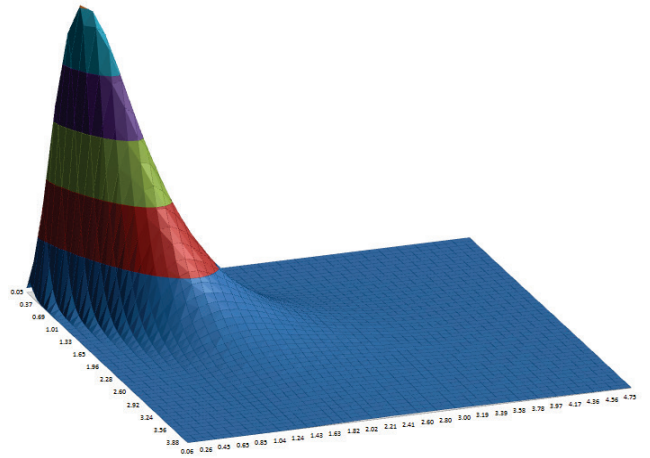
Surface Plot of Bivariate Normal Distribution with Copula (rho = 0.8)



Surface Plot of Bivariate F Distribution



Surface Plot of Bivariate F Distribution with Copula (rho=0.8)





## **Optimization**

### **Stochastic Versus Deterministic Optimization**

Monte-Carlo simulation enables you to quantify risk, whereas stochastic optimization enables you to minimize risk. Deterministic optimization is a more commonly used tool but has the same drawback as the single number estimate method described above in the introduction to Monte Carlo simulation; it does not take uncertainty into account. Stochastic optimization will not only find the optimum X settings that result in the best mean Y value, it will also look for a solution that will reduce the standard deviation.

Deterministic optimization will look for a minimum or maximum, whereas stochastic optimization looks for a minimum or maximum that is robust to variation in X, thus reducing the transmitted variation in Y. This is referred to as “Robust Parameter Design” in Design For Six Sigma (DFSS).

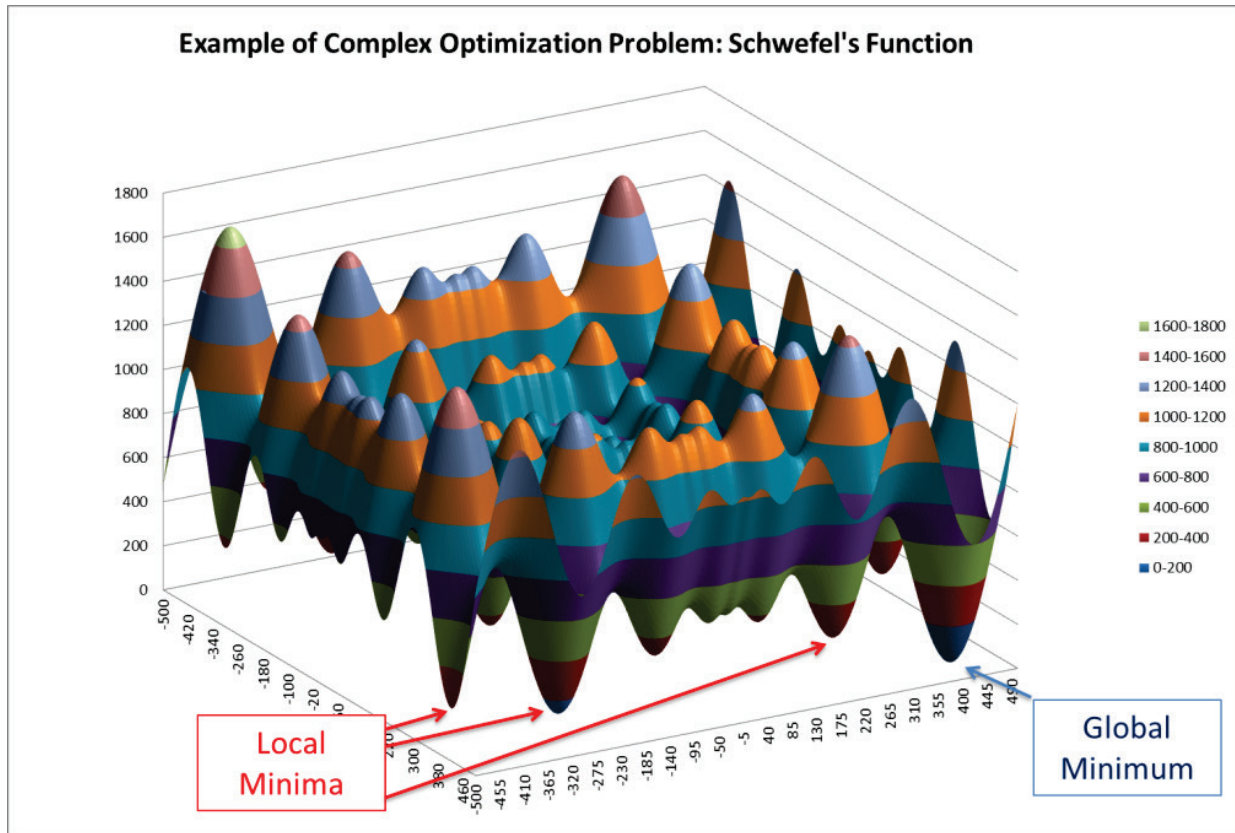
### **Local Versus Global Optimization**

