

Implementing Lean Six Sigma Using Statgraphics

Neil W. Polhemus, CTO, StatPoint Technologies, Inc.

Copyright 2011 by StatPoint Technologies, Inc.

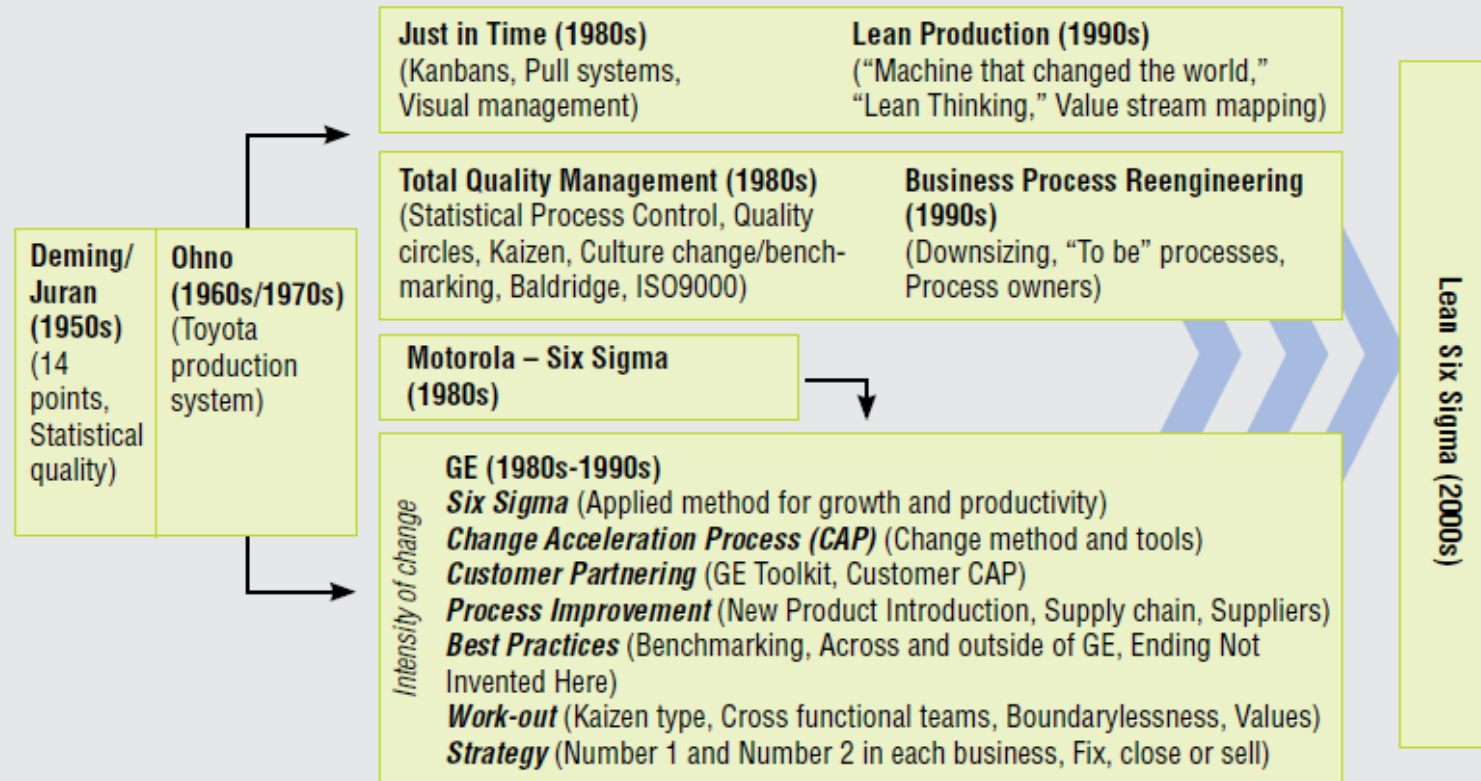
Web site: www.statgraphics.com



STATPOINT
TECHNOLOGIES, INC.

Lean Six Sigma

Lean Six Sigma builds on the practical lessons learned from previous eras of operational improvement.



Source: IBM Global Business Services analysis.



Lean Six Sigma

- Lean manufacturing – focuses on reducing cost through process optimization.
- Six Sigma – focuses on meeting customer requirements and stakeholder expectations, and improving quality by measuring and eliminating defects.

www-935.ibm.com/services/uk/bcs/pdf

[/driving_operational_innovation_using_lean_six_sigma.pdf](http://www-935.ibm.com/services/uk/bcs/pdf/driving_operational_innovation_using_lean_six_sigma.pdf)

