BCNN Simulation Tools Users Manual

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INTRODUCTION

BCNN Simulation Tools is a menu-driven VBA macro for Excel that provides an analyst access to a number of useful design and analysis tools through the use of *any* simulation software product. *BCNN Simulation Tools* provides the user with guidance as to what data to collect from the simulation and provides valid statistical analysis of that data. *BCNN Simulation Tools* depends on the user to obtain and import that simulation data into the software.

The user of *BCNN Simulation Tools* engages in an **analysis**, for which the software provides **procedures** that accomplish it. The following analysis procedures are included:

- **Utility Procedures**
    - *Mean plot:* used for determining transient performance in steady-state simulation
    - *Batch means:* used for transforming output data into batch means
    - *Get sample size:* used to determine the number of replications or batch means necessary to achieve a confidence interval of fixed precision

- **Estimation Procedures**
    - *t confidence interval:* used to form a confidence interval for a simulation's mean performance
    - *t prediction interval:* used to form an interval that will contain future simulation outputs with a given probability

   ○ *Paired-t confidence interval*: used to compare the mean performance of two simulated systems

 ● **Screening and Selection Procedures**
   ○ *Select the best:* used to select which of two or more simulated systems has the largest or smallest mean performance

All analyses follow the same sequence of steps:

1. The user opens an Excel spreadsheet containing the *BCNN Simulation Tools* macros.
2. The user selects the desired analysis from the *BCNN Simulation Tools* menu that is added to the standard Excel menus.
3. The software requests inputs that describe the analysis, including the name of an Excel worksheet on which the analysis will be performed.
4. The software instructs the user concerning what simulated data to collect as well as how much. The user inserts the required data (by any means, but typically by pasting it) into the location designated by the software.
5. The user selects *Continue Analysis* from the *BCNN Simulation Tools* menu.
6. Steps 4-5 are repeated until the analysis is complete, as indicated by the software.
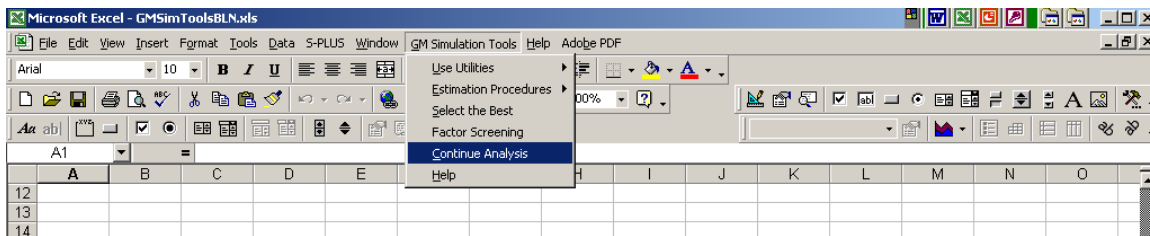
Any number of analyses can be performed in a single Excel workbook by naming a different worksheet for each analysis. At any time the user may obtain help from the *BCNN Simulation Tools:Help* menu, or by pressing the Help button available on many of the input forms.

USE UTILITIES MENU
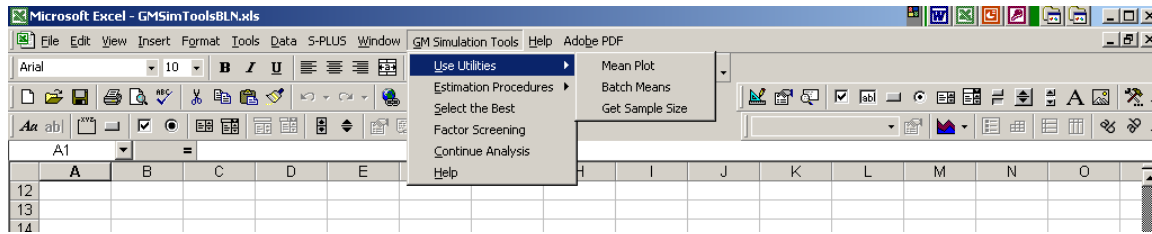

Use Utilities - Mean Plot

A *Mean Plot* is typically used for evaluating transient performance of a steady-state simulation. The goal is to find a truncation point after which the impact of the initial conditions for the simulation (e.g., empty and idle) no longer have a significant impact on the simulated performance measures. A moving average smoother is applied to the output data to make the trend more apparent. The Window parameter of the Mean Plot procedure defines the number of observations to include in the moving average; a good value is typically determined by trial and error, which this procedure allows.

The illustration that follows uses the data on the *Mean Plot* data worksheet; this data comes from 3 replications, each containing 200 product cycle times, from a manufacturing system that starts empty and idle.

Begin by selecting *BCNN Simulation Tools → Use Utilities → Mean menu*. The following form is displayed. For a Mean Plot, the Alpha Level is associated with the confidence interval that is displayed around the mean plot.

After selecting "OK," instructions are displayed indicating that the appropriate data should be inserted into the area highlighted in gray, where each column corresponds to a replication and each row corresponds to an observation of cycle time.
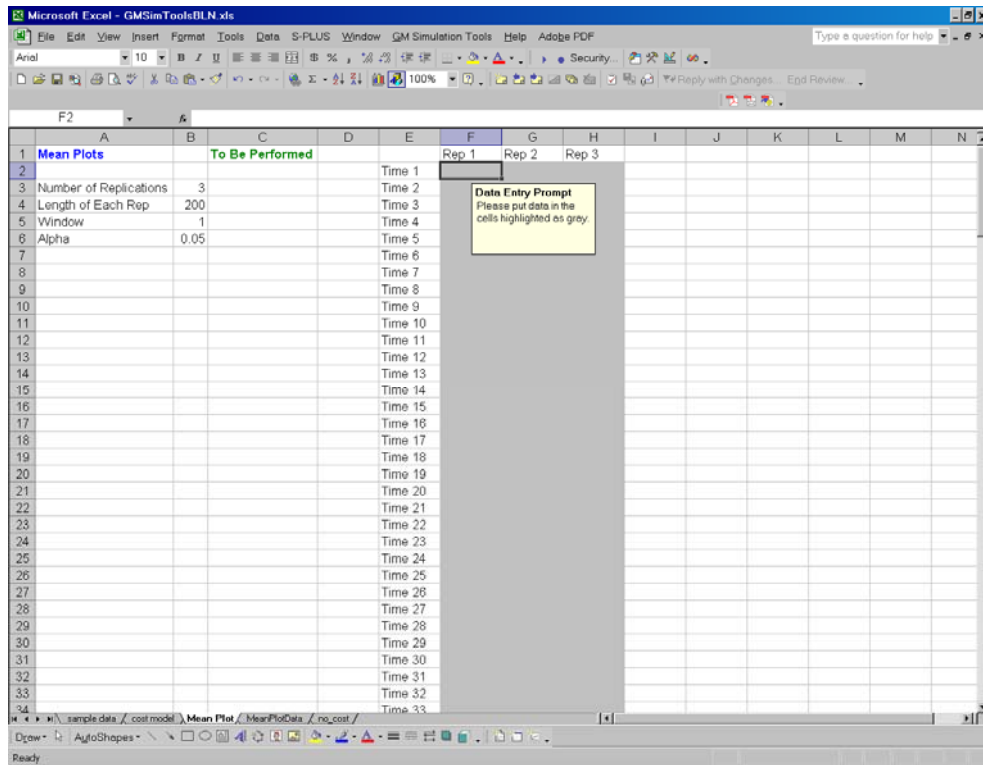
Once the data are inserted, select *BCNN Simulation Tools* → *Continue Analysis*. You will be given an option to display the Mean Plot on a separate worksheet (this is recommended), and then the Mean Plot is displayed as shown below. In this example a slight upward trend is apparent in the first 100 observations, after which the plot seems to stabilize. However, the widths of the confidence intervals around the plot are quite large; these can be tightened by making additional replications.