Local optimization methods are good at finding local minima, use derivatives of the objective function to find the path of greatest improvement, and have fast convergence. However, they require a smooth response so will not work with discontinuous functions. DiscoverSim uses Sequential Quadratic Programming (SQP) for local optimization.

Global optimization finds the global minimum, and is derivative free, so will work with discontinuous functions. However, because of the larger design space, convergence is much slower than that of local optimization. DiscoverSim uses DIRECT (Dividing Rectangles) and Genetic Algorithm (GA) for global optimization.

A hybrid of the above methodologies is also available in DiscoverSim, starting with DIRECT to do a thorough initial search, followed by GA, and then fine tuning with SQP.

The following surface plot illustrates a function with local minima and a global minimum.



## **Components of Optimization in DiscoverSim**

**Output:** The output will be a function of the model equation, intermediate cell calculations, as well as input distributions and input controls.

**Input Control:** The permissible range for the control is specified, and the control, which unlike an input distribution, has no statistical variation. Think of this as the temperature control knob of a thermostat. This is also known as a “Decision Variable”. An input control can be referenced by an input distribution parameter, constraint and/or an output function. It is possible to have a model that consists solely of controls with no input distributions. (In this case, the optimization is deterministic, so the number of replications,  $n$ , should be set to 1.) An input control can be continuous or discrete integer.

**Constraint:** A constraint can only be applied to an Input Control and cannot reference an Input Distribution or Output Response. A constraint cannot be a part of the model equation (i.e., an output cannot reference a constraint). Constraints can be simple linear or complex nonlinear. Each constraint will contain a function of Input Controls on the Left Hand Side (**LHS**), and a constant on the Right Hand Side (**RHS**). The constraint formula is specified in the **LHS**.

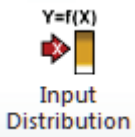
## Getting Started Tutorial

1. Open the workbook **DMAIC Project Duration**. This is an example model of a Six Sigma project with five phases: Define, Measure, Analyze, Improve and Control. We are interested in estimating the total project duration in days. Management requires that the project be completed in 120 days. We will model duration simply as:

Total Duration = Define + Measure + Analyze + Improve + Control

	A	B	C	D	E	F	G	H
1	<b>DiscoverSim Tutorial: Six Sigma DMAIC Project Expected Duration</b>							
2						Triangular Distribution		
3		Project Phase:	DiscoverSim Input:			Minimum	Mode (Most Likely)	Maximum
4		Define				5	10	15
5		Measure				10	20	30
6		Analyze				5	10	15
7		Improve				10	20	30
8		Control				15	30	45
9								
10		DiscoverSim Output:						
11		Total Duration (days):	0			45	90	135
12								
13		Management Requirement (days):	120					

