

A SunCam online continuing education course

# Engineering Methods in Microsoft Excel

# Part 5: Simulation and Systems Modeling II

by

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#### Abstract

This course is part of a series that presents *Microsoft Excel* methods that are useful for a wide range of engineering analyses and data management. This course presents simulation and systems modeling. Simulation is a technique for conducting experimentation of a system or process, virtually, on a computer. This course presents the fundamentals of the Monte Carlo simulation technique, and demonstrates, in detail, the framework for applying the technique to model a real engineering system, on an *Excel* spreadsheet. This course presents techniques for analyzing the results and how they are interpreted and applied in decision making. This course presents techniques for selecting and validating statistical distributions that are used to model the elements of the system being simulated, and how they are implemented in *Excel*. Upon completion of this course, practitioners will be able to apply the methods learned to a variety of engineering problems, and also to identify situations in their fields of specialty where the innovative application of these tools and methods will be advantageous to their output and to their work product.



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# **1. INTRODUCTION**

# 1.1 Overview

Engineers are constantly challenged with solving a wide range of complex analytical and computational problems in their fields of specialty. These problems involve analyses methodologies and the management of data. The application of computers enables repetitive, time-consuming and often tedious calculations to be conducted rapidly, efficiently, and less prone to errors. The application of computer tools also enables the results and outputs of such engineering analyses to be readily transferred and incorporated into reports and other engineering documents. An even greater advantage, in terms of productivity and efficiency, is realized when these calculations and outputs are replicated across numerous projects. Competence in computer skills predisposes engineers to pursue and develop more creative and innovative solutions to problems than otherwise.

*Microsoft Excel* is widely and increasingly being used as a tool to assist engineers in conducting and replicating intricate calculations and analyses, designing complex systems, and managing large data sets. *Microsoft Excel* is an electronic spreadsheet program developed by the *Microsoft* Company, and part of the *Microsoft Office* suite of products. A spreadsheet is a grid that organizes data and calculations into columns and rows. The intersection of a column and a row is called a cell. An electronic spreadsheet enables users to store, organize, manipulate, and analyze data in the cells of the spreadsheet.

This course presents fundamental principles and engineering applications of simulation and systems modeling, and demonstrates the *Microsoft Excel* tools, methods, and strategies that can be used to simulate and model real-life engineering systems. Simulation techniques involve conducting virtual experimentation of a system or process, on a computer, using mathematical and statistical models. This course presents how to formulate, implement and solve simulation and systems modeling problems in *Microsoft Excel*.

Upon completion of this course, participants will have gained insight into applying *Excel* tools, methods, and strategies in formulating, implementing and analyzing simulation models. Participants will also be able to identify professional situations where the application of these innovative *Excel* techniques will be of great benefit and advantage, and will enable practitioners to significantly improve their productivity and the quality of their work product.



# **2. SIMULATION**

#### **2.1 Introduction**

Simulation is a statistical analysis tool used in many fields such as the sciences, engineering, business, management and many others. Simulation techniques have been used to study a wide variety of problems and complex physical phenomena such as traffic congestion, the spread of public health epidemics, weather forecasting, the performance of financial markets, military operations, emergency response scenarios, the quality of product or duration of an industrial or manufacturing process, etc., etc. Simulation has been used to solve mathematical problems for which a direct solution is impractical.

If the processes being **simulated** involve an element of probabilistic behavior (random chance) the simulation is referred to as **Monte Carlo simulation**. Many complex and large-scale engineering problems are amenable to Monte Carlo simulation due to the fact that the simulation technique can handle large numbers of **random variables**, numerous statistical distributions, and nonlinear mathematical models.

Monte Carlo simulation is useful in situations where direct experimentation of a system or process is impractical, infeasible, time or cost prohibitive, or simply impossible. For example, it is not possible to conduct an experiment on the spread or impacts of a highly contagious disease outbreak on a large or densely populated U.S. city. Likewise, it would be impractical or time prohibitive for a light bulb manufacturer to test a large sample of a product over the product's entire design life. In Monte Carlo simulation, the experimentation is conducted rapidly and many times over on a computer using a simulation model. The incorporation of random variables in the simulation model to describe the discret elements of the system or process enables many multiple scenarios of the system or process to be modelled, thus synthesizing model output data. The model output data set is then analyzed by appropriate statistical methods, to draw conclusions and to make decisions and recommendations about the system or process.

Thus, Monte Carlo simulation enables one to see all possible outcomes of a process and make decisions that take into account the probability (uncertainty or risk) associated with the discrete elements of the process.

#### 2.2 Illustration of a Simulation Model

In this section a very simple example shall be used to illustrate a Monte Carlo simulation model.



Consider a small local contractor hired to prepare a site for a national company to come in and build a luxury apartment complex. The local contractor's activities, or work items, include clearing the site and setting up trailers for site offices and other facilities. The contractor breaks down the project into the following discrete tasks in sequential order, and their estimated completion times.

	Work Item	Description	Completion Time (days)	
1	Clearing and	Clear the site of vegetation, pull tree	10	
1.	Grubbing	stumps, and remove all debris.	10	
2	Furnish and install	Supply trailers and all ancillary work to	5	
۷.	trailers	complete installation.	5	
3	Connect services	Hook up power, utilities, and	7	
5.	Connect services	telecommunication services	,	
Δ	Furnish and install	Install bathrooms, kitchenette equipment,	4	
т.	interior amenities	office furniture, security devices	<u>т</u>	
5.	Final cleanup	Final cleanup of interior and exterior	2	
	Project completion		28	

The completion times are based on the local contractor's recent experience with similar projects, clients and suppliers. In this approach, the local contractor considers these times to be set and fixed to yield the overall project completion time. This is called a **deterministic** approach. Prior to any knowledge or experience in Monte Carlo methods, the deterministic approach would be the intuitive approach to handle this type of problem.

The fact that the deterministic approach considers the work items' completion times to be set and fixed is a major weakness of the approach. Practically, all of the work items' completion times are inherently **random** to varying degrees. For example, the completion of the clearing and grubbing is subject to randomness (or **uncertainty**) due to factors such as weather, equipment reliability, availability and punctuality of earth moving equipment and the operators, etc. etc. The work item to furnish and install the trailers is subject to randomness due to traffic conditions, availability or schedule of escort vehicles required to accompany the truck(s) that bring the

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trailer(s) to the site, as well as the randomness associated with obtaining the permits from governmental agencies to convey oversized cargo on state roads. Once the trailer(s) reaches the site, further uncertainty may be due to soil conditions that may slow down (or speed up for that matter) the process of anchoring and securing the trailer(s). There is also randomness associated with the quality of the workmanship, or lack thereof that may necessitate rework or additional inspections prior to approval. The uncertainty associated with each work item contributes to the uncertainty associated with the overall project completion time. The degree of uncertainty is called **risk**, and exposes the local contractor to potential unfavorable outcomes, particularly financial loss.

It is therefore justified to take a **probabilistic** approach to the analysis in order to incorporate the uncertainty associated with each work item's completion time. This can be done by describing each work item's completion time with an appropriate **random variable** (also called a **probability distribution**). The work items' completion times can be given at certain probabilities based on the appropriate probability distribution for that work item. Overall project completion times can then be determined at given probabilities. The local contractor can now select an acceptable level of uncertainty (or risk) and reach a more informed conclusion regarding the project completion time.