If you return to the analysis worksheet ("Mean Plot" in this example) and select *BCNN Simulation Tools* → *Continue Analysis* again, then you will be given the option to create another Mean Plot from the same data, but with a different Window size.

File Edit View Insert Format Tools Chart Window Help Adobe PDF

Chart 1

	A	B	C	D
1		Lower Bound	Est. MovingAverage	Upper Bound
2	Time 1	0.0000	0.0000	0.0000
3	Time 2	-0.3102	0.3222	0.9547
4	Time 3	-0.0741	0.6333	1.3408
5	Time 4	-0.5680	0.6778	1.9235
6	Time 5	0.1963	0.7000	1.2037
7	Time 6	0.0537	0.6333	1.2130
8	Time 7	-0.4743	0.6889	1.8521
9	Time 8	-1.6041	0.9333	3.4707
10	Time 9	-2.2733	0.9667	4.2066
11	Time 10	-3.1289	1.5444	6.2178
12	Time 11	-2.8990	2.2444	7.3879
13	Time 12	-3.2694	2.7000	8.6694
14	Time 13	-2.6339	2.5000	7.6339
15	Time 14	-3.2392	1.7444	6.7281
16	Time 15	-2.8123	1.3667	5.5456
17	Time 16	-3.3135	1.1333	5.5802
18	Time 17	-3.2140	1.1222	5.4585
19	Time 18	-3.1294	1.0556	5.2405
20	Time 19	-3.8292	1.2889	6.4069
21	Time 20	-5.0692	1.6000	8.2692
22	Time 21	-6.4986	2.0111	10.5208
23	Time 22	-6.5379	2.0444	10.6268
24	Time 23	-6.0257	2.1222	10.2701
25	Time 24	-4.8954	2.1000	9.0954
26	Time 25	-4.1784	2.3000	8.7784
27	Time 26	-3.9834	2.0222	8.0279
28	Time 27	-3.3459	1.5222	6.3904
29	Time 28	-3.2311	1.0000	5.2311
30	Time 29	-2.8908	1.1667	5.2241
31	Time 30	-3.2170	1.2667	5.7504
32	Time 31	-2.8322	1.5778	5.9877

Mean Plot

Sheets: sample data / cost model / Plot / Mean Plot / MeanPlotData / no_cost /
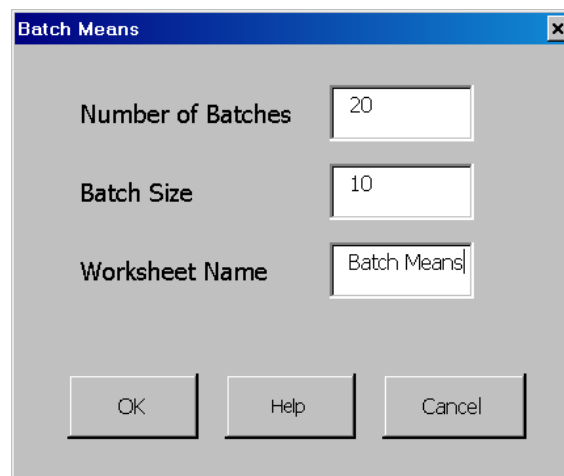
Draw AutoShapes

Ready

Use Utilities - Batch Means

Batch means are a transformation of raw output data, typically from within a single replication of a steady-state simulation, so that the batch means are more nearly independent and normally distributed than the raw output data.

The illustration that follows uses the data on the *Batch Means* data worksheet; this data comes from a single replication containing 200 product cycle times from a manufacturing system.

Begin by selecting *BCNN Simulation Tools → Use Utilities → Batch Mean*s menu. The following form is displayed.

After selecting "OK," instructions are displayed indicating that the appropriate data should be inserted into the area highlighted in gray, where each row corresponds to an observation of cycle time. Notice that the number of data values should be the Number of Batches x the Batch Size.

Once the data are inserted, select *BCNN Simulation Tools → Continue Analysis* and the batch means will be displayed, as shown below.

Microsoft Excel - GMSimToolsBLN.xls

File Edit View Insert Format Tools Data S-PLUS Window GM Simulation Tools Help Adobe PDF

Cell E2

	A	B	C	D	E	F	G	H
1	Batch Means		To Be Performed		Data Column			Batch Means
2				1			1	
3	Number of Batches	20		2			2	
4	Batch Size	10		3			3	
5				4			4	
6				5			5	
7				6			6	
8				7			7	
9				8			8	
10				9			9	
11				10			10	
12				11			11	
13				12			12	
14				13			13	
15				14			14	
16				15			15	
17				16			16	
18				17			17	
19				18			18	
20				19			19	
21				20			20	
22				21				
23				22				
24				23				
25				24				
26				25				
27				26				
28				27				
29				28				
30				29				
31				30				
32				31				
33				32				

Data Entry Prompt
Please put data in the cells highlighted as gray.

sample data / cost model / Plot / Plot2 / Mean Plot / Batch Means / BatchMeansData / MeanPlotData / no_cost /

Draw · AutoShapes ·

Ready

Microsoft Excel - GMSimToolsBLN.xls

File Edit View Insert Format Tools Data S-PLUS Window GM Simulation Tools Help Adobe PDF