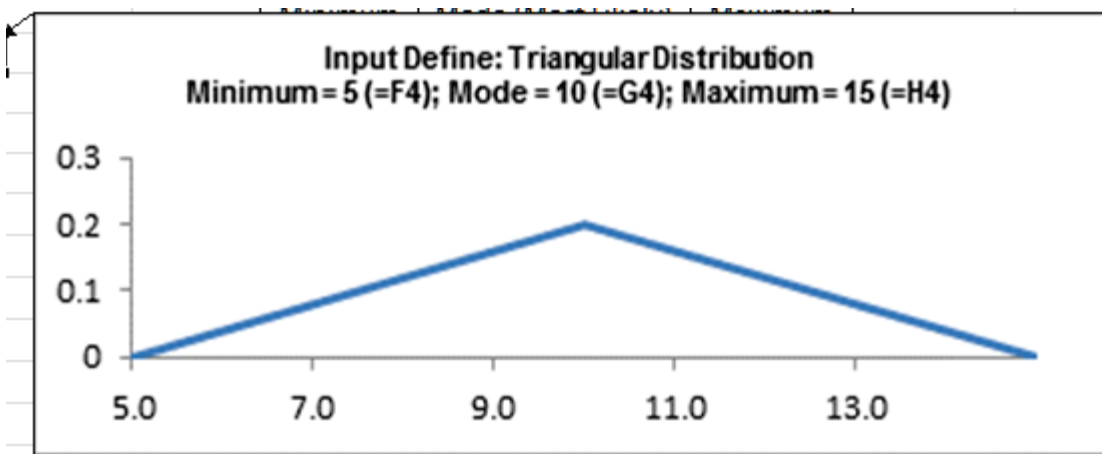
2. We will model each phase using a Triangular Distribution, which is popular when data or theory is not available to estimate or identify the distribution type and parameter values. (Another similar distribution that is commonly used for project management is PERT). The Minimum, Mode (Most Likely) and Maximum durations were estimated by the Six Sigma project team based on their experience.
3. Click on cell **C4** to specify the Input Distribution for Define. Select **DiscoverSim > Input Distribution**:
 


4. Select **Triangular Distribution**. A brief description of the Triangular Distribution is given in the dialog.
5. Click input **Name** cell reference  and specify cell **B4** containing the input name “Define”. After specifying a cell reference, the dropdown symbol changes from  to .
6. Click the **Minimum** parameter cell reference  and specify cell **F4** containing the minimum parameter value = 5.
7. Click the **Mode** parameter cell reference  and specify cell **G4** containing the mode (most likely) parameter value = 10.
8. Click the **Maximum** parameter cell reference  and specify cell **H4** containing the maximum parameter value = 15.

9. Click **Update Chart** to view the triangular distribution as shown:

The screenshot shows the 'DiscoverSim - Create/Edit Input Distribution' dialog box. At the top, 'Input' is set to 1 and 'Name' is 'Define'. The 'Cell Address' is 'Sheet1!\$C\$4'. A chart displays a triangular distribution with a minimum of 5.0, mode of 10.0, and maximum of 15.0. The 'Parameters' section has dropdowns for Minimum (5), Mode (10), and Maximum (15). The 'Options' section includes checkboxes for 'Truncate' (unchecked) and 'Include in Specified Input Correlations' (checked). On the right, 'Specify Distribution' is set to 'Common Continuous', and 'Common Continuous Distributions' includes Normal, Triangular (selected), Uniform, Pearson Family, and Log Normal. A 'View Distribution Formulas' button is at the bottom right.

10. Click **OK**. Hover the cursor on cell **C4** to view the DiscoverSim graphical comment showing the distribution and parameter values:

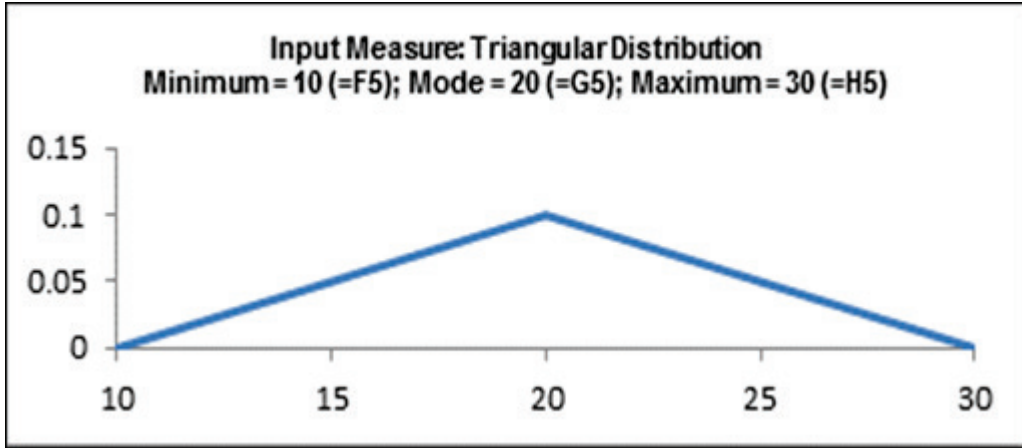


11. Click on cell C4. Click the **DiscoverSim Copy Cell** menu button  **Copy Cell** (Do not use Excel's Copy – it will not work!).