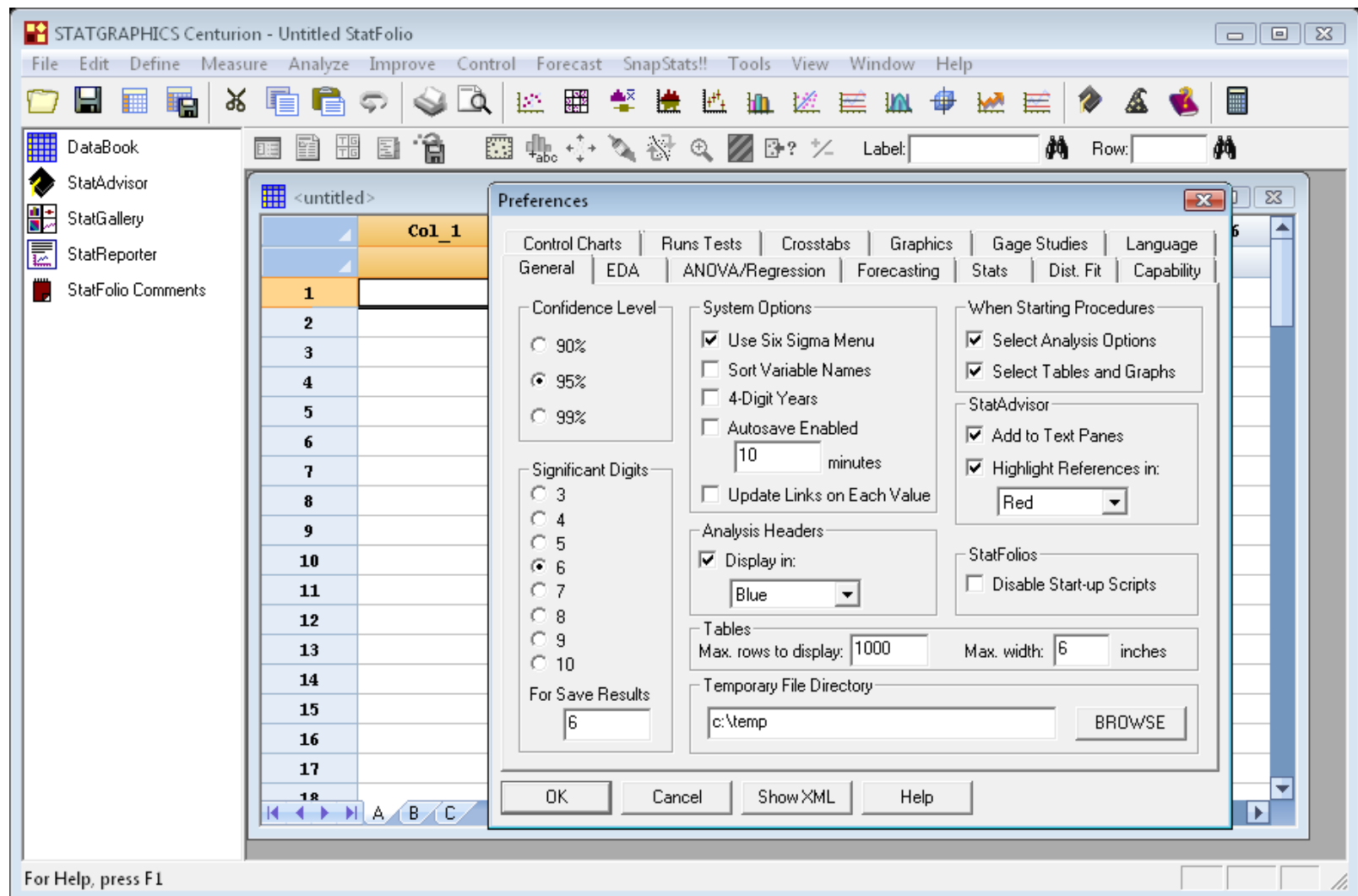


Statgraphics Software

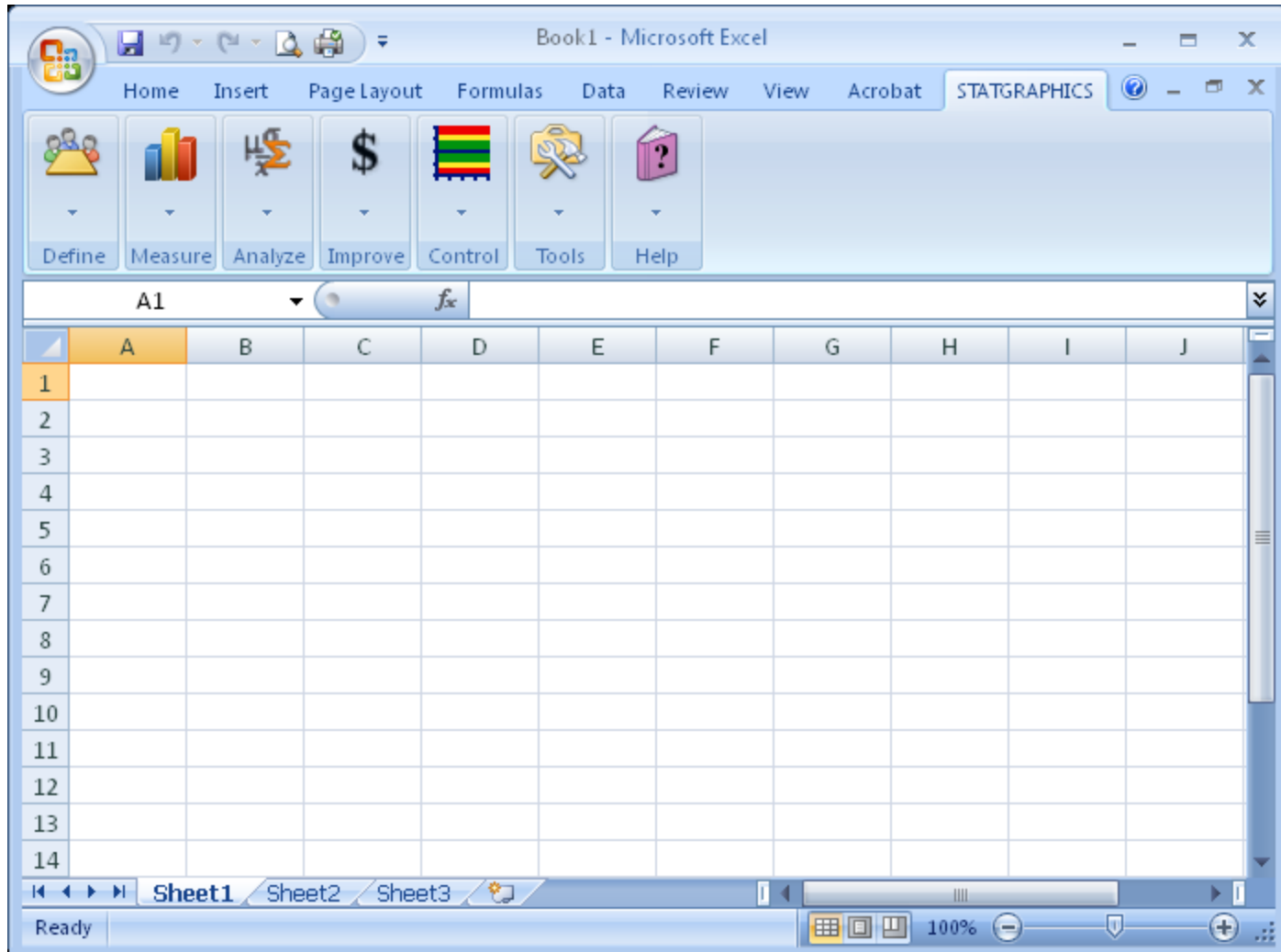
- *Statgraphics Centurion XVI.I* – Windows standalone application with over 170 basic and advanced statistical methods.
- *Statgraphics Sigma Express 1.1* – Excel add-in with 70+ procedures covering the needs of Six Sigma green belts and most black belts. Available for Excel 2003, 2007, 2010.*

*Pre-release evaluation version available by sending contact information to info@statgraphics.com

Statgraphics Centurion XVI.I



Statgraphics Sigma Express



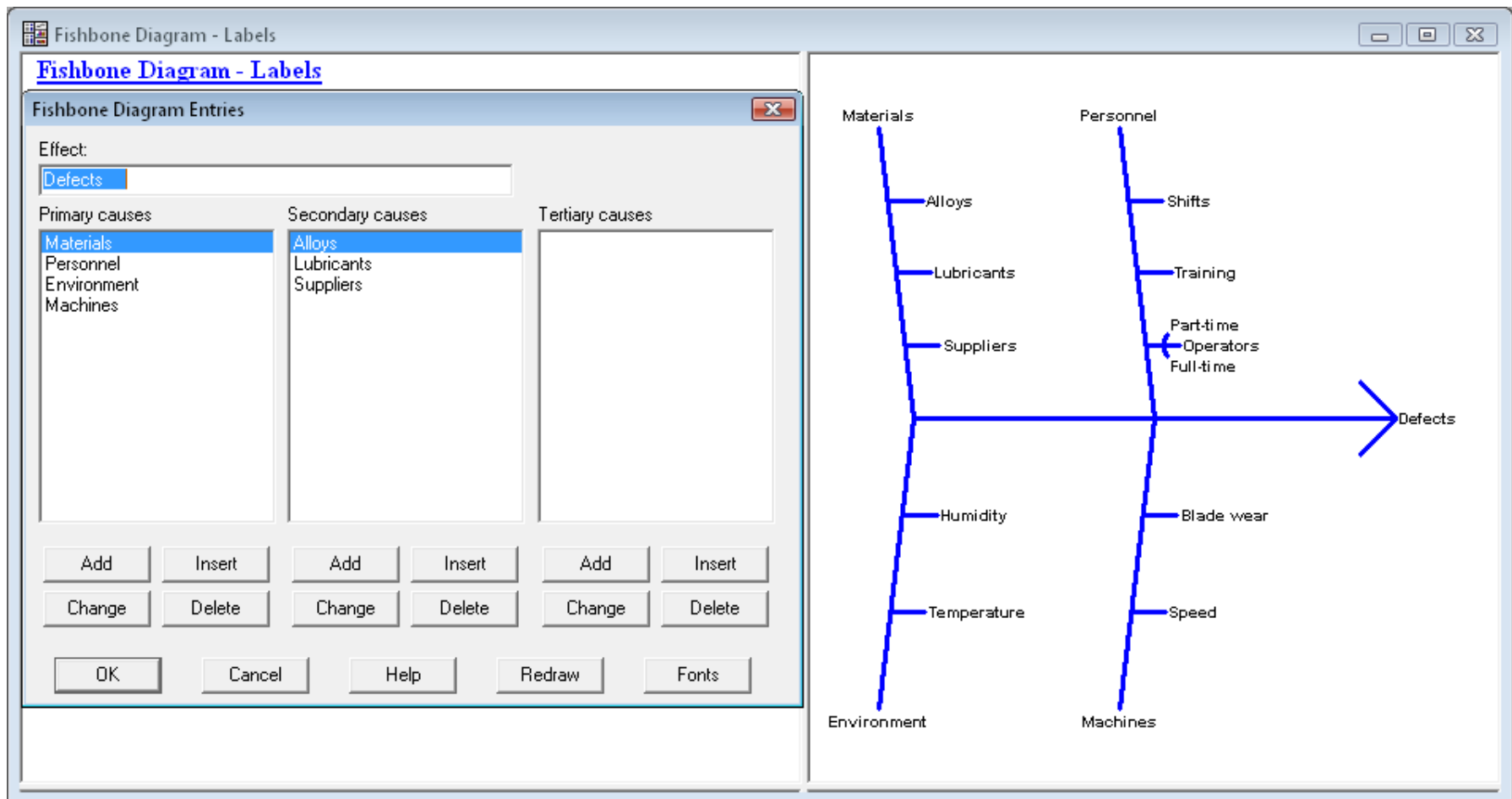
Example #1 (Define) – Cause-and-Effect Diagram

Cause-and-effect diagrams (also called fishbone or Ishikawa diagrams) illustrate the causes of specific events.