Cell C1 Completed

	A	B	C	D	E	F	G	H
1	Batch Means		Completed		Data Column			Batch Means
2				1	0		1	2.01
3	Number of Batches	20		2	1.2		2	5.16
4	Batch Size	10		3	1.7		3	5.41
5				4	2.8		4	12.27
6				5	1.6		5	14.13
7				6	1.9		6	6.93
8				7	2.2		7	12.49
9				8	2.1		8	13.11
10				9	4.1		9	14.11
11				10	2.5		10	16.22
12				11	7.3		11	14.97
13				12	10.4		12	8.47
14				13	6.6		13	6.51
15				14	5.5		14	11.09
16				15	3.6		15	16.88
17				16	3.2		16	21.38
18				17	3.4		17	23.25
19				18	3.5		18	29.75
20				19	2.6		19	31.05
21				20	5.5		20	34.29
22				21	6.3			
23				22	6.3			
24				23	5.8			
25				24	7			
26				25	6.1			
27				26	7.6			
28				27	4.5			
29				28	1.6			
30				29	2.9			
31				30	6			
32				31	2.5			
33				32	5.7			

sample data / cost model / Plot / Plot2 / Mean Plot / Batch Means / BatchMeansData / MeanPlotData / no_cost /
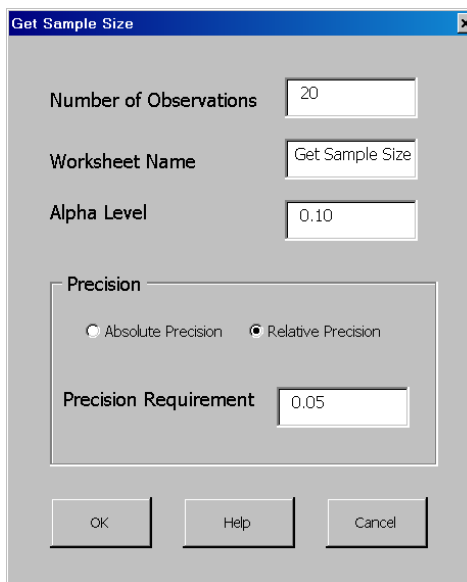
Draw · AutoShapes ·

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Use Utilities - Get Sample Size

Get Sample Size is used to determine the number of replications or batch means necessary to achieve a confidence interval of fixed absolute or relative precision given an initial pilot sample of data.

The illustration that follows uses the data on the *Get Sample Size* data worksheet; these data are the batch means of manufacturing cycles times from the *Batch Means* example above.

Begin by selecting BCNN *Simulation Tools* → *Use Utilities* → *Get Sample Size* menu. The following form is displayed. Number of Observations refers to the number pilot observations available, while Alpha Level refers to the error level of the desired confidence interval. Absolute Precision refers to the half length of the final confidence interval, while Relative Precision refers to the half length of the confidence interval relative to the sample mean. In the example below, 5% relative error is specified.

After selecting "OK," instructions are displayed indicating that the appropriate data should be inserted into the area highlighted in gray, where each row corresponds to a batch mean of cycle time.

Once the data are inserted, select *BCNN Simulation Tools* → *Continue Analysis* and the minimum required sample size will be displayed, as shown below. In this case, only 2 additional batch means are necessary. Once the data have been collected, *BCNN Simulation Tools* → *Estimation Procedures* → *T Confidence Interval* can be used to form the confidence interval.

Screenshot 1 — Microsoft Excel - GMSimToolsBLN.xls (cell E2 selected)

	A	B	C	D	E	F	G	H
1	Get Sample Size		To Be Performed		Data Column			Minimum Sample Size
2				1				
3	Number of Observations	20		2				
4	Alpha	0.1		3				
5	Precision Type	2		4				
6	Precision Value	0.05		5				
7				6				
8				7				
9				8				
10				9				
11				10				
12				11				
13				12				
14				13				
15				14				
16				15				
17				16				
18				17				
19				18				
20				19				
21				20				

Data Entry Prompt
Please put data in the cells highlighted as gray.

Screenshot 2 — Microsoft Excel - GMSimToolsBLN.xls (cell C1 = "Completed")

	A	B	C	D	E	F	G	H
1	Get Sample Size		Completed		Data Column			Minimum Sample Size
2				1	2.01			22
3	Number of Observations	20		2	5.16			
4	Alpha	0.1		3	5.41			
5	Precision Type	2		4	12.27			
6	Precision Value	0.05		5	14.13			
7				6	6.93			
8				7	12.49			
9				8	13.11			
10				9	14.11			
11				10	16.22			
12				11	14.97			
13				12	8.47			
14				13	6.51			
15				14	11.09			
16				15	16.88			
17				16	21.38			
18				17	23.25			
19				18	29.75			
20				19	31.05			
21				20	34.29			

ESTIMATION PROCEDURES MENU

Estimation Procedures – T Confidence Interval

T Confidence Interval is used to calculate a confidence interval for the average performance of a system.

Suppose that you have a manufacturing system simulation and you want to estimate the average cycle time for the system. The illustration that follows uses the data on the *T conf int* worksheet; these data are average cycle times from independent simulation replications (say, two weeks of production for each simulation replication) of the manufacturing system under the same conditions (typically with the transient portion of each simulation replication removed.).

Begin by selecting *BCNN Simulation Tools → Estimation Procedures → T Confidence Interval* menu. The following form is displayed. Number of Observations refers to the number simulation replications that will be available, while Alpha Level refers to the error level of the desired confidence interval. If Type I error is set to α (Alpha), then the procedure produces a 100(1-α)% confidence interval. (e.g. Choosing α to be 0.05 will result in a 95% confidence interval for the average cycle time.)

After selecting "OK," instructions are displayed indicating that the appropriate data should be inserted

into the column highlighted in gray, where each row corresponds to an average cycle time for a single replication.

Once the data have been inserted, select *BCNN Simulation Tools → Continue Analysis* and the results will be displayed, as shown below. Given the assumptions that the cycle times are independent and all come from the same normal distribution, a 95% confidence interval for the average cycle time is 31.047 ± 3.278. In other words, there is 95% confidence that the average cycle time is between 27.769 and 34.325 hours.

Estimation Procedures – T Prediction Interval

T Prediction Interval is used to calculate an interval which will contain the performance of a future individual replication of the system.

Suppose that it was desired to quote an average lead time for the next two weeks of production. The T prediction interval provides an interval that contains that "two week" average lead time with a specified level of confidence. The illustration that follows uses the data on the *T pred int* worksheet; these data are average cycle times from independent simulation replications (two weeks of production for each simulation replication) of the manufacturing system under the same conditions (typically with the transient portion of each simulation replication removed.).