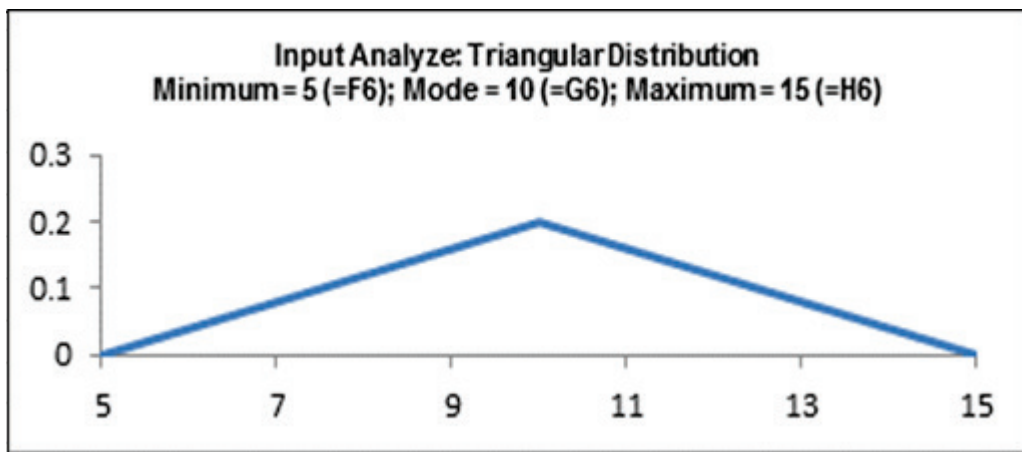
12. Select cells **C5:C8**. Click the **DiscoverSim Paste Cell** menu button  **Paste Cell** (**Do not use Excel's Paste – it will not work!**).

13. Verify that the input comments appear as shown:

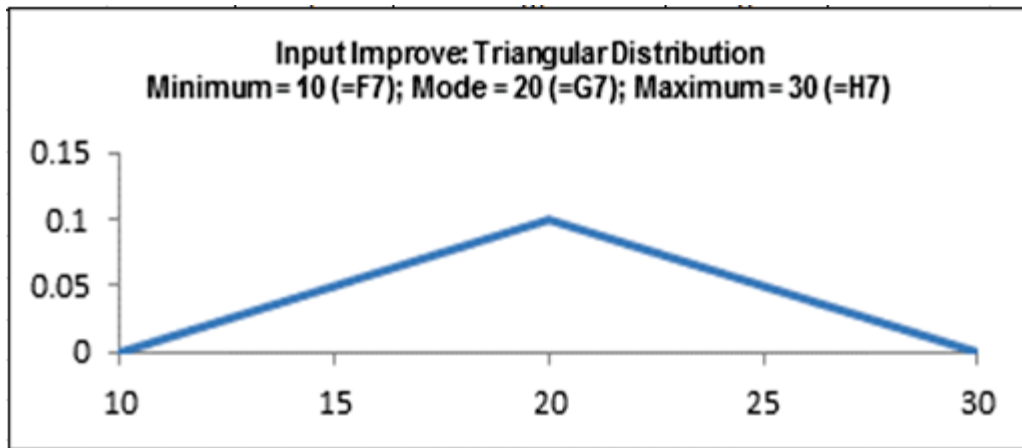
Cell C5:



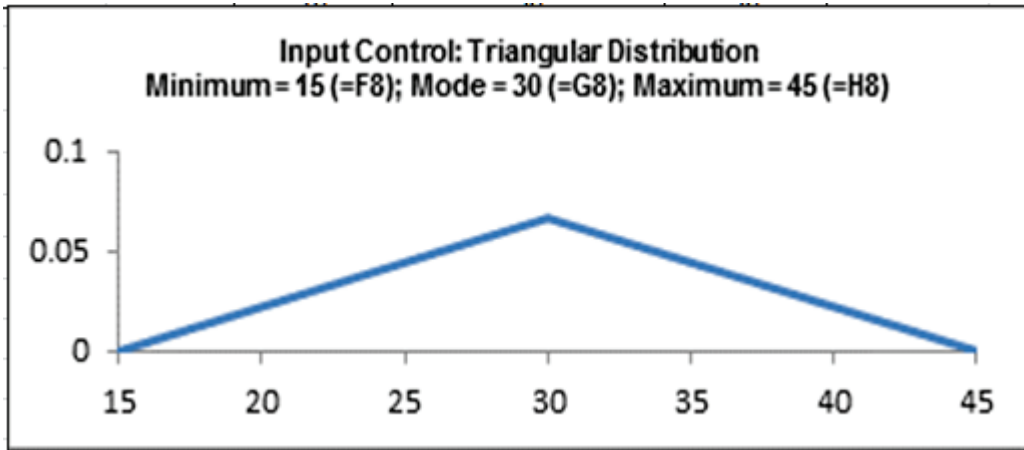
Cell C6:



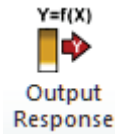
Cell C7:



Cell C8:



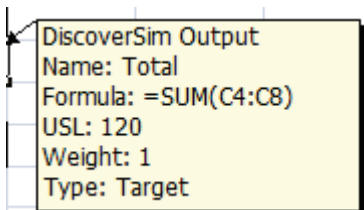
14. Click on cell C11. Note that the Excel formula =SUM (C4:C8) has already been entered. Select **DiscoverSim > Output Response:**



15. Enter the output **Name** as “Total”. Enter the Upper Specification Limit (**USL**) as 120 (or specify cell reference C13).

Click **OK**.

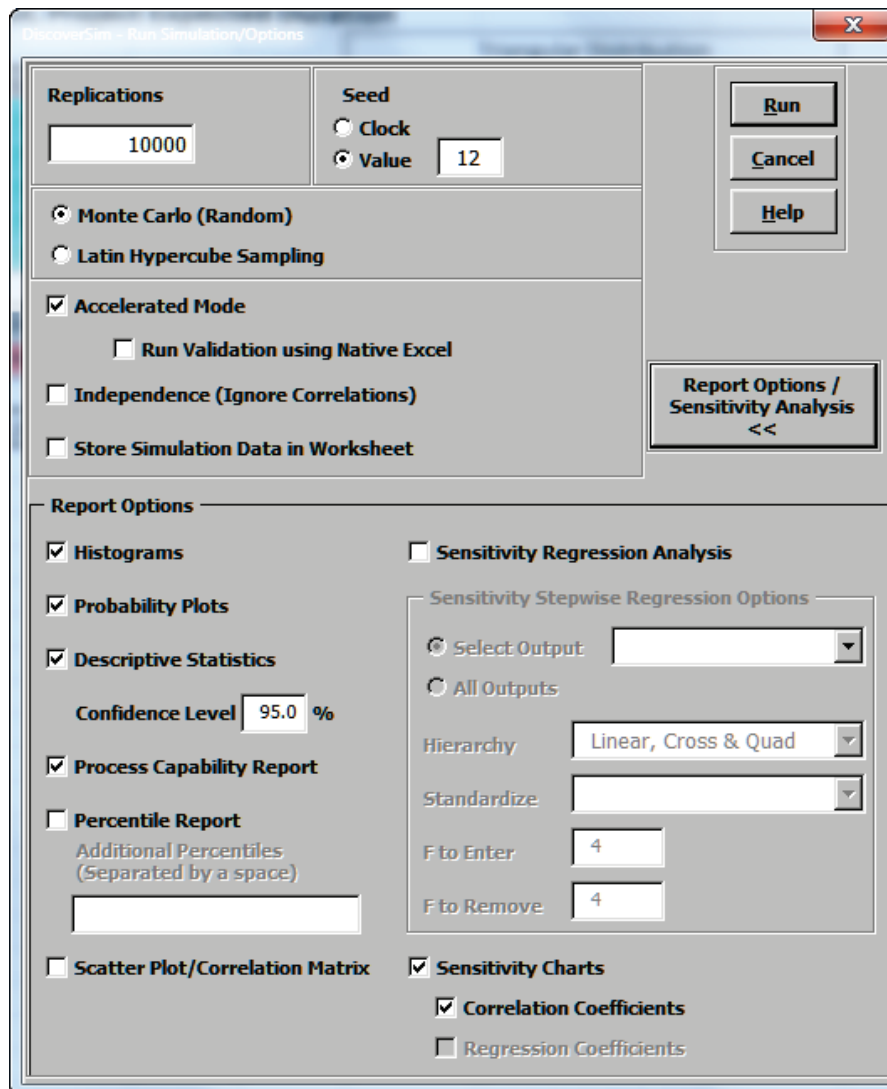
16. Hover the cursor on cell C11 to view the DiscoverSim Output information.