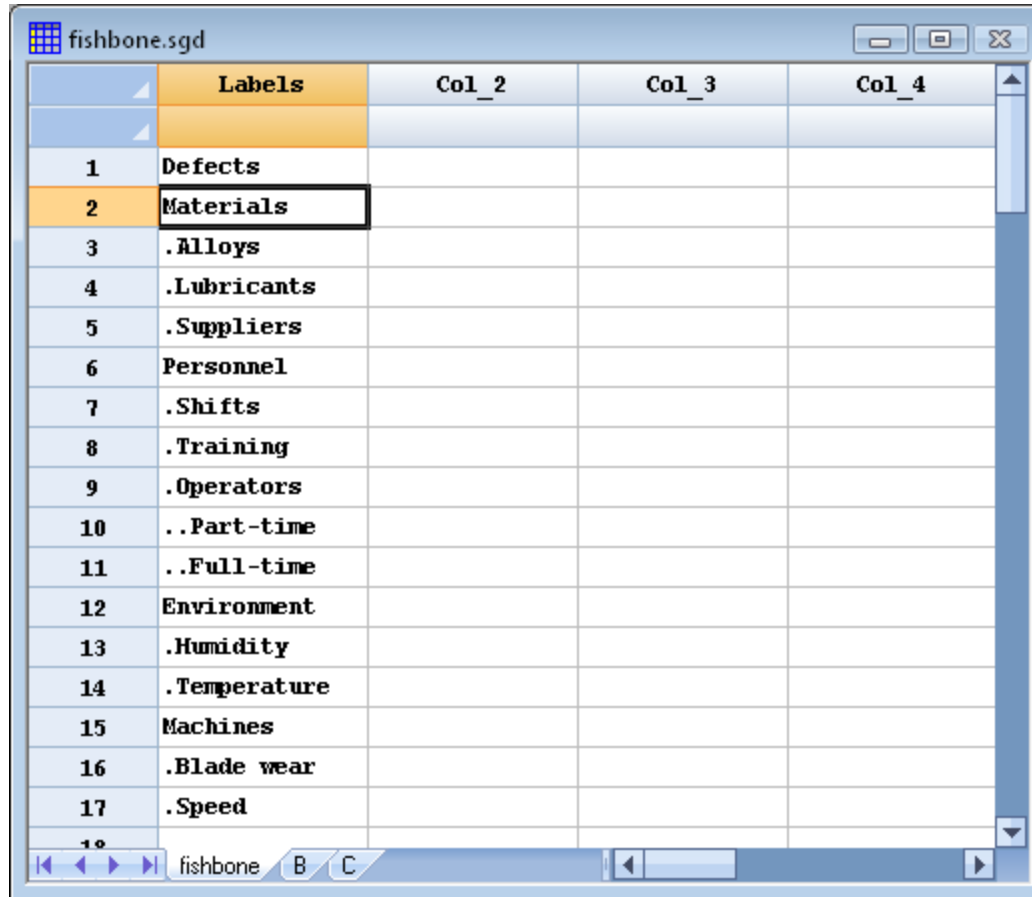
Event: defects

Major causes: material, personnel, environment, machines, ...

Input – Analysis Options dialog box creates diagram

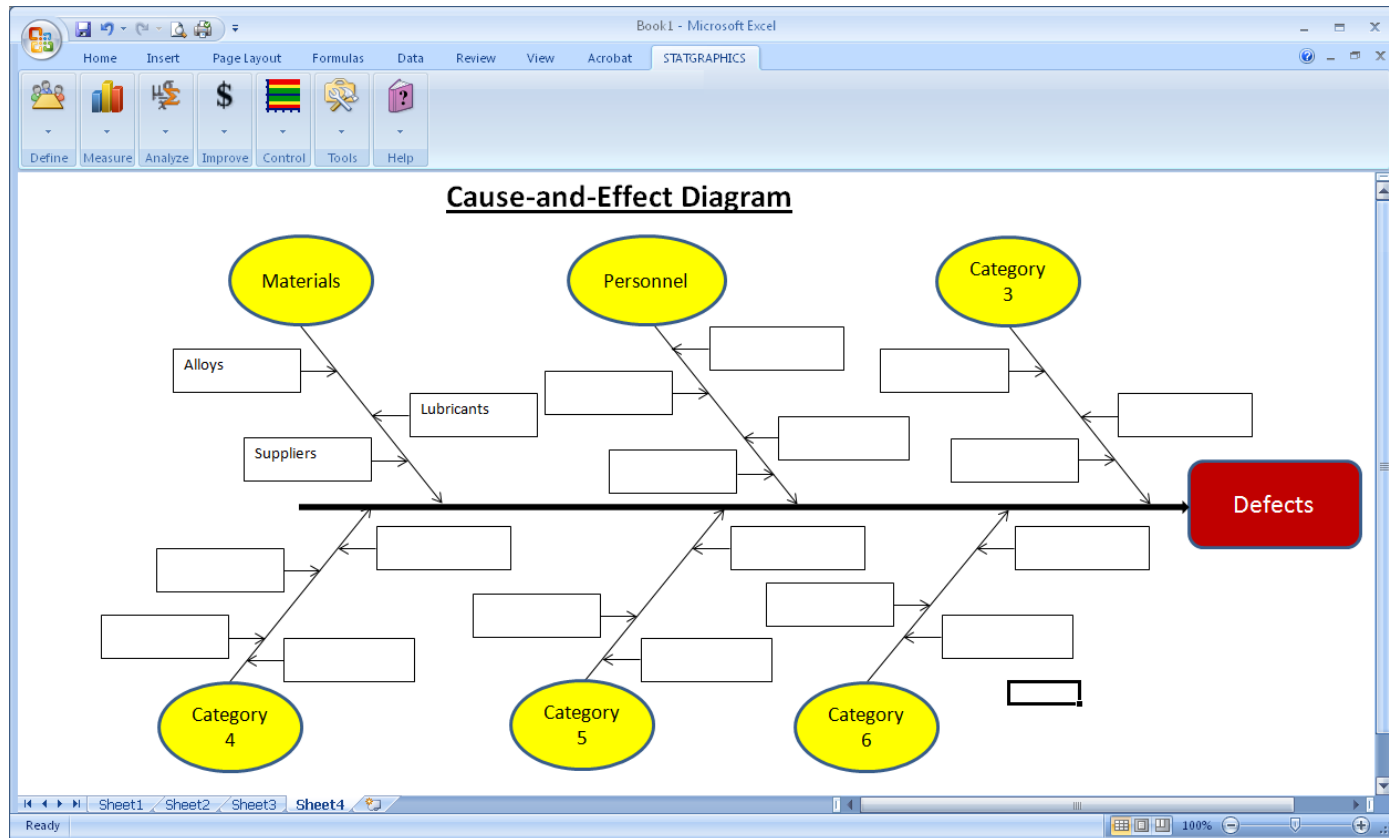


Data structure for saving



	Labels	Col_2	Col_3	Col_4
1	Defects			
2	Materials			
3	.Alloys			
4	.Lubricants			
5	.Suppliers			
6	Personnel			
7	.Shifts			
8	.Training			
9	.Operators			
10	..Part-time			
11	..Full-time			
12	Environment			
13	.Humidity			
14	.Temperature			
15	Machines			
16	.Blade wear			
17	.Speed			
18				

Sigma Express also provides Excel template



Example #2 (Measure) – Gage Studies

“Gage Studies” refers to the process of evaluating measurement processes to verify that they are capable of measuring responses well enough to permit the use of SPC and DOE techniques.