Begin by selecting *BCNN Simulation Tools → Estimation Procedures → T Prediction Interval* menu. The following form is displayed. Number of Observations refers to the number simulation replications that will be available, while Alpha Level refers to the error level of the desired confidence interval. If Type I error is set to α (Alpha), then the procedure produces a 100(1-α)% prediction interval. (e.g. Choosing α to be 0.05 will result in a 95% prediction interval for the average cycle time over the next two weeks.)

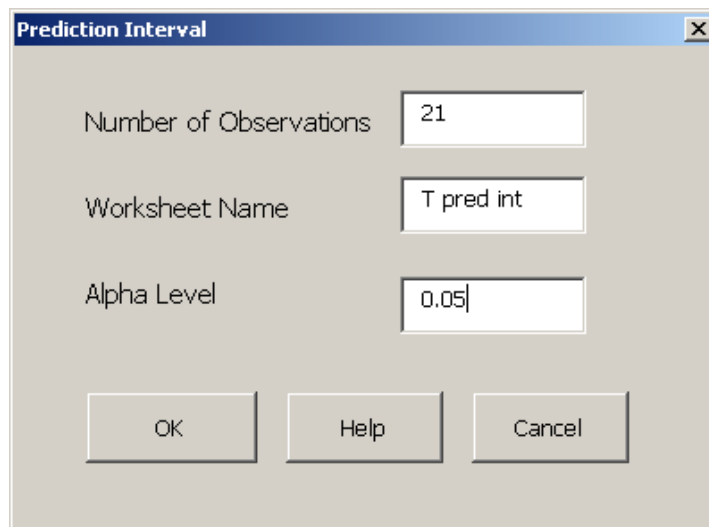
After selecting "OK," instructions are displayed indicating that the appropriate data should be inserted into the column highlighted in gray, where each row corresponds to an average cycle time for a single replication.

Once the data have been inserted, select *BCNN Simulation Tools → Continue Analysis* and the results will be displayed, as shown below. Given the assumptions that the average cycle times are independent and all come from the same normal distribution, a 95% prediction interval for the average cycle time is 31.047 $\pm$ 15.373. In other words, there is 95% confidence that the average cycle time over the next two weeks will be between 15.674 and 46.42 hours.

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E2   =

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	T-Prediction Interval		To Be Performed		Data Column			Sample Mean						
2				1				Half Width of PI						
3	Number of Observations	21		2										
4	Alpha	0.05		3										
5				4										
6				5										
7				6										
8				7										
9				8										
10				9										
11				10										
12				11										
13				12										
14				13										
15				14										
16				15										
17				16										
18				17										
19				18										
20				19										
21				20										
22				21										
23														

Data Entry Prompt
Please put data in the cells highlighted as gray.

C1   = Completed

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	T-Prediction Interval		Completed		Data Column			Sample Mean	31.04762				
2				1	21			Half Width of PI	15.37349				
3	Number of Observations	21		2	24								
4	Alpha	0.05		3	36								
5				4	22								
6				5	43								
7				6	34								
8				7	23								
9				8	26								
10				9	39								
11				10	25								
12				11	21								
13				12	45								
14				13	34								
15				14	33								
16				15	28								
17				16	35								
18				17	37								
19				18	27								
20				19	29								
21				20	32								
22				21	38								

Estimation Procedures – Paired-T Confidence Interval

Paired-T Confidence Interval is used to compare the performance of two competing systems. Specifically it calculates a confidence interval for the average difference in the performance of the two systems. If the resulting confidence interval does not contain zero then it shows that one of the systems significantly outperforms the other. The two ends of the confidence interval show the range of improvement that one might expect by choosing the better system. If zero does not appear in resulting confidence interval, then more data would be needed to distinguish between the two systems' performance. However, using the confidence interval as the range of likely differences between the two systems' performance often leads to the conclusion that there is no practical difference between the two systems. For maximum efficiency of the procedure, common random numbers should be used for each pair of simulation runs.

Suppose that it was desired to compare the average cycle time for the two different queueing policies (eg. FIFO first in first out vs SPT shortest processing time first) in a manufacturing system. With a specified level of confidence, the Paired-T confidence interval provides an interval that contains the difference between the average cycle time under FIFO and the average cycle time under SPT. The illustration that follows uses the data on the *Paired T conf int* worksheet; these data are average cycle times from paired simulation replications (one observation under each policy and typically using the same random number seeds for both runs within the pair).

Begin by selecting *BCNN Simulation Tools → Estimation Procedures → Paired-T Confidence Interval* menu. The following form is displayed. Number of Observations refers to the number of pairs of simulation replications that will be available, while Alpha Level refers to the error level of the desired confidence interval. If Type I error is set to α (Alpha), then the procedure produces a 100(1-α)% confidence interval. (e.g. Choosing α to be 0.05 will result in a 95% confidence interval.)
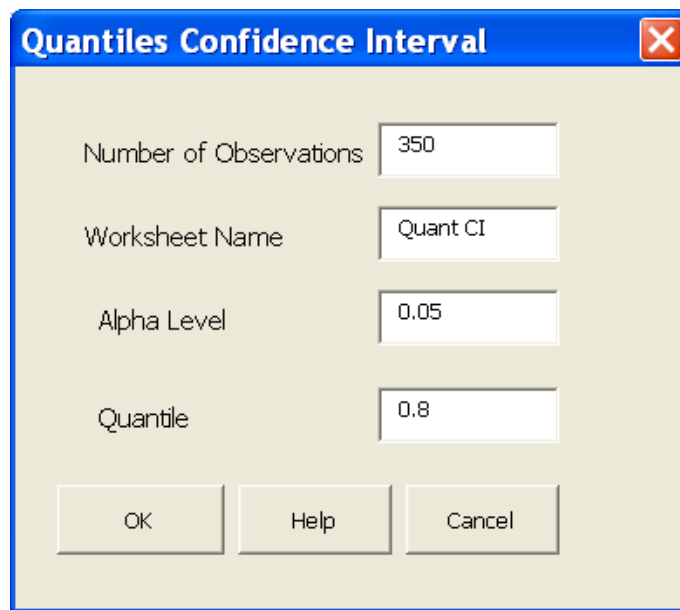

After selecting "OK," instructions are displayed indicating that the appropriate data should be inserted into the columns highlighted in gray, where each column corresponds to a different policy and each

row corresponds to a pair of replications that use different policies but have the same random number seeds (if possible). Observations in different rows should have different random number seeds.