17. Select **DiscoverSim > Run Simulation**:



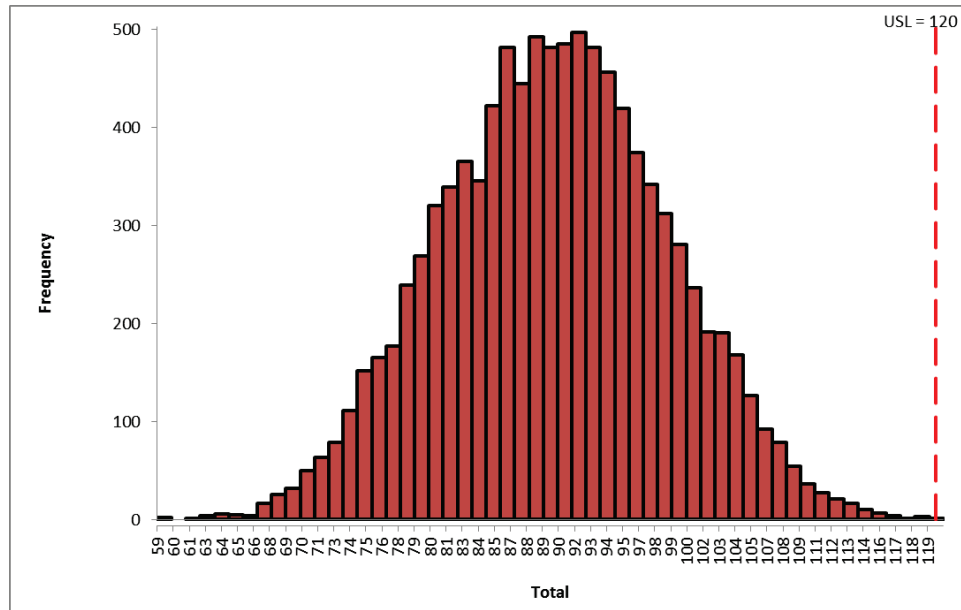
18. Click **Report Options/Sensitivity Analysis**. Check **Sensitivity Charts** and **Correlation Coefficients**. Select **Seed Value** and enter “12” as shown, in order to replicate the simulation results given below.



Click **Run**.

19. The DiscoverSim output report shows a histogram, descriptive statistics and process capability indices:





Output 1 Model Information	
Output Name (or Cell Address)	Total
Function	=SUM(C4:C8)
USL	120
Target	
LSL	
Weight	1
Output Goal	Target

Descriptive Statistics	
Count	10000
Mean	90.023
StDev	8.925891
Range	61.842
Minimum	58.770
25th Percentile (Q1)	83.784
50th Percentile (Median)	90.119
75th Percentile (Q3)	96.123
Maximum	120.612
95.0% CI Mean	89.84819 to 90.19812
95.0% CI Median	89.84714 to 90.30615
95.0% CI StDev	8.803885 to 9.05135

Normality Tests	
Anderson-Darling Normality Test	1.548445
p-value (A-D Test)	0.0006
Skewness	0.008590875
p-value (Skewness)	0.7256
Kurtosis	-0.238108
p-value (Kurtosis)	0.0000

Process Capability Indices	
Pp	
Ppu	1.12
Ppl	
Ppk	1.12
Cpm	

Expected Overall Performance (Assuming Normal Distribution)	
ppm > USL	391.95
ppm < LSL	
ppm Total	391.95
% > USL	0.04
% < LSL	
% Total (out of spec.)	0.04
% Total (within spec.)	99.96

Actual Performance (Empirical)	
ppm > USL	100.00
ppm < LSL	
ppm Total	100.00
% > USL	0.01
% < LSL	
% Total (out of spec.)	0.01
% Total (within spec.)	99.99

From the histogram and capability report we see that the Total Project duration should easily meet the requirement of 120 days, assuming that our model is valid. The likelihood of failure (based on the actual simulation performance) is approximately .01%.