In Statgraphics, the main procedures all follow the AIAG guidelines:

- *Gage Study Setup* – to create a data template.
- Analysis of Variable Data
 1. *Average and Range Method* and *ANOVA Method* evaluate R&R based on full study.
 2. *Range Method* evaluates R&R based on short study.
 3. **Gage Linearity and Accuracy* evaluates bias.
- Analysis of Attribute Data
 1. **Risk Assessment Method* – based on consistency of appraisals
 2. **Analytic Method* and **Signal Theory Method* – other approaches

Statistical Model

$$\sigma_{total} = \sqrt{\sigma_{product}^2 + \sigma_{measurement.process}^2}$$

$$\sigma_{measurement.process} = \sqrt{\sigma_{repeatability}^2 + \sigma_{reproducibility}^2}$$

Gage study setup

Gage Study Setup

Number of Operators/Appraisers/Labs:

Number of Parts/Samples/Items:

Number of Trials:

Study Header:

Spreadsheet Structure

- ☐ Data and code columns
- ☒ Single row for each part

☒ Randomize trials

☐ Include column for reference values

OK Cancel Help

Operator/Appraiser/Lab Names Options

Operator/Appraiser/Lab Labels:

Anne	
Bob	
Carlos	

OK Cancel Help



Typical gage study data file

gagestudy.xls [Compatibility Mode] - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Acrobat STATGRAPHICS

Define Measure Analyze Improve Control Tools Help

	A	B	C	D	E	F	G	H	I	J	K	L
1	Parts	Anne_1	Anne_2	Anne_3	Bob_1	Bob_2	Bob_3	Carlos_1	Carlos_2	Carlos_3	Header	
2												
3	1	56	55	57	57	58	56	56	57	56		
4	2	63	62	62	64	64	64	62	64	64		
5	3	56	54	55	57	55	56	55	55	55		
6	4	57	55	56	56	57	55	56	57	55		
7	5	58	58	57	59	60	60	57	60	60		
8	6	56	55	54	60	59	57	55	57	56		
9	7	56	55	56	58	56	56	55	55	57		
10	8	57	57	56	57	58	57	57	58	57		
11	9	65	65	64	64	64	65	65	64	65		
12	10	58	57	57	61	60	60	58	59	60		
13												

Sheet1 Sheet2 Sheet3

Ready 100%

Data input dialog box

Excel Data Selection

Selected cells include

☐ Column names

☒ Column names and comments

☐ Data only

OK Cancel Help

Gage Studies

Input

☐ Data and code columns

☒ One row per part

OK Cancel Help

ANOVA Method (Crossed)

Parts

Anne_1
Anne_2
Anne_3
Bob_1
Bob_2
Bob_3
Carlos_1
Carlos_2
Carlos_3

Header

Data:

Anne_1
Anne_2
Anne_3
Bob_1
Bob_2
Bob_3
Carlos_1
Carlos_2
Carlos_3

Number of Appraisers/Evaluators/Labs: 3

(Part/Sample/Item Labels:)

Parts

(Header:)

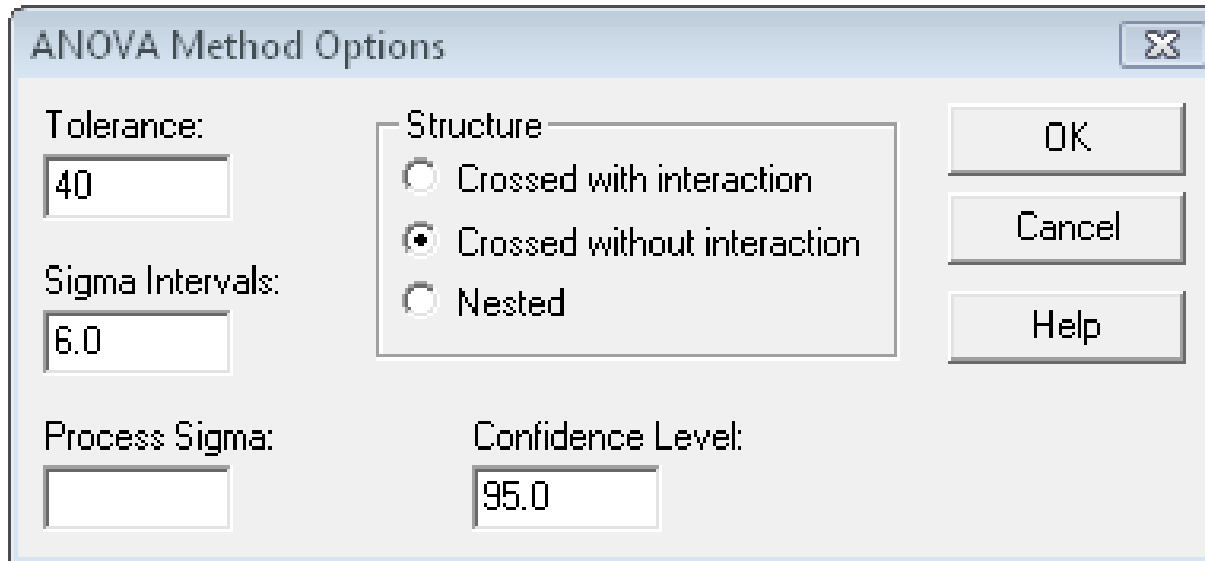
(Select:)

☐ Sort column names

OK Cancel Delete Transform... Help



Analysis Options



The image shows a software dialog box titled "ANOVA Method Options". It contains several input fields and a group of radio buttons. The "Tolerance" field is set to 40, "Sigma Intervals" is set to 6.0, and "Confidence Level" is set to 95.0. The "Process Sigma" field is empty. Under the "Structure" group, the "Crossed without interaction" option is selected with a radio button. There are three buttons on the right: "OK", "Cancel", and "Help".

ANOVA Method Options

Tolerance: 40

Sigma Intervals: 6.0

Process Sigma:

Confidence Level: 95.0

Structure

- ☐ Crossed with interaction
- ☒ Crossed without interaction
- ☐ Nested

OK

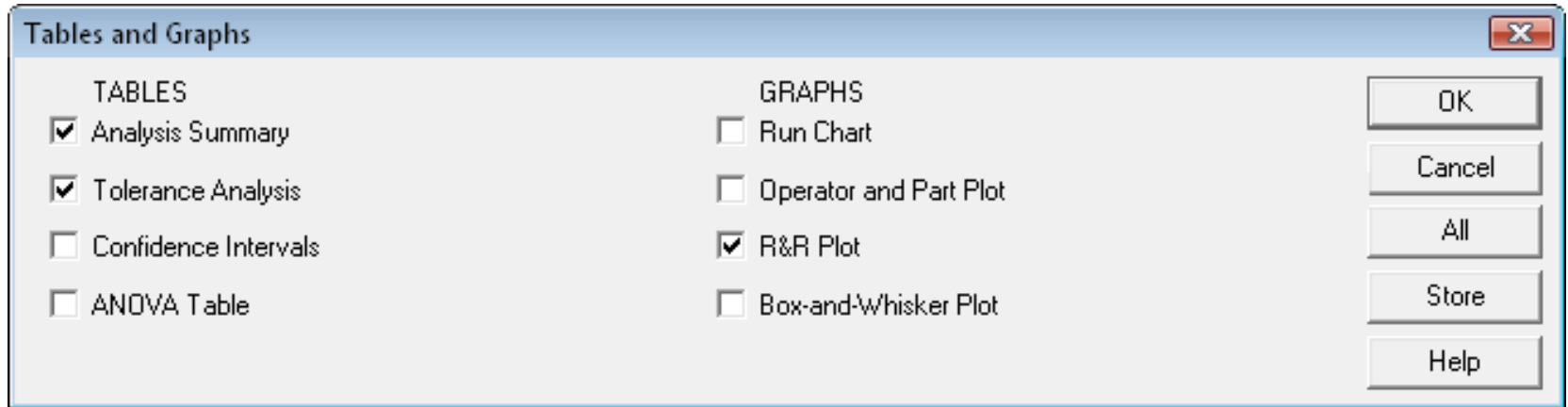
Cancel

Help

Tolerance = $USL - LSL$ (distance between specification limits)

If operators measure the same parts, the structure is “crossed”.