Once the data are inserted, select *BCNN Simulation Tools* → *Continue Analysis* and the results will be displayed, as shown below. Given the assumptions that the average cycle times for a given policy follow the same normal distribution, a 95% confidence interval for the difference between average cycle time for FIFO and SPT is 3.048 ± 1.138. In other words, there is 95% confidence that the average cycle time using SPT will be between 1.91 and 4.19 hours less than using a FIFO policy. Since zero is not in the confidence interval, then SPT is significantly better than FIFO with 95% confidence. Of course, if implementing the SPT policy is so expensive that a decrease of 4.19 hours of cycle time does not justify the change, then FIFO would still be the most cost effective policy even though it has a significantly higher average cycle time.

Estimation Procedures – Quantiles Confidence Interval

Quantiles Confidence Interval is used to calculate a confidence interval for a quantile (equivalently percentile) of the performance of a system.

Suppose that you have a manufacturing system simulation and you want to estimate the average cycle time for the system. The illustration that follows uses the data on the *Quant CI Data* worksheet; these data are average cycle times (in hours) from independent simulation replications (say, two weeks of production for each simulation replication) of the manufacturing system under the same conditions (typically with the transient portion of each simulation replication removed.). We are interested in the 0.8 quantile (80th percentile) of these cycle time data.

Begin by selecting *BCNN Simulation Tools* → *Estimation Procedures* → *Quantiles Confidence Interval* menu. The following form is displayed. Number of Observations refers to the number simulation replications that will be available, while Alpha Level refers to the error level of the desired confidence interval. If Type I error is set to α (Alpha), then the procedure produces a 100(1-α)% confidence interval. (e.g. Choosing α to be 0.05 will result in a 95% confidence interval for the average cycle time.). Quantile is the quantile of interest and should be a value between 0 and 1.


After selecting "OK," instructions are displayed indicating that the appropriate data should be inserted into the column highlighted in gray.

Once the data are inserted, select *BCNN Simulation Tools* → *Continue Analysis* and the results will be displayed, as shown below. The confidence interval for a quantile is not of the $\pm$ type; instead, distinct upper and lower confidence bounds are given that typically will not be symmetric around the estimated quantile value. For this data, the 0.8 quantile (80th percentile) of average cycle time is 117.56 hours, with 95% confidence interval (116.60, 117.01) hours.
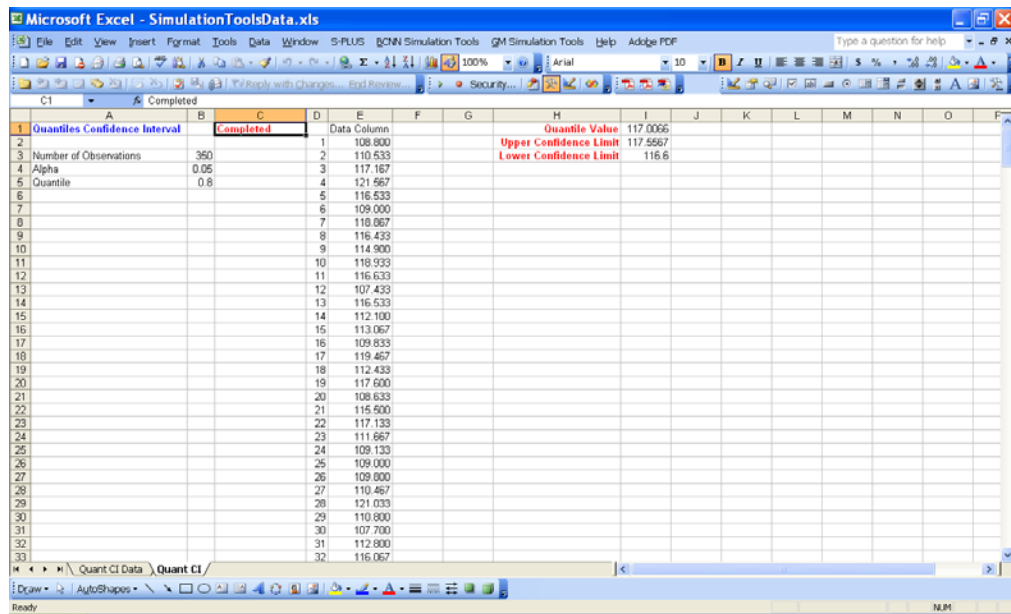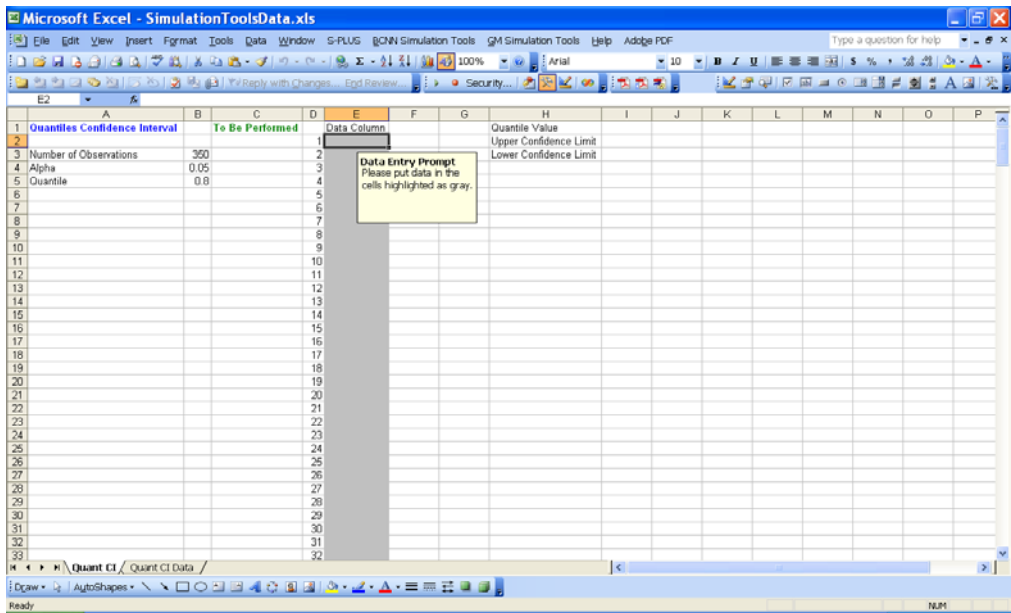
SELECT THE BEST
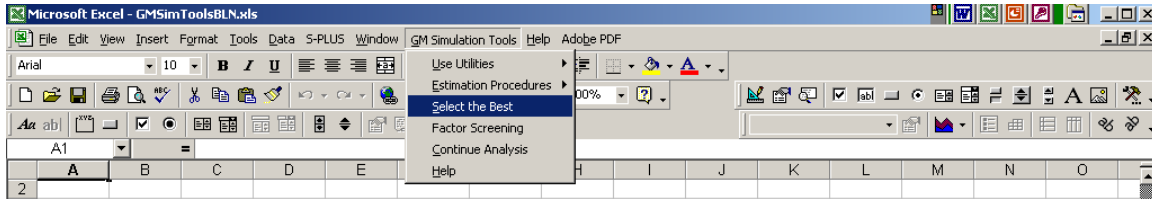
Select the Best procedure is a statistical method specifically developed to select the system that has the best expected performance measure, along with the sample average performance of each system simulated. Suppose that throughput is the measure of performance and the data is reported in units of a thousand products. The user is asked to confidence level and an indifference zone. Below 95% confidence and an indifference zone of 1 are selected. Given these selections, the system that is selected by the procedure is guaranteed (with 95% confidence) to be either the best system or no more than 1 unit (in this case, 1000 products) worse on average than the best system.