Using assumed probability distributions, the work items' completion times for this project can be described probabilistically as follows



	Work Item	Probability Distribution	Completion Time (days)
1.	Clearing and Grubbing	Normal distribution Parameters: Mean $(\mu) = 10$ Standard deviation $(\sigma) = 3$	C.14 Augree of the second sec
2.	Furnish and install trailers	Uniform distribution Parameters: $\alpha = 3$ $\beta = 7$	0.30 0.25 0.30 0.30 0.30 0.35 0.30 0.35 0.30 0.35 0.30 0.35 0.30 0.35 0.30 0.35 0.30 0.35 0.30 0.35 0.30 0.35 0.30 0.35 0.55
3.	Connect services	Normal distribution Parameters: Mean ( $\mu$ ) = 7 Standard deviation ( $\sigma$ ) = 1.5	0.30 0.25 0.10 0.15 0.00 0 5 10 15 20 completion time (days)
4.	Furnish and install interior amenities	Uniform distribution Parameters: $\alpha = 2$ $\beta = 6$	0.30 0.25 0.20 0.15 0.10 0.06 0.00 0 1 2 3 4 5 6 7 completion time (days)
5.	Final cleanup	Uniform distribution Parameters: $\alpha = 1$ $\beta = 3$	0.60         0.50         0.00           0.40         0.30         0.00           0.20         0.10         0.00           0.10         0.00         0.10           0.00         1         2         3         4         5         6         7           completion time (days)
	Total (J	$\sum$ (completion times)	

# Figure 2. 1: Framework for simulation



To generate a possible scenario for a particular work item's completion time, the contractor can randomly pick a probability value and read off the completion time from the probability distribution graph (or calculate it from the graph function). The process is repeated for each work item, and the project completion time for the scenario is the aggregate of the individual completion times obtained. This process can now be replicated several times over to synthesize a data set of project completion times. The project completion time data can be analyzed to obtain the descriptive statistics, quartiles and percentiles, or other statistical measures which are used for appropriate decision making.

Although it is not a required prerequisite for this course, it will be helpful if readers take a moment to review and refresh their knowledge on random variables and statistical distributions. An earlier part of this course series provides a preparatory in-depth presentation of those topics.



# **3. THE SIMULATION PROCEDURE**

# 3.1 Monte Carlo Simulation

The Monte Carlo simulation procedure can be concisely described by the following steps.

Step 1:

Take the first work item, which is a random variable (X), guess a random probability value (F). Use the inverse cumulative density function (also known as the percent point function or the quantile function) of the random variable that describes the work item (X), to determine the corresponding value (x) (an actual completion time) of the random variable (X) for that probability value (F).

Step 2: Repeat Step 1 for each of the other work items.

Step 3:

Sum the x values (completion times) to generate the overall completion time for the current simulation (or iteration).

Step 4:

Repeat Step 1 through Step 3 (n - 1) times to synthesize a dataset of completion times of size n for the n simulations conducted.

# Step 5:

Compute statistical measures for the synthesized completion time dataset, such as mean, median, standard deviation, quartiles, percentiles etc.

Use the statistical measures to make conclusions, recommendations, decisions etc., based on engineering performance criteria, industry standards, regulatory requirements, business and financial considerations etc., etc.

It is pertinent to note that in practice, the number of simulations (n) needed to be conducted is not subject to hard and fast rules. It is determined by judgement or experience, based on factors such as the type and complexity of the system being simulated, as well as the complexity of the breakdown of the work items, which itself may be driven by the available data. A small-scale civil engineering model may use a few hundred or a few thousand simulations, whereas a large-



scale mechanical system may need several hundred-thousand simulations to synthesize good data for appropriate decision making.

The Monte Carlo simulation procedure can be depicted as follows.



Figure 3. 1: Monte Carlo simulation procedure



Conducting the Monte Carlo procedure by hand in a tabular format will be of the following structure.

Simulation	Activity 1	Activity 2	Activity 3	 Completion Time
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	Distribution: Parameters, Quantile function	Distribution: Parameters, Quantile function	Distribution: Parameters, Quantile function	
	guess probability $F_{11}$	guess probability $F_{12}$	guess probability $F_{13}$	
1.	calculate duration $x_{11}$	calculate duration $x_{12}$	calculate duration $x_{13}$	 $T_1 = \sum x_{1i}$
2	guess probability $F_{21}$	guess probability $F_{22}$	guess probability $F_{23}$	
2.	calculate duration $x_{21}$	calculate duration $x_{22}$	calculate duration $x_{23}$	 $T_2 = \sum x_{2i}$
3	guess probability $F_{31}$	guess probability $F_{32}$	guess probability $F_{33}$	
5.	calculate duration $x_{31}$	calculate duration $x_{32}$	calculate duration $x_{33}$	 $T_3 = \sum x_{3i}$
:	:	:	:	 :
	guess probability $F_{n1}$	guess probability $F_{n2}$	guess probability $F_{n3}$	
п.	calculate duration $x_{n1}$	calculate duration $x_{n2}$	calculate duration $x_{n3}$	 $T_n = \sum x_{ni}$

#### Figure 3. 2: Monte Carlo simulation tabulation



The synthesized completion times  $(T_j)$  can now be analyzed using appropriate statistical measures from which conclusions, recommendations, decisions, etc., can be made.



# 4. MONTE CARLO SIMULATION IN EXCEL

# 4.1 Implementation in *Excel*

In this section, the site clearing project described in Section 2.2 shall be implemented in a Monte Carlo simulation model, in Microsoft *Excel* following the tabulated framework depicted in Figure 3.2. The details of the project activities and their descriptions and statistical parameters are shown in Figure 2.1.

Open a new session of *Excel*.

Set up the following headers for the first work item, Activity 1: Clearing and Grubbing.

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ATTENTION! Due to the random nature of the output generated by the RAND function, one may get a completely different value than shown in this demonstration. Also, one will notice the random value changes intermittently automatically whenever some other operation is conducted elsewhere on the spreadsheet. For now, both of the above are normal and not a problem. Do not be alarmed. The focus for now is on the procedure and implementation of the simulation model.



The next task is to call the inverse cumulative density function (also known as the percent point function or quantile function) of the distribution that describes the random behavior of the activity, to calculate the x value (completion time of the activity) corresponding to the random probability value F previously generated. This first activity is described by the Normal distribution.

With the cursor in the x value cell, begin typing "NORMAL" to activate a candidate list of relevant functions.

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For the **mean** value, point and click on the mean value.

Hit **F4** on the keyboard.

Type a comma (",").

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The **F4** button is used to make the cell reference to the mean value an **Absolute Reference**. This will prevent the mean value cell reference from changing, albeit inadvertently, later when the formula is copied and replicated down the table for the subsequent simulations.



For the **standard\_dev** value, point and click on the standard deviation value.

Hit  $\mathbf{F4}$  on the keyboard.

Type a comma (",").

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Close parenthesis. Hit **Enter** on the keyboard. The x value is calculated.