Tables and Graphs



Tables and Graphs

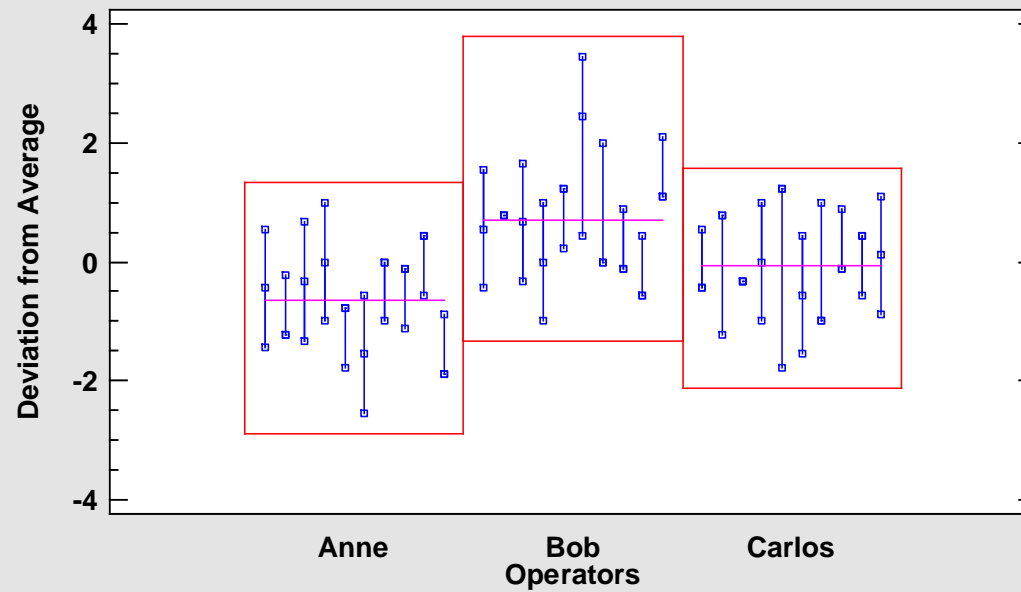
TABLES	GRAPHS
<input checked="" type="checkbox"/> Analysis Summary	<input type="checkbox"/> Run Chart
<input checked="" type="checkbox"/> Tolerance Analysis	<input type="checkbox"/> Operator and Part Plot
<input type="checkbox"/> Confidence Intervals	<input checked="" type="checkbox"/> R&R Plot
<input type="checkbox"/> ANOVA Table	<input type="checkbox"/> Box-and-Whisker Plot

OK
Cancel
All
Store
Help



R&R Plot

R&R Plot for Anne_1-Carlos_3



R&R Table

Gage Repeatability and Reproducibility Report

<i>Measurement</i>	<i>Estimated</i>	<i>Percent</i>	<i>Estimated</i>	<i>Percent</i>	<i>Percent</i>
<i>Unit</i>	<i>Sigma</i>	<i>Total Variation</i>	<i>Variance</i>	<i>Contribution</i>	<i>of R&R</i>
Repeatability	0.956757	28.3524	0.915385	8.03857	67.60
Reproducibility	0.662379	19.6288	0.438746	3.85291	32.40
R & R	1.16367	34.484	1.35413	11.8915	100.00
Parts	3.16753	93.8661	10.0333	88.1085	
Total Variation	3.37452	100.0	11.3874		

Number of distinct categories (ndc): 3



Tolerance Analysis

Tolerance Analysis

3 operators 10 parts 3 trials

Tolerance = 40.0

<i>Measurement</i>	<i>6.0</i>	<i>Percent of</i>
<i>Unit</i>	<i>Std. Dev.</i>	<i>Tolerance</i>
Repeatability	5.74054	14.3514
Reproducibility	3.97428	9.93569
R & R	6.98203	17.4551
parts	19.0052	47.513

Precision-to-tolerance ratio:

$$100 \frac{6\hat{\sigma}_{\text{measurement.process}}}{\text{tolerance}} \%$$



Example #3 (Analyze) – Capability Analysis

Determines whether a process is “capable” of meeting established specification limits.

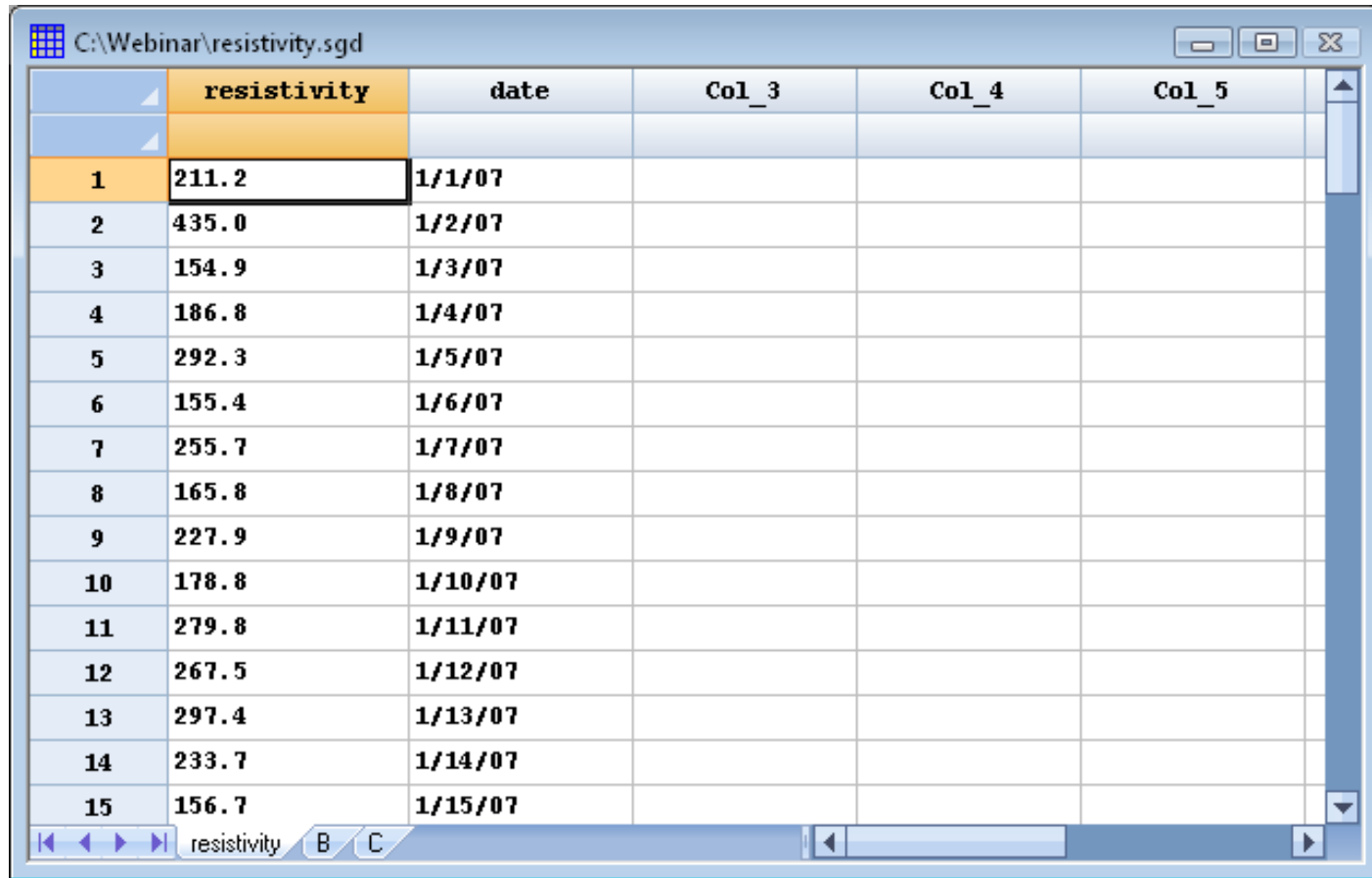
DPMO – Defects Per Million Opportunities.

$$DPMO = \frac{1,000,000 \times \text{number of defects}}{\text{number of units} \times \text{number of opportunities per unit}}$$

“Defect” = nonconformance to a specification.