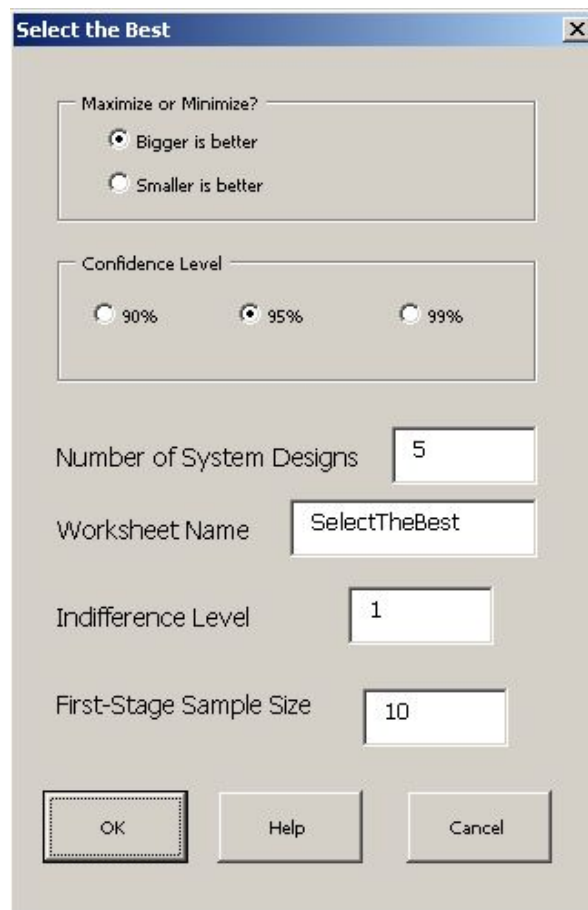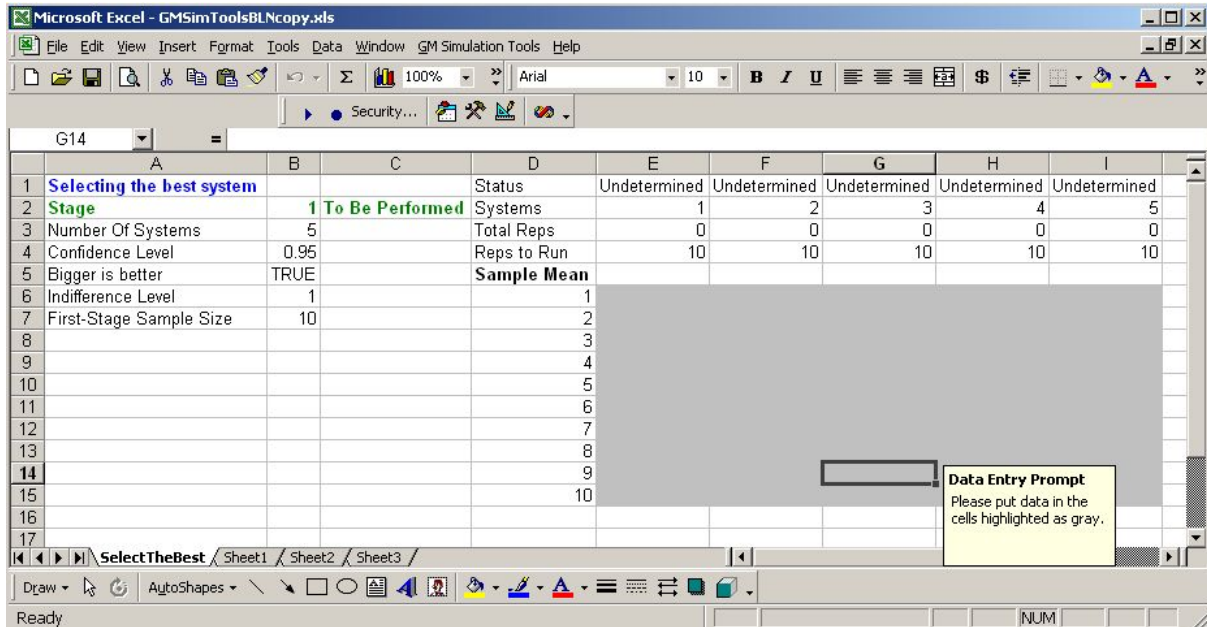Go to *BCNN Simulation Tool* → *Select the Best*