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Note that the original random number has changed, but due to the cell referencing used in the NORM.INV calculation, the corresponding value (x) for the current probability value (F) is computed and displayed.

This result, stated in ordinary language, is that there is 0.136 probability that the activity will be completed in less than or equal to 6.709 days. Or one could say there is 0.136 probability that the activity's completion time will not exceed 6.709 days. (Again! The actual values you get may be completely different from those depicted here due to the random numbers being generated and passed into the formula).



One may now explore other scenarios (or simulations) of the activity completion time based on other random probability values.

Select the F and x values previously calculated. Hover over the bottom right border of the selection. The cursor will change from a thick plus sign to a thinner plus sign.

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With the thinner plus sign on the bottom right corner of the selection, click and hold the click down.

Drag the cursor down a few rows.

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Release the click.

The original formulas/ calculations are replicated down the sheet.

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The process of selecting cells, and then clicking, holding down and dragging to replicate the formulas/ contents of the cell is the *Excel* technique called **fill handling**.

Review the probabilities (F) of the completion times (x) of the scenarios (simulations) generated. Again, one may obtain completely different numbers than depicted due to the random numbers being generated and passed into the formulas. Again, notice that the original random value has changed, again. Again, this is not a problem to worry about, the focus is on the procedure and implementation of the simulation model.

Save your work.



At this time, it is pertinent for readers to note that the random numbers generated by the *Excel* RAND function are actually not truly random. They are the best "random" numbers *Excel* can provide. The "random" numbers are being pulled from a Uniform distribution. The "randomness" of the values can be improved by changing the random seed settings of the *Excel* program. (Adjusting the random seed settings is beyond the scope of this course and participants are encouraged to research this issue on their own). Adjusting the *Excel* random seed generator will yield some improvement, but it still does not make the "random" numbers truly random. Henceforth "random" numbers generated by the *Excel* program will be better described as **pseudo-random numbers**.

Revert to the simulation spreadsheet.

Set up the headers for Activity 2: Furnish & Install Trailers.

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This Activity 2 completion time is described by a Uniform distribution with parameters  $\alpha = 3, \beta = 7,$ 

where the probability of any x in  $[\alpha, \beta]$  equals  $1/(\beta - \alpha)$ 

and the probability of any x not in  $[\alpha, \beta]$  equals zero.

Thus, the density function of the Uniform distribution is a horizontal line.

The cumulative density of a value x in  $[\alpha, \beta]$  is the rectangular area under the density function from  $\alpha$  through x.



Therefore, for a pseudo-random cumulative probability value *F*,  $x = \alpha + F(\beta - \alpha)$ 



On the spreadsheet, generate a pseudo-random value F.

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#### Hit **Enter** on the keyboard.

Enter the formula for the corresponding x value from the uniform distribution of the activity as follows,



Type " = "

Click on the cell holding the  $\alpha$  value.

Hit **F4** on the keyboard to make the reference to the  $\alpha$  value an absolute reference.

Type " + "

Click on the cell holding the *F* value.

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Click on the cell holding the  $\beta$  value.

Hit **F4** on the keyboard to make the reference to the  $\beta$  value an absolute reference.

Type " - " (minus sign).

Click on the cell holding the  $\alpha$  value.

Hit **F4** on the keyboard to make the reference to the  $\alpha$  value an absolute reference.

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Hit **Enter** on the keyboard to implement the formula.

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The results appear to be normal and reasonable.

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Activity 3 is described by a Normal distribution. Therefore, to save effort, we may copy over Activity 1 and update the statistical parameters and other input data.



Select the Activity 1 data. Press the Copy icon.

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13	0.733697209	11.87210051	0.703452668	5.813810671									
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12		0.687837749	11.46919199	0.558608272	5.2344330	0.262140458	8.089718763							
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Update the data accordingly for Activity 3.

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12		0.61604456	10.88532596	0.601531827	5.40612730	9 0.882823509	13.56766095					
13		0.659038537	11.22952162	0.564702437	5.25880974	7 0.849518802	13.10311532					
14		0.341165408	8.772146205	0.92496116	6.6998446	4 0.066544304	5.493901249					
15		0.868730831	13.36123527	0.05754301	3.2301720	4 0.829108538	12.851945					
16		0.363313431	8.951151844	0.811546253	6.24618501	1 0.742780937	11.95582815					
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Activity 4 is described by a Uniform distribution. Therefore, to save effort, we may copy over Activity 2 and update the statistical parameters and other input data, as follows.

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9	0.687873843	11.469498	0.448962301	4.795849204	0.666705544	11.2925026	0.26094909	4.043796362					
10	0.146110455	6.840213872	0.58376816	5.335072642	0.089164477	5.96224591	0.253852112	4.015408447					
11	0.103239744	6.210084149	0.225703308	3.902813232	0.418770048	9.38487701	0.718978716	5.875914866					
12	0.969056253	15.60130282	0.23995946	3.959837841	0.152765092	6.9260615	0.591009682	5.364038726					
13	0.440616258	9.551779103	0.551984397	5.207937587	0.984701667	16.4868374	0.948855958	6.795423834					
14	0.601385203	10.7708025	0.357610037	4.430440148	0.915222386	14.1209030	0.790351774	6.161407098					
15	0./5189/698	12.04142093	0.928068035	6./122/2139	0.425303635	9.43496904	0.055696698	3.222/86/93					
10	0.991196005	17.12128014	0.253249433	4.012997733	0.77984952	12.3150552	0.107238951	3.428955803					
10	0.330733087	8.733817891	0.805588351	0.479903004	0.247907749	7.93730340	0.992537918	0.970131072					
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Activity 5 is described by a Uniform distribution. Therefore, to save effort, we may copy over Activity 4 and update the statistical parameters and other input data, as follows.

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5	Mean	Std Dev	Alpha	Beta	Mean	Std Dev	Alpha	Beta	Alpha	Beta			
7	10	3	3	/	/	1.5	2	0	1	3			
8	F	x	F	x	F	x	F	x	F	x			
9	0.58821862	10.66889495	0.011014464	3.044057854	0.842434463	13.01354108	0.104533536	3.41813414	0.192210805	3.768843218			
10	0.778560995	12.30202698	0.785018818	6.140075271	0.276668072	8.221694734	0.690489707	5.76195882	0.831344379	6.325377517			
11	0.594574548	10.71798536	0.693505628	5.774022511	0.488319631	9.912152417	0.12021242	3.48084967	0.376405555	4.505622219			
12	0.696402379	11.54224351	0.94796467	6.79185868	0.66079244	11.24388043	0.382014327	4.52805730	0.980460338	6.921841351			
13	0.741528976	11.944199	0.003910834	3.015643337	0.745033934	11.97683012	0.090890036	3.36356014	0.966851792	6.867407169			
14	0.56471914	10.48883507	0.698825778	5.795303114	0.551004631	10.38459986	0.877751268	6.51100507	0.861876498	6.447505992			
15	0.769481731	12.21142335	0.892502425	6.570009698	0.483398844	9.875125169	0.429501153	4./1800461	0.062194892	3.248//9568			
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The activities' simulations are now implemented. Additional simulations may be added by fill handling down the spreadsheet as needed.