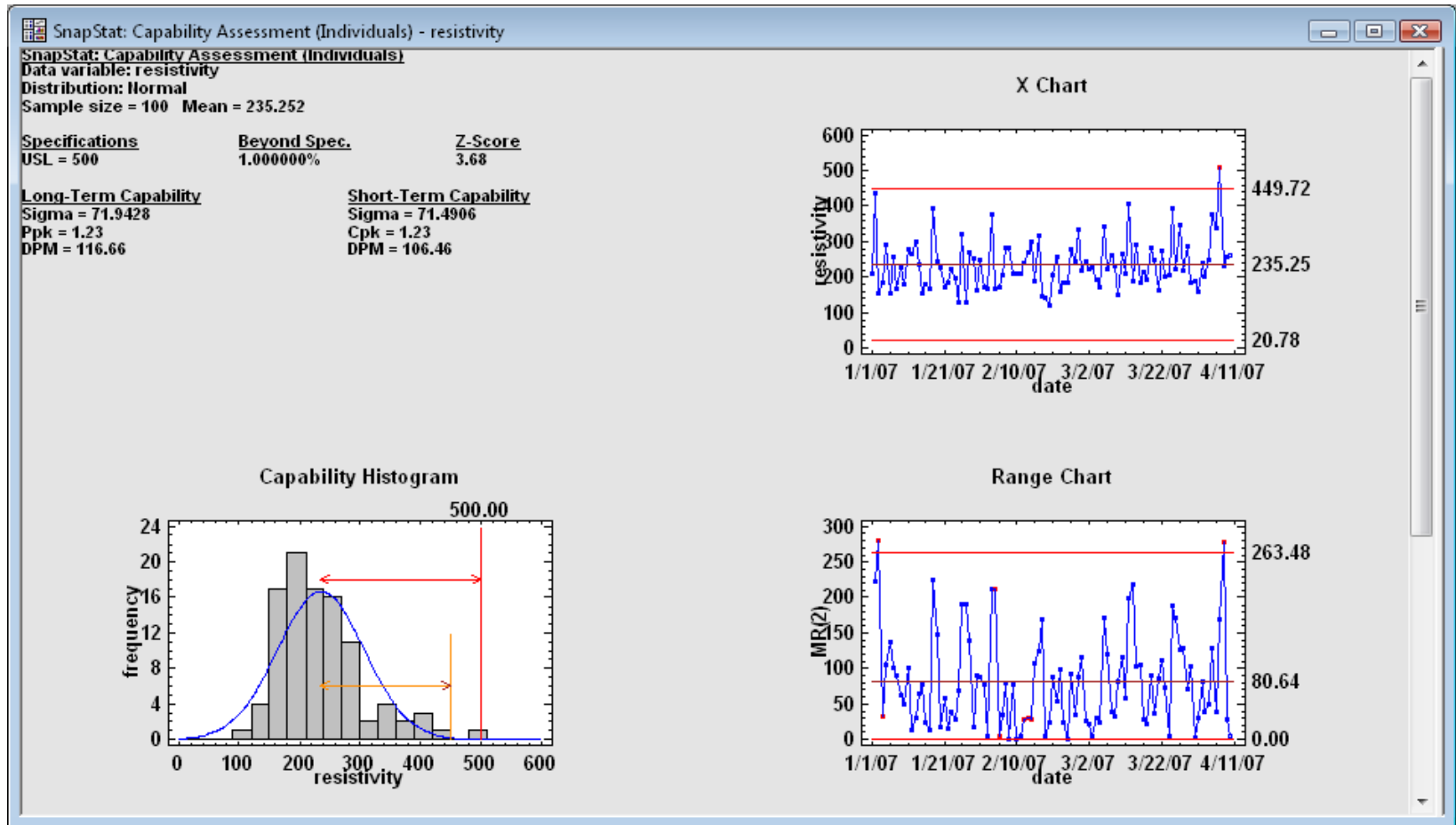
Typical Data

Measured resistivity of $n = 100$ electronic components. USL = 500.



	resistivity	date	Col_3	Col_4	Col_5
1	211.2	1/1/07			
2	435.0	1/2/07			
3	154.9	1/3/07			
4	186.8	1/4/07			
5	292.3	1/5/07			
6	155.4	1/6/07			
7	255.7	1/7/07			
8	165.8	1/8/07			
9	227.9	1/9/07			
10	178.8	1/10/07			
11	279.8	1/11/07			
12	267.5	1/12/07			
13	297.4	1/13/07			
14	233.7	1/14/07			
15	156.7	1/15/07			

Capability Assessment SnapStat



Analysis Options

Process Capability Analysis Options

Distribution

<input type="radio"/> Birnbaum-Saunders	<input type="radio"/> Generalized Logistic	<input type="radio"/> Lognormal (3-parameter)
<input type="radio"/> Cauchy	<input type="radio"/> Half Normal (2-parameter)	<input type="radio"/> Maxwell (2-parameter)
<input type="radio"/> Exponential	<input type="radio"/> Inverse Gaussian	<input checked="" type="radio"/> Normal
<input type="radio"/> Exponential (2-parameter)	<input type="radio"/> Laplace	<input type="radio"/> Pareto
<input type="radio"/> Exponential Power	<input type="radio"/> Largest Extreme Value	<input type="radio"/> Pareto (2-parameter)
<input type="radio"/> Folded Normal	<input type="radio"/> Logistic	<input type="radio"/> Rayleigh (2-parameter)
<input type="radio"/> Gamma	<input type="radio"/> Loglogistic	<input type="radio"/> Smallest Extreme Value
<input type="radio"/> Gamma (3-parameter)	<input type="radio"/> Loglogistic (3-parameter)	<input type="radio"/> Weibull
<input type="radio"/> Generalized Gamma	<input type="radio"/> Lognormal	<input type="radio"/> Weibull (3-parameter)

Include

- ☒ Long-term and short-term
- ☐ Long-term only (labeled P)
- ☐ Long-term only (labeled C)
- ☐ Short-term only

Data Transformation

- ☐ None
- ☐ Logarithm
- ☐ Power:
- ☒ Box-Cox (optimized)

Lower Threshold:

Sigma Limits:

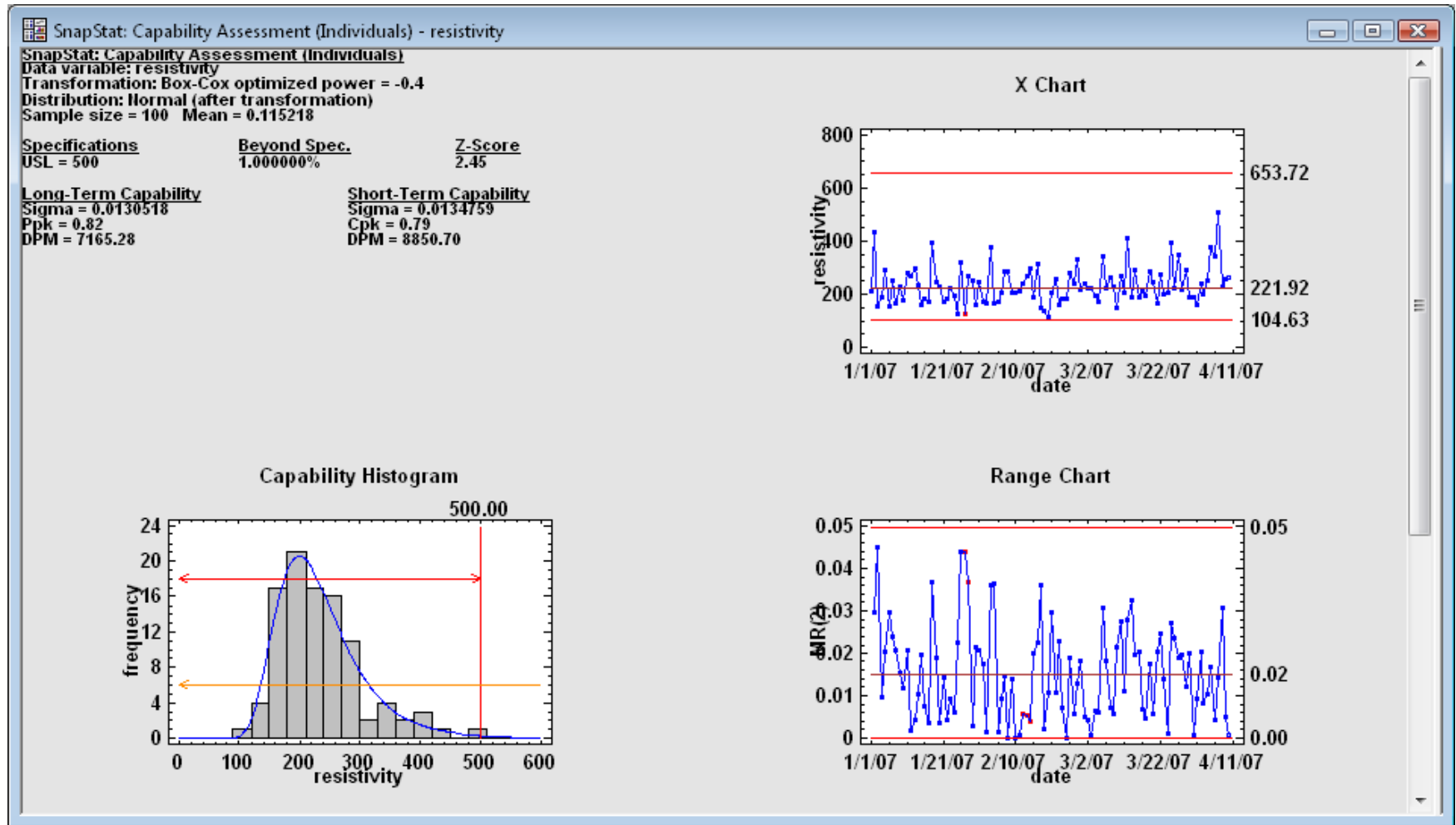
OK

Cancel

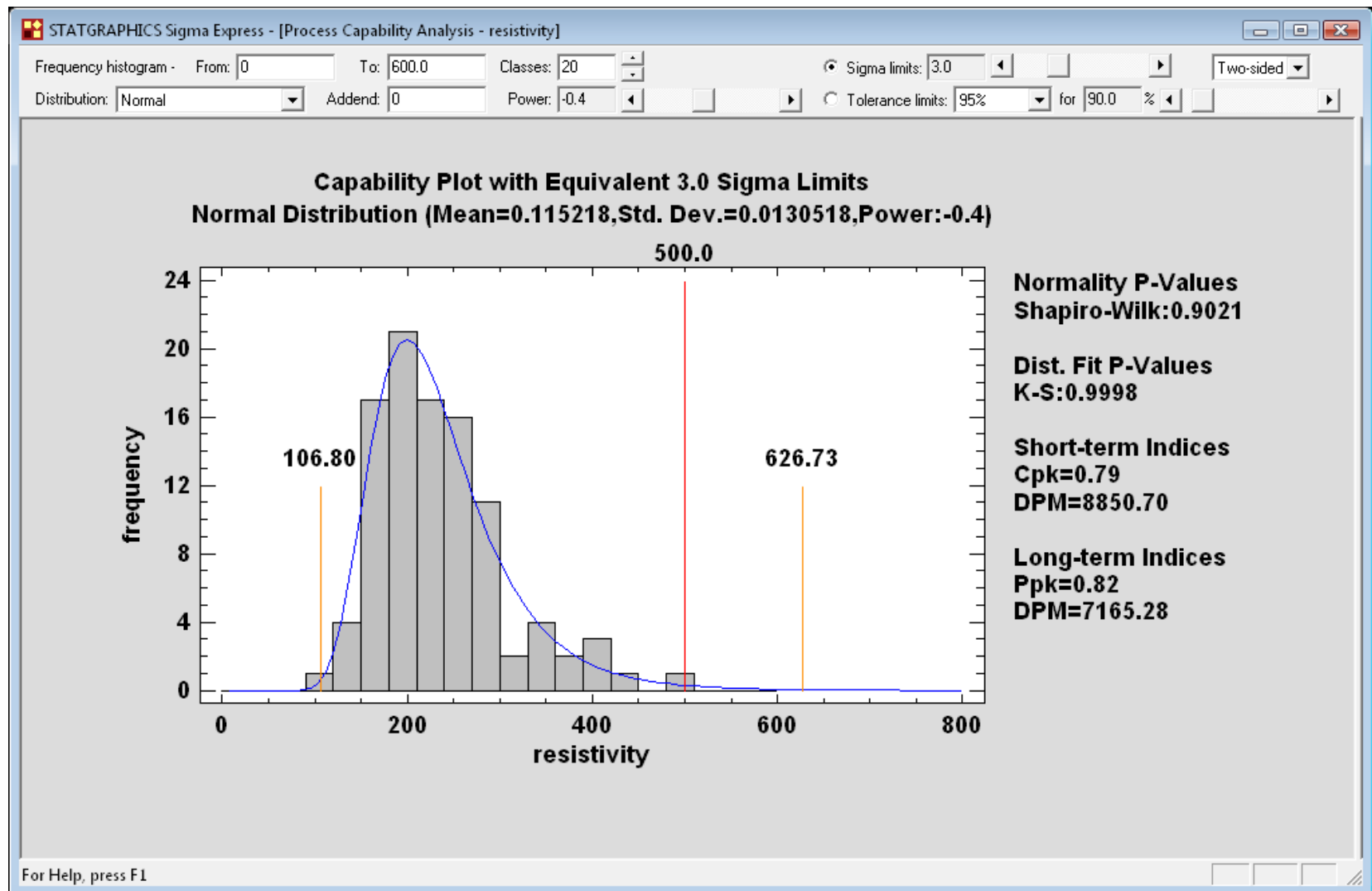
Help

Parameters

After Box-Cox Transformation



Capability Analysis Statlet®



Example #4 (Improve) – DOE

Step 1: Define Responses

DOE Step 1 - Define Responses

Number of responses:

	Response Name	(Units)
1	<input type="text" value="yield"/>	<input type="text" value="grams"/>
2	<input type="text" value="strength"/>	<input type="text" value="psi"/>
3	<input type="text" value="Y3"/>	<input type="text"/>
4	<input type="text" value="Y4"/>	<input type="text"/>

OK
Cancel
Help

Step 2 – Define Experimental Factors

DOE Step 2 - Define Experimental Factors

Number of experimental factors: 5

Factor	Name	(Units)	Type	Low	High	Levels for categorical factors
A	temperature		Continuous	150	180	A,B,C,D
B	flow rate		Continuous	10	12	A,B,C,D
C	concentration		Continuous	5	8	A,B,C,D
D	agitation rate		Continuous	125	150	A,B,C,D
E	catalyst		Continuous	1.0	1.5	A,B,C,D
F	X6		Continuous	-1.0	1.0	A,B,C,D
G	X7		Continuous	-1.0	1.0	A,B,C,D
H	X8		Continuous	-1.0	1.0	A,B,C,D

OK Back Cancel Help

Step 3 – Select Design

DOE Step 3 - Select Design

Design type

☒ Screening

☐ Optimization

Total runs: 16

Error degrees of freedom: 0

Design for continuous and 2-level categorical factors:

1/2 fraction (resolution V with 16 runs)