Figure 1

Figure 2
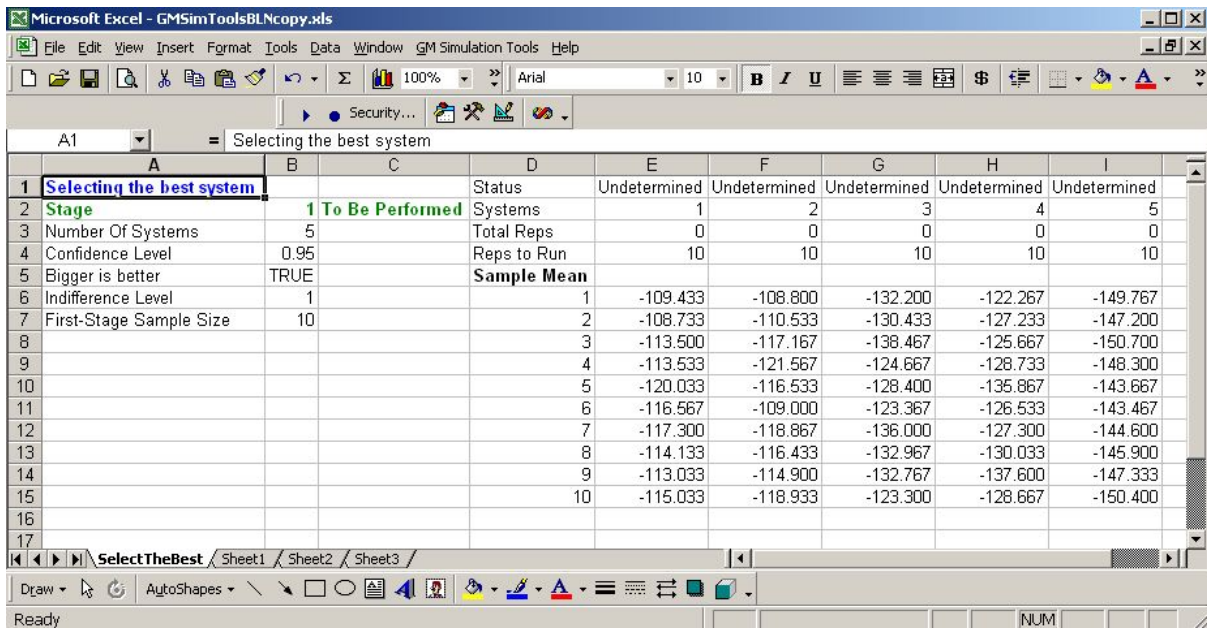
Figure 3

Then go to *BCNN Simulation Tools → Continue Analysis* to perform the first-stage analysis, and the results are shown as below. At this point, systems 3, 4, and 5 have been found to be inferior to other systems and are eliminated (shown in G1-I1) from the candidate pool of the best systems (with the biggest performance measure), and no further experiments are needed for these three. For system 1 and 2, 198 and 340 additional replications are needed, respectively. The difference indicates that system 2 is more variable and thus requires more replication. The cells for data entries are highlighted in gray as shown in Figure 4.
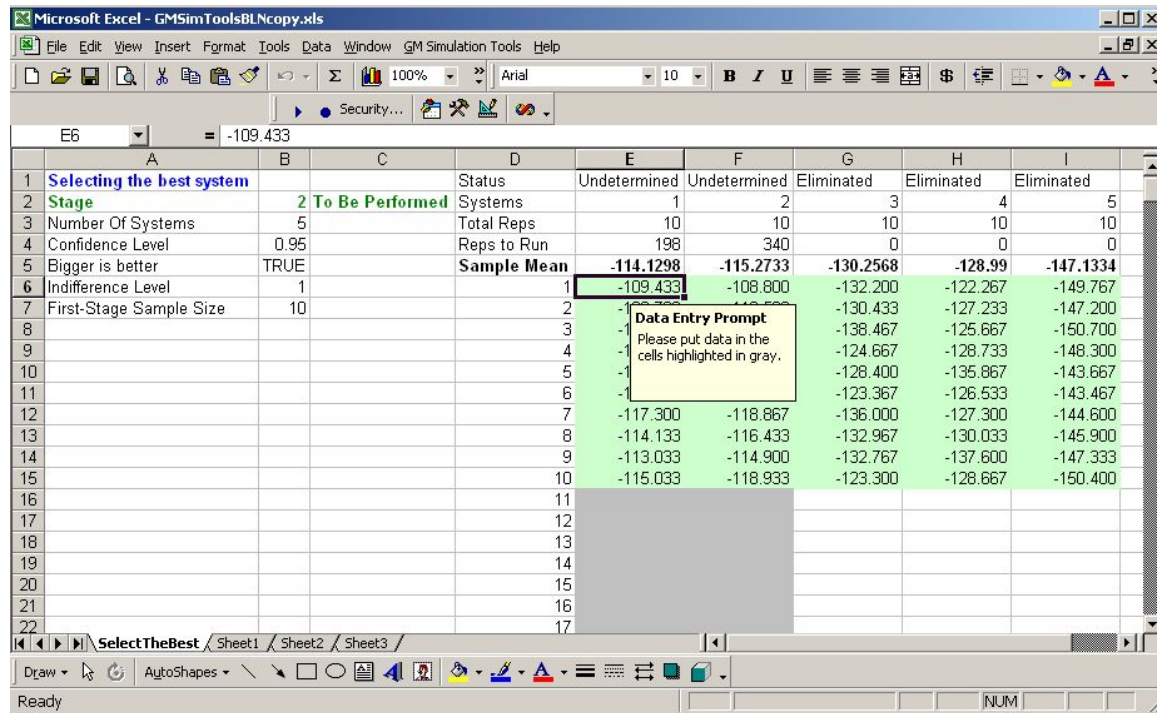
Figure 4

Put in the additional data required for the second-stage analysis and come to Figure 5.
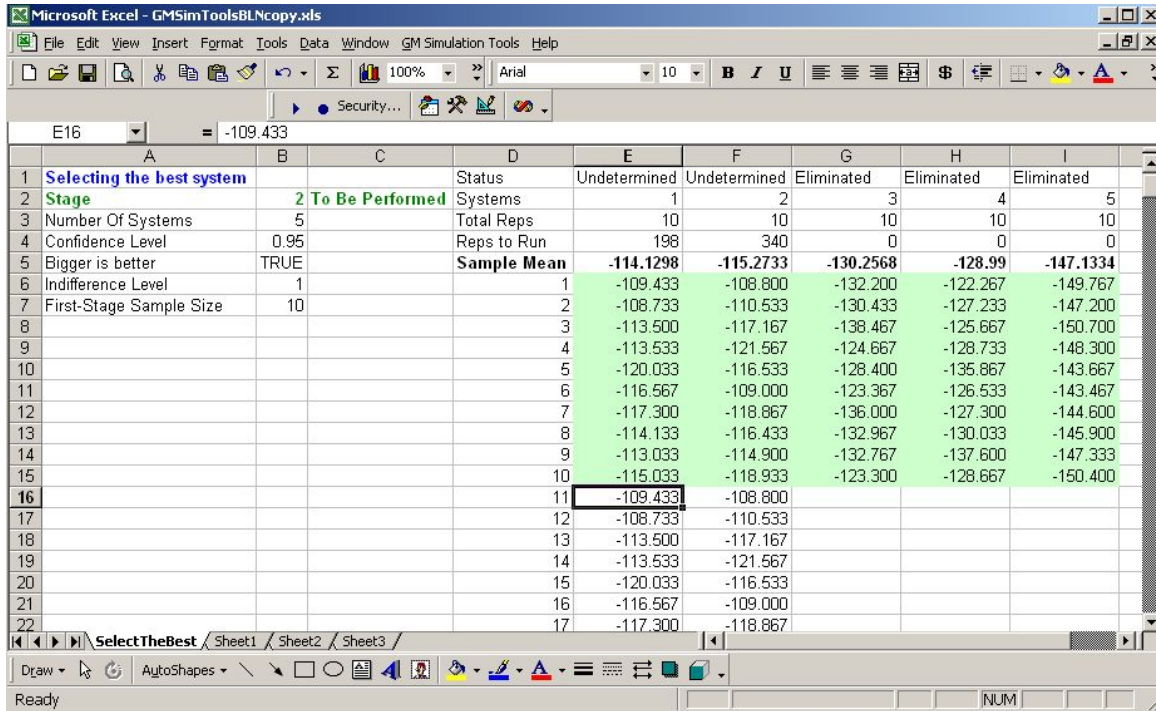
Figure 5