The next step is to calculate the overall project completion time for a simulation, and then replicate this calculation for the multiple simulations conducted, to synthesize a dataset of the simulated project completion times that will be analyzed statistically to reach the conclusions, recommendations and decisions of the simulation study.



Add a header for the project completion time.

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9	0.691988235	5.767952941	0.913399807	14.08597623	0.316522259	4.200089030	0.912033214	6.64813285 5.2022772	/ c					
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12	0.951349345	6 805397382	0.01035131	9 454725432	0.075531804	3 302127022	0.330331322	4 98030877	2					
13	0.657042201	5.628168806	0.588466174	10.67080352	0.436664053	4.746656211	0.350428295	4.4017131	8					
14	0.633813611	5.535254443	0.854040806	13.16176758	0.967090074	6.868360295	0.41329187	4.65316748	2					
15	0.073052176	3.292208705	0.236281978	7.845059244	0.057105566	3.228422262	0.375518482	4.50207392	9					
16	0.269539561	4.078158244	0.826295807	12.81888413	0.91192363	6.64769452	0.051106219	3.20442487	4					
17	0.739442402	5.957769609	0.606044175	10.8070703	0.065747672	3.262990686	0.34615411	4.38461643	9					
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Enter an addition formula that sums the completion time (x) values of Activity 1 through Activity 5 of the first simulation.

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9	0.691988235	5.767952941	0.913399807	14.08597623	0.316522259	4.266089036	0.912033214	6.6481328	7	=C9+F9+G9+I9+K9				
10	0.448348148	4.793392593	0.659471918	11.23306698	0.928027877	6.712111508	0.57334434	5.2933773	6	0.00.00.00.00				
11	0.11919338	3.476773522	0.81659131	12.70735278	0.107531406	3.430125622	0.996991522	6.98796608	39	_				
12	0.951349345	6.805397382	0.427886249	9.454725432	0.075531804	3.302127217	0.495077193	4.98030877	72	_				
13	0.657042201	5.628168806	0.588466174	10.67080352	0.436664053	4.746656211	0.350428295	4.4017131	18					
14	0.633813611	5.535254443	0.854040806	13.16176758	0.967090074	6.868360295	0.41329187	4.65316748	32					
15	0.073052176	3.292208705	0.236281978	7.845059244	0.057105566	3.228422262	0.375518482	4.50207392	29					
16	0.269539561	4.078158244	0.826295807	12.81888413	0.91192363	6.64769452	0.051106219	3.20442487	74					
17	0.739442402	5.957769609	0.606044175	10.8070703	0.065747672	3.262990686	0.34615411	4.38461643	39					
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The overall project completion time for the first simulation is computed.

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9	0.26103394	4.044135758	0.31100842	8.521018054	0.472562414	4.890249656	0.06471363	3.25885451	.8	28.90940988				
10	0.897842145	6.59136858	0.78605997	12.3784736	0.941182059	6.764728236	0.423111928	4.6924477	1					
11	0.409064814	4.636259256	0.233492357	7.817818415	0.773353753	6.093415013	0.88748367	6.54993468	1	_				
12	0.515052588	5.060210352	0.852833352	13.14598869	0.469437335	4.8///49339	0.3934118//	4.5/364/50	·/					
13	0.615020216	5.460080864	0.646889631	10.10520014	0.079307055	3.31/228219	0.772439304	0.089/5/21	.5					
14	0.480902434	4.923009730	0.321900101	7 9607056	0.839903302	6.339013447	0.400403418	4.84185307	0					
15	0.103923139	5.642902771	0.238100881	7.8027230	0.333817748	4 210602209	0.41/01209/	4.07043078	7					
17	0.3/17371806	1 289/87225	0.559625312	10 45005795	0.19116031	3 764641239	0.370346379	6 28536736	6	_				
18	0.347371000	4.303407223	0.000020012	10.45003755	0.19110031	3.70-041233	0.021341042	0.20030730		_				
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Select the first project completion time. Fill handle a few rows. Review the results.

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9	0.226272614	3.905090456	0.568963234	10.52120576	0.000649273	3.002597091	0.234458044	3.937832174	4	29.50911395			
10	0.568335315	5.273341259	0.733004575	11.86577653	0.419988014	4.679952055	0.281809599	4.12723839	7	34.52424948			
11	0.018757523	3.075030091	0.890708427	13.69091312	0.914894698	6.659578794	0.238527155	3.954108619	9	41.40882226			
12	0.636578562	5.54631425	0.199393293	7.468629045	0.331890173	4.327560692	0.337189634	4.348/58538	8 7	35.27694992			
14	0.740000000	5.05904166	0.262425104	0.370312044	0.400728553	4.842914211	0.008775339	5 51910707	1	20.93094002			
15	0.292559597	A 574228288	0.870056326	12 27997229	0.100249293	5.424557175	0.029549209	A 72207706	+ 5	36 86085233			
16	0.321184509	4.374238388	0.496704943	9 975221273	0 1334176	3 533670401	0.624816605	5 4992664	2	36 27941312			
17	0.97525835	6.901033402	0.447974651	9.607659839	0.741700193	5.96680077	0.436438353	4,74575341	3	40.34127849			
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We will now like to run 2,000 simulations of this system. In other words, we shall investigate 2,000 possible scenarios of this project, taking into account the random outcomes of the project's constituent activities.

Select the entire row of the last simulation.