**Note:** If **Seed** is set to **Clock**, there will be slight differences in the reported values with every simulation run due to a different starting seed value derived from the system clock.

20. A summary of the model input distributions, parameters and output response is also given in the simulation report.

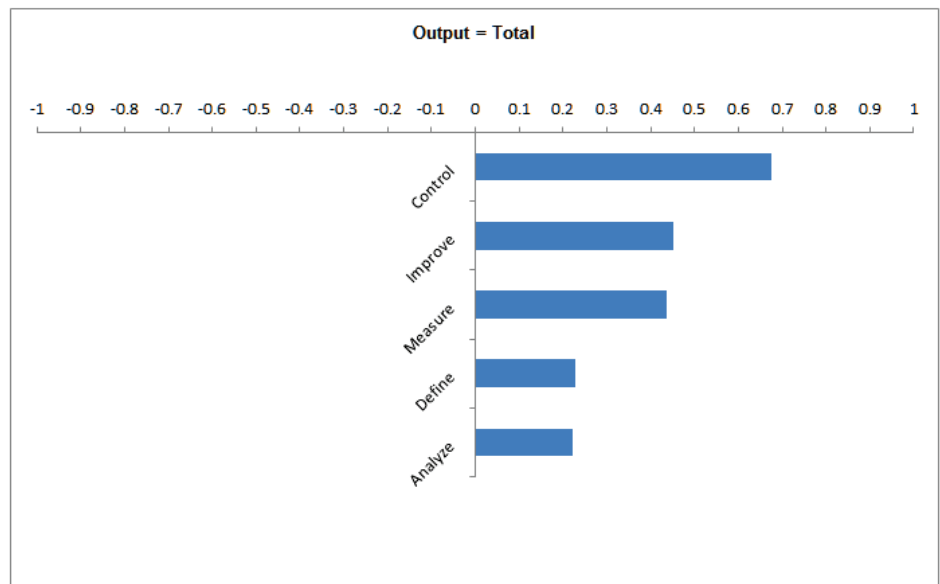
Input Name	Input Cell Address	Distribution	Distribution Type	Parameter 1 Name	Parameter 1 Value	Parameter 2 Name	Parameter 2 Value	Parameter 3 Name	Parameter 3 Value
Define	C4	Triangular	Continuous	Minimum	5 (=Sheet1!\$F\$4)	Mode	10 (=Sheet1!\$G\$4)	Maximum	15 (=Sheet1!\$H\$4)
Measure	C5	Triangular	Continuous	Minimum	10 (=Sheet1!\$F\$5)	Mode	20 (=Sheet1!\$G\$5)	Maximum	30 (=Sheet1!\$H\$5)
Analyze	C6	Triangular	Continuous	Minimum	5 (=Sheet1!\$F\$6)	Mode	10 (=Sheet1!\$G\$6)	Maximum	15 (=Sheet1!\$H\$6)
Improve	C7	Triangular	Continuous	Minimum	10 (=Sheet1!\$F\$7)	Mode	20 (=Sheet1!\$G\$7)	Maximum	30 (=Sheet1!\$H\$7)
Control	C8	Triangular	Continuous	Minimum	15 (=Sheet1!\$F\$8)	Mode	30 (=Sheet1!\$G\$8)	Maximum	45 (=Sheet1!\$H\$8)

Output Name	Output Cell Address	LSL	Target	USL	Weight	Output Goal	Function
Total	C11			120	1	Target	=SUM(C4:C8)

**Tip:** Use this summary to keep track of simulation runs with modified parameter values.

21. If we needed to improve the performance, the sensitivity charts would guide us where to focus our efforts. Click on the **Sensitivity Correlations** sheet:

Inputs	Spearman Rank
Control	0.675972435
Improve	0.451123789
Measure	0.436461129
Define	0.22775111
Analyze	0.222844794



The control phase is the dominant input factor affecting Total Duration, followed by Measure and Improve.

**Tip:** This Sensitivity Chart uses the Spearman Rank Correlation, and the results may be positive or negative. If you wish to view R-Squared percent contribution to variation, rerun the simulation with **Sensitivity Regression Analysis** and **Sensitivity Charts, Regression Coefficients** checked.

The results in this simple example are intuitively obvious from the input values, but keep in mind that a real model will likely be considerably more complex with sensitivity analysis results identifying important factors that one might not have expected.

Please see DiscoverSim workbook for further information including case studies.