Again, go to *BCNN Simulation Tool → Continue Analysis* to perform the second-stage analysis. As shown in Figure 6, System 1 is eliminated and System 2 is selected as the best one. Thus, we can conclude with 95% confidence that System 2 has the highest throughput or is within 1 unit (1000 products) of the best system. Sample means are calculated for each system based on the data highlighted in green.

The analysis is now completed.

Figure 6

Microsoft Excel - GMSimToolsBLNcopy.xls

File Edit View Insert Format Tools Data Window GM Simulation Tools Help

Arial 10

C2 = Completed

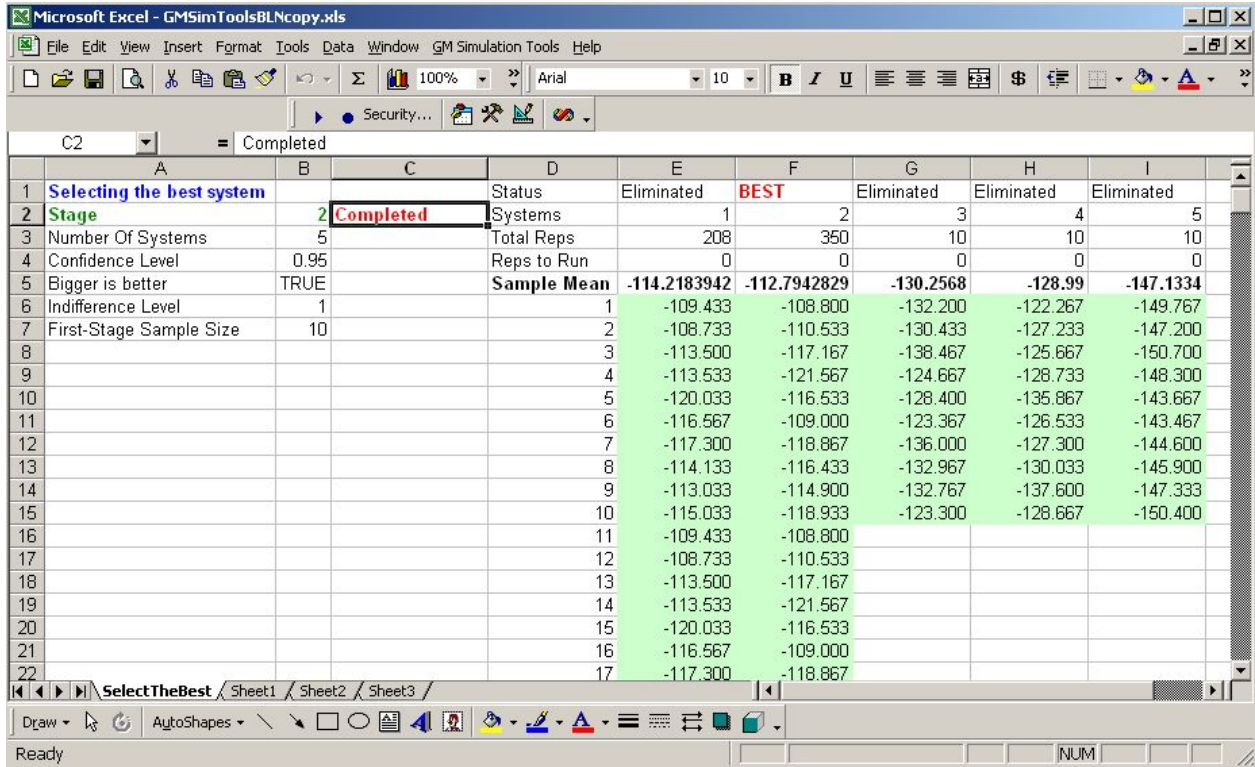|	A	B	C	D	E	F	G	H	I
1	Selecting the best system			Status	Eliminated	BEST	Eliminated	Eliminated	Eliminated
2	Stage	2	Completed	Systems	1	2	3	4	5
3	Number Of Systems	5		Total Reps	208	350	10	10	10
4	Confidence Level	0.95		Reps to Run	0	0	0	0	0
5	Bigger is better	TRUE		Sample Mean	-114.2183942	-112.7942829	-130.2568	-128.99	-147.1334
6	Indifference Level	1		1	-109.433	-108.800	-132.200	-122.267	-149.767
7	First-Stage Sample Size	10		2	-108.733	-110.533	-130.433	-127.233	-147.200
8				3	-113.500	-117.167	-138.467	-125.667	-150.700
9				4	-113.533	-121.567	-124.667	-128.733	-148.300
10				5	-120.033	-116.533	-128.400	-135.867	-143.667
11				6	-116.567	-109.000	-123.367	-126.533	-143.467
12				7	-117.300	-118.867	-136.000	-127.300	-144.600
13				8	-114.133	-116.433	-132.967	-130.033	-145.900
14				9	-113.033	-114.900	-132.767	-137.600	-147.333
15				10	-115.033	-118.933	-123.300	-128.667	-150.400
16				11	-109.433	-108.800			
17				12	-108.733	-110.533			
18				13	-113.500	-117.167			
19				14	-113.533	-121.567			
20				15	-120.033	-116.533			
21				16	-116.567	-109.000			
22				17	-117.300	-118.867			

SelectTheBest / Sheet1 / Sheet2 / Sheet3 /

Draw AutoShapes

Ready NUM

Figure 6