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_	0.26789104	8.14238848	0.22627261	3.90509046	0.56896323	10.5212058	0.00064927	3.00259709	0.23445804	3.93783217		29.50911395	
	0.31774297	8.57794124	0.56833531	5.27334126	0.73300458	11.8657765	0.41998801	4.67995206	0.2818096	4.1272384		34.52424948	
	0.91037435	14.0291916	0.018/5/52	3.07503009	0.89070843	13.6909131	0.9148947	6.65957879	0.23852715	3.95410862		41.40882226	
-	0.88400124	13.5856874	0.63657856	5.54631425	0.19939329	7.46862905	0.33189017	4.32756069	0.33718963	4.348/5854		35.27694992	
	0.13/5/6/6	6.72618603	0.7406066	5.96242638	0.11315944	0.37031264	0.46072855	4.84291421	0.00877534	5.03510136		26.93694062	
	0.55509528	8 00656022	0.31473542	1 57422820	0.30243519	12 2700722	0.10624929	5.42499718	0.02954927	4 72207707		35.19540810	
	0.8402548	12 986517	0.33333350	4.28473804	0.49670494	997522127	0 1334176	3 5336704	0.43031327	5 49926642		36 27941312	
I	0.85083246	13 1200311	0.97525835	6 9010334	0.43070434	9.60765984	0.74170019	5 96680077	0.43643835	4 74575341		40 34127849	
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1995	0.35140624	8.85541994	0.94047855	6.76191421	0.90787009	13.983258	0.94795982	6.79183928	0.59773178	5.39092713		41,7833585	
1996	0.56908052	10.5221012	0.80839351	6.23357405	0.7965472	12.4880541	0.3933252	4.57330081	0.32913275	4.31653101		38.1335612	
1997	0.68003465	11.4033871	0.27343529	4.09374116	0.58367575	10.633918	0.54307907	5.17231627	0.30807545	4.23230181		35.5356643	4
1998	0.3546317	8.88146332	0.09336018	3.3734407	0.80540776	12.5832917	0.42435939	4.69743755	0.79915057	6.19660226		35.7322355	is.
1999	0.25192521	7.99466893	0.05496096	3.21984385	0.22388781	7.72261419	0.19798696	3.79194783	0.32825353	4.3130141		27.0420888	15
2000	0.75532309	12.0740108	0.97001458	6.88005832	0.67015665	11.3210373	0.57746641	5.30986564	0.56911184	5.27644736		40.8614194	LE .
2001	0.86021031	13.2437941	0.39315103	4.57260411	0.35216581	8.86156067	0.36418446	4.45673785	0.38641695	4.5456678		35.6803645	62
2002	0.85304175	13.1487059	0.25109801	4.00439204	0.91791542	14.1735567	0.27327301	4.09309202	0.58953719	5.35814878		40.7778954	15
2003	0.43334119	9.49637788	0.23416412	3.93665648	0.10258371	6.19910175	0.08967874	3.35871496	0.73256617	5.9302647		28.9211157	a -
2004	0.11475022	6.39505996	0.74593645	5.9837458	0.9722232	15.7435636	0.44364167	4.77456668	0.27266625	4.09066499		36.98760	p:
2005	0.62366812	10.9453868	0.95180518	6.8072207	0.50108633	10.0081691	0.23899135	3.9559654	0.71456792	5.85827168		37.5750136	ić.
2006	0.5596176	10.4499993	0.25817688	4.03270754	0.6267609	10.9698598	0.2028283	3.81131319	0.65640231	5.62560923		34.8894890	12
2007	0.96251794	15.3420513	0.5126198	5.0504792	0.65678409	11.2111062	0.73134816	5.92539266	0.74138822	5.96555286		43.4945822	4
2008	0.50808224	10.0607817	0.1380657	3.55226281	0.90018707	13.8478546	0.02348293	3.09393173	0.24254978	3.97019913		34.5250300	12
2009	0.93015979	14.4309465	0.43923981	4.75695923	0.49128801	9.93448166	0.04998853	3.1999541	0.82819987	6.31279947		38.6351409	6
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To obtain a stable dataset (that does not continuously, automatically update itself due to the random number function), select the synthesized project completion times.

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9	0.570454185	10.33239181	0.531375283	3.123301131	0.753313004	6 659552197		33.50070131				_
11	0.651324073	11 16669297	0.437344303	4.331778037	0.314038237	4 720096092		37,32313328				_
12	0.360905276	8 931879767	0.210547553	3 842190214	0.84569643	6 382785722		35 32893183				
13	0.659789583	11.2356668	0.670627355	5.682509419	0.773740804	6.094963217		38.58991509				
14	0.968847422	15.59235357	0.329182154	4.316728616	0.792757928	6.171031711		32.49151062				
15	0.91276772	14.07399173	0.494553716	4.978214865	0.699196818	5.796787272		38.24574571				
16	0.521934027	10.16502454	0.545399496	5.181597983	0.035182191	3.140728764		38.93808826				
17	0.977237704	15.99932427	0.51492359	5.05969436	0.349575482	4.398301928		38.78544321				
18	0.163827068	7.063450221	0.052256219	3.209024875	0.504639739	5.018558957		33.83015021				
19	0.931997768	14.47250907	0.341058726	4.364234905	0.958605522	6.834422087		43.6542277				
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11	0.575202511	11 16669297	0.497944309	4.551776037	0.514036257	4 720096092		1 37.32313320				
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13	0.659789583	11.2356668	0.670627355	5.682509419	0.773740804	6.094963217		38,58991509				
14	0.968847422	15.59235357	0.329182154	4.316728616	0.792757928	6.171031711		32.49151062				
15	0.91276772	14.07399173	0.494553716	4.978214865	0.699196818	5.796787272		38.24574571				
16	0.521934027	10.16502454	0.545399496	5.181597983	0.035182191	3.140728764		38.93808826				
17	0.977237704	15.99932427	0.51492359	5.05969436	0.349575482	4.398301928		38.78544321				
18	0.163827068	7.063450221	0.052256219	3.209024875	0.504639739	5.018558957		33.83015021				
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16	0.521934027	10.16502454	0,545399496	5,181597983	0.035182191	3,140728764		38,93808826			
17	0.977237704	15.99932427	0.51492359	5.05969436	0.349575482	4.398301928		38,78544321			
18	0.163827068	7.063450221	0.052256219	3.209024875	0.504639739	5.018558957		33.83015021			
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12	0.360905276	8.931879767	0.210547553	3.842190214	0.84569643	6.382785722		35.32893183			
13	0.659789583	11.2356668	0.670627355	5.682509419	0.773740804	6.094963217		38.58991509			
14	0.968847422	15.59235357	0.329182154	4.316728616	0.792757928	6.171031711		32.49151062			
15	0.91276772	14.07399173	0.494553716	4.978214865	0.699196818	5.796787272		38.24574571			
16	0.521934027	10.16502454	0.545399496	5.181597983	0.035182191	3.140728764		38.93808826			
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A stable (non-changing) dataset of completion times values is obtained.

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9	0.948012356	14.87763856	0.904695369	6.618781476	0.129294226	3.517176902		40.34536505	33.50076131		
10	0.635285057	11.03765203	0.98788607	6.95154428	0.816239396	6.264957585		40.78662515	37.52915528		
11	0.740991742	11.93921772	0.46687808	4.867512318	0.833257883	6.333031533		37.08344154	37.79838685		
12	0.88817922	13.65070557	0.471050765	4.884203061	0.559555022	5.238220088		36.95008193	35.32893183		
13	0.221588467	7.69948143	0.312405457	4.249621827	0.25920828	4.036833121		29.14437913	38.58991509		
14	0.705633118	11.62201564	0.955762549	6.823050198	0.8/10/9912	6.484319649		35.24968682	32.49151062		
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18	0.0463151	4.954949053	0.122237087	3.488948348	0.462604116	4.850416465		26.27984981	33.83015021		
19	0.915703281	14.13021233	0.615346411	5.461385642	0.094729989	3.378919955		43.83889087	43.6542277		
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The next step is to compute statistical measures that shall serve as the performance measures for this simulation study. For the purposes of this exercise, the following statistical measures shall be computed.

- Mean
- Standard Deviation
- Median
- 3<sup>rd</sup> Quartile
- 95% Percentile

Add a summary table to the spreadsheet as follows.

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9	3.75291059	0.256179317	4.024717269		34.480415	33.50076131								
10	5.379125484	0.479309107	4.917236429		42.55374564	37.52915528								
11	5.361904144	0.43285761	4.731430439		39.65036979	37.79838685								
12	0.499918704	0.725014899	5.900059597		40.52991259	35.32893183								
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15	6 3893052	0.448704444	4 794817776		35 77713283	38 24574571								
16	6.272159322	0.642249596	5 568998386		34,19571824	38,93808826								
17	6.046813053	0.202262489	3.809049954		28.37533525	38,78544321								
18	4.426441144	0.132931835	3.531727339		39.6919368	33.83015021								
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13	4.495417044	0.920496984	6.681987936		44.65710596	38.58991509		🕭 AVER	AGEIFS				
14	6.36456768	0.729385717	5.917542868		42,98661614	32,49151062							
15	4.854028148	0.540536875	5.162147498		32.23231063	38.24574571							
16	3.427960817	0.172347712	3.689390848		42.35433694	38.93808826							
17	4.976510313	0.242365438	3.969461751		34.61025812	38.78544321							
18	5.559627182	0.670086078	5.680344311		35.58277768	33.83015021							
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13	6.866437841	0.037470435	3.149881741		31,29419445	38.58991509							
14	4.751011813	0.504729484	5.018917936		34,64148919	32,49151062							
15	3.473309006	0.800873081	6.203492324		32.37745018	38.24574571							
16	3.537816466	0.702842952	5.811371807		27.70039608	38.93808826							
17	6.487195749	0.872832927	6.491331709		39.30619195	38.78544321							
18	4.379751175	0.47233234	4.889329362		28.45855597	33.83015021							
19	4.317897825	0.268506018	4.074024071		38.51402723	43.6542277							Ψ.
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1994	4.036986217	0.148885528	3.595542111		27.33515909	38.19956683						
1995	3.340768325	0.35216783	4.408671319		27.01643214	41.78335858		AVERAGE	(number1, [nu	mber2],)		
1996	5.961535011	0.826336168	6.305344671		37.0527511	38.13356122						
1997	5.209315693	0.389834127	4.559336507		38.23515626	35.53566434						
1998	6.822761556	0.580035372	5.320141487		34.9687994	35.73223559						
1999	6.761835955	0.26855698	4.07422792		33.19186499	27.04208889						
2000	3.464949417	0.844063918	6.376255673		38.32601965	40.86141945						
2001	3.763271255	0.689158019	5.756632074		37.46839046	35.68036452						
2002	3.582933882	0.861422373	6.445689494		43.15526428	40.77789545						
2003	3.552492997	0.627245874	5.508983497		44.44562213	28.92111577						
2004	6.108331736	0.948260449	6.793041797		39.52146571	36.987601						
2005	6.168867166	0.384269322	4.537077287		35.86613183	37.57501363						
2006	6.158671378	0.23147507	3.925900279		41.19698817	34.88948902						
2007	4.059830208	0.495352959	4.981411838		34.05032219	43.49458224						
2008	4.479143634	0.995652866	6.982611464		37.06571128	34.52503001						
2009	4.997129613	0.482643803	4.930575213		36.57243831	38.63514097						
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14	6.937573497	0.646957963	5.58783185		38.31640598	32,49151062							
15	3.476011158	0.393610133	4.574440532		41,75941686	38.24574571							_
16	3.591448486	0.720885636	5.883542543		29.14609946	38.93808826							
17	3.966796217	0.075852722	3.30341089		21.54381861	38.78544321							
18	4.308598581	0.481426995	4.925707979		31.79634638	33.83015021							
19	6.048591894	0.473828295	4.895313179		40.75598698	43.6542277							
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**Standard Deviation** 

## Type "=STANDARD" Select, and then double click on STDEV.S Select your "stable" completion times data.

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9	3.718692629	0.507793378	5.031173513		39.78171475	33.50076131			STDEV.S	(number1, [r	number	2],)	
10	3.630543449	0.816392761	6.265571046		31.78075973	37.52915528							
11	3.846806387	0.669701272	5.678805087		33.41630377	37.79838685							
12	4.305268491	0.347768631	4.391074524		32.82357977	35.32893183							
13	6.067485665	0.125120652	3.500482607		33.62743999	38.58991509							
14	6.93/5/349/	0.046957963	5.58/83185		38.31640598	32.49151062							
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17	3.966796217	0.075852722	3.30341089		21.54381861	38.78544321							
18	4.308598581	0.481426995	4.925707979		31.79634638	33.83015021							
19	6.048591894	0.473828295	4.895313179		40.75598698	43.6542277							
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Hit **Enter** on the keyboard.

The standard deviation of the completion times is computed and displayed.

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12	4.175810724	0.720455483	5.88182193		36,96573817	35.32893183							_	
13	3.394503481	0.850550907	6.402203628		39.12522473	38.58991509								
14	4.938499667	0.521589971	5.086359883		31.17445809	32.49151062								
15	6.258014282	0.843708086	6.374832343		29.92668093	38.24574571								
16	4.256872464	0.030838052	3.123352209		33.49604305	38.93808826								
17	6.974776246	0.357822626	4.431290504		36.57217344	38.78544321								
18	5.35679542	0.004267941	3.017071765		30.13816201	33.83015021								
19	4.188892805	0.62015097	5.48060388		41.14578166	43.6542277							[	Ŧ
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Thus, on the "average" the completion times deviate from the mean value by 4.62 days.



#### Median

The median is a value such that half (or 50%) of the data values are less than it, and 50% of the data is greater than it. Thus, there is a 50% probability that the project completion time will be less than this value and a 50% probability that the project completion time will be greater than this value.

Type "=MEDIAN" Select, and then double click on MEDIAN

Select your "stable" completion times data.

Close parenthesis.

Hit **Enter** on the keyboard.

The median completion time is computed and displayed.

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10	3.511657189	0.209091173	3.836364691		45.03498559	37.52915528								
11	3.508916752	0.791316684	6.165266737		36.82654062	37.79838685								
12	6.853049171	0.783176283	6.132705134		33.506848	35.32893183								
13	4.639488288	0.714759909	5.859039638		38.01763727	38.58991509							_	
14	3.767735996	0.819990345	6.279961381		33.15173664	32.49151062								
15	3.910101741	0.642900678	5.571602711		33.47088595	38.24574571								
16	3.143480871	0.412440734	4.649762937		31.69997246	38.93808826								
10	5.2/5344642	0.284147608	4.130390433		35.0220/010	38.78344321 22.92015021								
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## <u>3<sup>rd</sup> Quartile (also called the Upper Quartile)</u>

The 3<sup>rd</sup> quartile is a value such that three-quarters (or 75%) of the data values are less than it. Thus, there is a 75% probability that the project completion time will not exceed this value.

### Type "=QUARTILE"

Select, and then double click on QUARTILE.INC (note that QUARTILE.EXC also computes quartiles by using a different *Excel* algorithm).

For the **array** argument, select your "stable" completion times data.

Type a comma (",")

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9	4.74935	5951	0.575932771	5.303731085		32.047156	33.50076131					QUART	ILE.INC(array, quar	:)	0 - Minimum value
10	3.51165	7189	0.209091173	3.836364691		45.03498559	37.52915528							()	1 - First quartile (25th percentile)
11	3.50891	6752	0.791316684	6.165266737		36.82654062	37.79838685							()	2 - Median value (50th percentile)
12	6.85304	9171	0.783176283	6.132705134		33.506848	35.32893183							()	4 - Maximum value
13	4.63948	8288	0.714759909	5.859039638		38.01763727	38.58991509							1	
14	3.76773	5996	0.819990345	6.279961381		33.15173664	32.49151062							_	
15	3.91010	1741	0.642900678	5.571602711		33.47088595	38.24574571							-	
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## Engineering Methods in Excel A SunCam online continuing education course

For the **quart** argument, select, and then double click "Third quartile (75<sup>th</sup> percentile)"

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10	4.74555	7100	0.373932771	3.505751065		45 02409550	35.50070151								Image: 1	- Minimum value - First quartile (25th percentile)
11	3 50891	5752	0.203031173	6 165266737		36 82654062	37 79838685								🖂 2	- Median value (50th percentile)
12	6.85304	9171	0.783176283	6.132705134		33,506848	35.32893183								<b>()</b> 3	- Third quartile (75th percentile)
13	4.63948	3288	0.714759909	5.859039638		38.01763727	38.58991509								<u>6</u> 4	- Maximum value
14	3.76773	5996	0.819990345	6.279961381		33.15173664	32.49151062									
15	3.91010	1741	0.642900678	5.571602711		33.47088595	38.24574571									
16	3.14348	0871	0.412440734	4.649762937		31.69997246	38.93808826									
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Close parenthesis. Hit **Enter** on the keyboard.



The 3<sup>rd</sup> quartile completion time is computed and displayed.

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11	4.590803186	0.881437821	6.525751283		40.38067296	37.79838685									
12	0.74476058	0.740230939	5.960923754		34.05720092	35.32893183									
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17	5.216185565	5 216185565 0 604264768 5 417059071			41.67763894	38.78544321									
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#### 95<sup>th</sup> Percentile

The 95<sup>th</sup> percentile is a value such that 95% of the data values are less than it. Thus, there is a 95% probability that the project completion time will not exceed this value. One is therefore 95% confident that the project will be completed by this time.

Type "=PERCENTILE"

For the **array** argument, select, and then double click on PERCENTILE.INC (note that PERCENTILE.EXC also computes percentiles by using a different *Excel* algorithm). Select your "stable" completion times data.

Type a comma (",")

For the **k** argument, type in "0.95"

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15	4.781532687	0.223783169	3.895132676		38.15113524	38.24574571									
16	3.496367846	0.408095591	4.632382364		32.75540119	38.93808826									
17	5.216185565	0.604264768	5.417059071		41.67763894	38.78544321									
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Hit **Enter** on the keyboard.

The 95<sup>th</sup> percentile completion time is computed and displayed.

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The next step is the analysis of the results, for making conclusions, recommendations or decision-making.

Many engineering fields have adopted various statistical measures such as those demonstrated above as criteria for reaching conclusions and decision-making. For example, in the field of traffic engineering, the posted speed limit on a roadway is based on the 85<sup>th</sup> percentile speed (except where the posted speed limit is prescribed by state law, for example, on the interstate highway system in the State of Florida). Another example from traffic engineering is the length of a left-turn lane at an intersection controlled by a traffic signal. Generally, the turn lane length is based on the 95<sup>th</sup> percentile vehicular queue length obtained from a simulation model.



For the construction site example, a deterministic approach using the estimated average duration of each constituent work item, the conclusion was that the project will be completed in 28 days. However, using a probabilistic approach and modeling the uncertainty associated with each constituent activity by some known probability distribution, and conducting 2,000 simulations, the average project completion time is 35 days, and furthermore there is a 95% probability that the project will be completed in no more than approximately 43 days.



## 5. SELECTING DISTRIBUTIONS FOR SIMULATION

### 5.1 Selecting a Probability Distribution

In the construction site project simulation, each constituent activity of the project was described, or modelled, by some known statistical distribution, such as the Normal distribution, the Uniform distribution, the LogNormal distribution etc. This leads to the question as to how the distributions were selected or justified. In other words, how does one know what distribution to pick or how does one confirm or otherwise, that a given theoretical distribution is suitable to describe the activity, based on data for that activity.

One cursory method of selecting a distribution or confirming a **distributional assumption** for an activity is to look at the shape of the histogram or frequency polygon of the data for the activity and compare it to the shape of the probability density function of the theoretical candidate distribution.

[A comprehensive presentation of histograms, frequency polygons and other frequency diagrams can be found elsewhere, including a course by this author that is available on Suncam].

For example, consider the following data for an activity, for which the simulation engineer makes an educated guess to go with the Normal distribution. Recall that the distribution function (of the data) will have a bell-shape if it is indeed described by a (theoretical) Normal distribution, such as



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The histogram (and superimposed frequency polygon) of the data turns out as follows.



The histogram (or the frequency polygon) does show a rise and fall trend of a somewhat symmetrical bell shape. Thus, the Normal distribution is a good candidate distribution to describe this data. In fact, other bell-shaped distributions may also be suitable, for example, the Logistic distribution.



In a similar analysis, the following example suggests that a LogNormal distribution may be suitable to describe the data.



In fact, a Weibull distribution or some other skewed distribution may also be a good candidate.

Inspecting the frequency diagram provides a quick and useful means of assessing the suitability of a distribution or checking a distributional assumption. However, as with graphical methods in general, it does involve an element of subjective judgement.

#### **5.2 Probability Plot**

A probability plot, also known as a **quantile plot** or **Q-Q plot**, is a graphical method for checking whether a dataset follows a given theoretical distribution or otherwise. The method involves using the cumulative probability values observed in the data to compute theoretical variates (*x*-values) from the quantile function of the candidate theoretical distribution. The theoretical values versus the corresponding actual (data) values are plotted. If the plot appears to



be a straight line through the origin at an angle of 45 degrees to the horizontal, one can conclude that the data does indeed follow that candidate theoretical distribution. Or one may say the data comes from the candidate distribution. Generally, a dataset of at least 15 to 20 observations is required for the conclusions of the probability plot technique to be tenable.

The probability plot can be constructed by the following steps.

- 1. Arrange the data from smallest to largest
- 2. Divide the area of the distribution (the data) into (n + 1) equal sub-areas of area  $\frac{1}{(n + 1)}$ , where n is the number of observations in the data.
- 3. Compute the theoretical variate from the quantile function of the candidate distribution for each ordered observation, where the cumulative probability of an ordered observation *i* is given by

$$\sum_{k=1}^{i} \left( \frac{1}{n+1} \right)$$

4. Plot the *i*th ordered observation versus the *i*th theoretical variate.

Example:

A traffic engineer constructs a probability plot from 50 vehicle speed measurements (in miles per hour) to check whether the speed data follows a Normal distribution.

The data is as follows.



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Select the data. Click on **Home**. Click on **Sort & Filter**. Click on **Sort Smallest to Largest**.





The data is rearranged in ascending order.

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Step 2:

Divide the area under the distribution (the data) into (50 + 1) equal sub-areas of area  $\frac{1}{51}$  or 0.0196.

Graphically,





In tabular format on the spreadsheet.

Type in the formula as follows.

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Compute the cumulative areas (cumulative probabilities) as follows.

The cumulative probability of an ordered value is the sum of the probabilities of the values up to that value. Therefore, the cumulative probability of the second value is the area for the second value plus the cumulative probability of the preceding value, the first value, and so on and so forth.

Replicate the following formula.

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These are the observed cumulative probabilities.



Step 3:

In this step the theoretical variate shall be computed from the quantile function of the candidate distribution. In this example the candidate distribution is the Normal distribution. For the special case of the Normal distribution, if this exercise were to be done by hand, one would compute the Standard Normal variate (commonly called the *z*-score), and then convert it to the Normal variate (x).

Compute the Standard Normal variate as follows.

Type in "NORM.S.INV" to look up and select the *Excel* Standard Normal distribution quantile function.

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Double click on NORM.S.INV



Select the cumulative probability computed from the data.

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The theoretical variate (x) can be computed from the Standard Normal variate (z-score) by the relation

$$z = \frac{x - \mu}{\sigma}$$

or by the *Excel* NORM.INV function.

Begin to type "NORM.INV" to pull up the Excel NORM.INV function

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Double click on NORM.INV.



Select the cumulative **probability** value. Type a comma (","). Select the **mean** ( $\mu$ ) value. Hit **F4** on the keyboard.

Type a comma (",").

Select the **standard\_dev** ( $\sigma$ ) value.

Hit **F4** on the keyboard.

(Note that the **F4** manipulation is needed to make those cell references absolute references which shall be needed to replicate the formula, by fill handle, correctly down the spreadsheet in the subsequent step).

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Select the computed standard variate and the theoretical variate cells. Fill handle down the entire table.

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Step 4:

Plot the ordered observed data, in this case the ordered speed data, versus the theoretical variate. This is the probability plot.



Figure 5. 1: Normal probability plot

The plotted points appear to follow a straight line through the origin at an angle of 45 degrees to the horizontal. It can therefore be concluded that the data come from the candidate distribution, in this case the Normal distribution.

The above plot is a **Normal probability plot**. The probability plot for any other distribution will be constructed in a similar manner, the only difference being using the quantile function of the candidate distribution to compute the theoretical variate values.

This concludes the probability plot example.



The following Normal probability plot illustrates an example where the plotted points do not appear to line up with a straight line through the origin at an angle of 45 degrees to the horizontal.



Thus, the conclusion is that the data do not come from a Normal distribution. An analyst will now have to repeat the probability plot process as many times as needed, testing other known theoretical probability distributions, until a suitable distribution is found.

It is pertinent to note that the suitability or otherwise of one theoretical distribution does not imply or infer that some other theoretical distribution(s) may be suitable or otherwise. In other words, there can be multiple suitable theoretical distributions for a data set. In such cases, it is up to the analyst to conduct the relevant testing and ultimately select the appropriate theoretical distribution based on a combination of the results, experience and expert knowledge of the system under investigation.



#### Other Probability Plotting Techniques

There are many variations of the probability plot procedure demonstrated in this chapter. One popular variation found in the literature, particularly for the Normal probability plot, is to plot the Standard Normal variate (*z*-score) on the horizontal axis. For the speed data example previously demonstrated in this chapter, the probability plot will be as follows.



Standard Normal Variate

The straight-line behavior of the plotted points is apparent, confirming that the data follows a Normal distribution. If a trendline is fitted to the points, it can be seen that the intercept of the trendline on the vertical axis will be equal to the mean of the data, and the slope of the trendline will be equal to the standard deviation of the data.



Another popular variation of the probability plot involves plotting the rank (j) of the ordered observed data versus the Standard Normal variate (*z*-score). The ranking is such that the lowest observed value in the data has a rank of 1, the next value has a rank of 2 and so on, and the highest observed value has a rank of *n*, where *n* is the number of observations in the dataset. Each Standard Normal variate is computed from a cumulative probability (p) that is approximated by the formula,

$$p = \frac{j - 0.5}{n}$$

Probability plots may also be constructed from probabilities, not cumulative probabilities. Such probability plots are often referred to as P-P plots.

# 5.3 Other Methods

Other methods of assessing the validity of a probability distribution for modeling a random phenomenon fall under the **Goodness-of-Fit Tests**. Goodness-of-fit tests are statistical inference tests (or **Hypothesis tests**) that result in a conclusion of "**reject**", or "**fail to reject**" the given distribution based on the data. The Goodness-of-fit tests are generally applied to verify the validity of a given theoretical distribution after the visual inspections of histograms and probability plots suggest the given distribution is suitable. The Goodness-of-fit tests available include the **Chi-Square** test, the **Kolmogorov-Smirnov** (or **K-S**) test, and the **Anderson-Darling** (or **A-D**) test.

The Chi-Square test (pronounced "kai" or "chai" or "shy" or "chee" or "she") involves comparing observed frequencies of the data with corresponding theoretical frequencies computed from the candidate theoretical distribution model. As with any hypothesis test, a test statistic is computed and a comparison is made with a critical value at a given level of confidence for the test procedure, based on which, the candidate theoretical distribution will be rejected or will fail to be rejected.

In the K-S test, the observed cumulative frequencies of the data are compared to the cumulative distribution function of the given theoretical distribution. If the discrepancy between the observed and theoretical frequencies is greater than normally expected for a given sample size,



then the given theoretical distribution is rejected. If the discrepancy is less than a critical value at a given level of confidence for the test procedure, then the conclusion is to fail-to-reject the theoretical distribution.

The A-D test compares the observed cumulative frequencies of the data to the cumulative distribution function of the given theoretical distribution, but captures discrepancies between the two that are intrinsically weighted towards the tails of the distributions, unlike the other Goodness-of-fit tests which are unable to make this discrimination.

A detailed presentation of the Goodness-of-fit tests is beyond the scope of this course. Readers are strongly encouraged to review the extensive literature available on these topics on their own.



# 6. CONCLUSION

This course presented an overview of the Monte Carlo simulation technique, and how it can be implemented in *Excel*.

This course began with an illustrative introductory example of a simulation problem encountered by a practicing engineer. This was followed by a presentation of the fundamentals of the overall structure of the Monte Carlo simulation method. A demonstration of the implementation of the elements of a Monte Carlo simulation model on an *Excel* spreadsheet was presented. This course covered how the results of a Monte Carlo simulation can be analyzed, interpreted and applied in decision making. The final part of this course presented techniques used to select and validate statistical distributions that are used to model the constituent components or activities of the system or process that is being simulated, and how these techniques can be conducted in *Excel*.

Upon completion of this course, participants have gained skills in statistical distributions and Monte Carlo simulation and will be able to apply these skills in the simulation and modeling of real engineering systems. This course has enabled participants to identify professional situations where the innovative application of techniques learned in this course are relevant and will be of benefit to their productivity, efficiency, and the quality of their work product. Practitioners are strongly encouraged to look for situations in their domains of expertise where simulation and systems modeling are applicable and will be of benefit to their work product and to their organization.

A successful application of engineering methods in *Excel* requires a careful and meticulous approach, and can only be mastered and retained by practice and repetition. It has been my utmost pleasure presenting this topic to you. Thank you.



## REFERENCES

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- Meeker, W. Q., & Escobar, L. A. (1998). *Statistical Methods for Reliability Data*. John Wiley & Sons.
- The National Institutute of Standards and Testing. (2013). NIST/SEMATECH e-Handbook of Statistical Methods. Retrieved November 2019, from http://www.itl.nist.gov/div898/handbook/

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