☒ Randomize order of runs

Additional centerpoints:

0

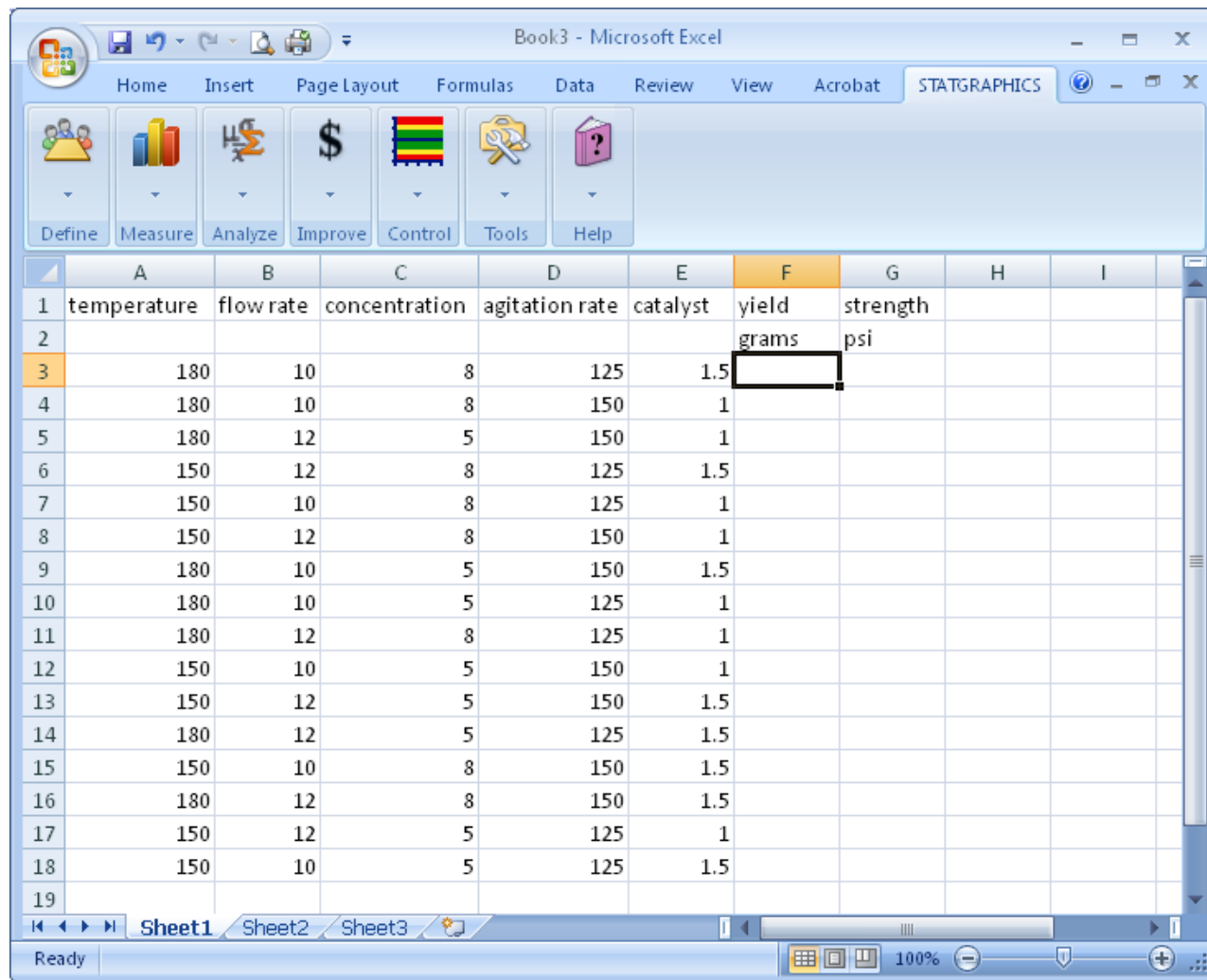
Additional replicates of base design:

0

Show more choices

OK Back Cancel Help

Step 4 – Paste to Excel Worksheet



Book3 - Microsoft Excel

Home Insert Page Layout Formulas Data Review View Acrobat STATGRAPHICS

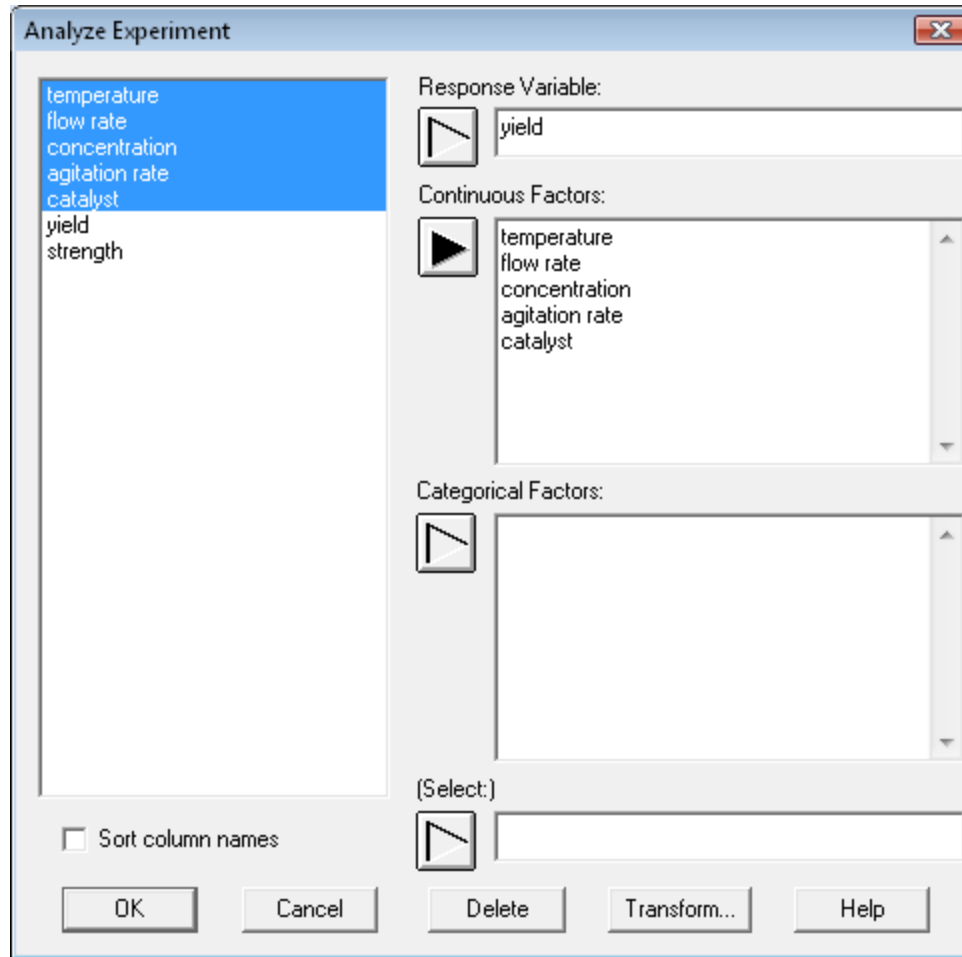
Define Measure Analyze Improve Control Tools Help

	A	B	C	D	E	F	G	H	I
1	temperature	flow rate	concentration	agitation rate	catalyst	yield	strength		
2						grams	psi		
3	180	10	8	125	1.5				
4	180	10	8	150	1				
5	180	12	5	150	1				
6	150	12	8	125	1.5				
7	150	10	8	125	1				
8	150	12	8	150	1				
9	180	10	5	150	1.5				
10	180	10	5	125	1				
11	180	12	8	125	1				
12	150	10	5	150	1				
13	150	12	5	150	1.5				
14	180	12	5	125	1.5				
15	150	10	8	150	1.5				
16	180	12	8	150	1.5				
17	150	12	5	125	1				
18	150	10	5	125	1.5				
19									

Sheet1 Sheet2 Sheet3

Ready 100%

Analyze Experiment



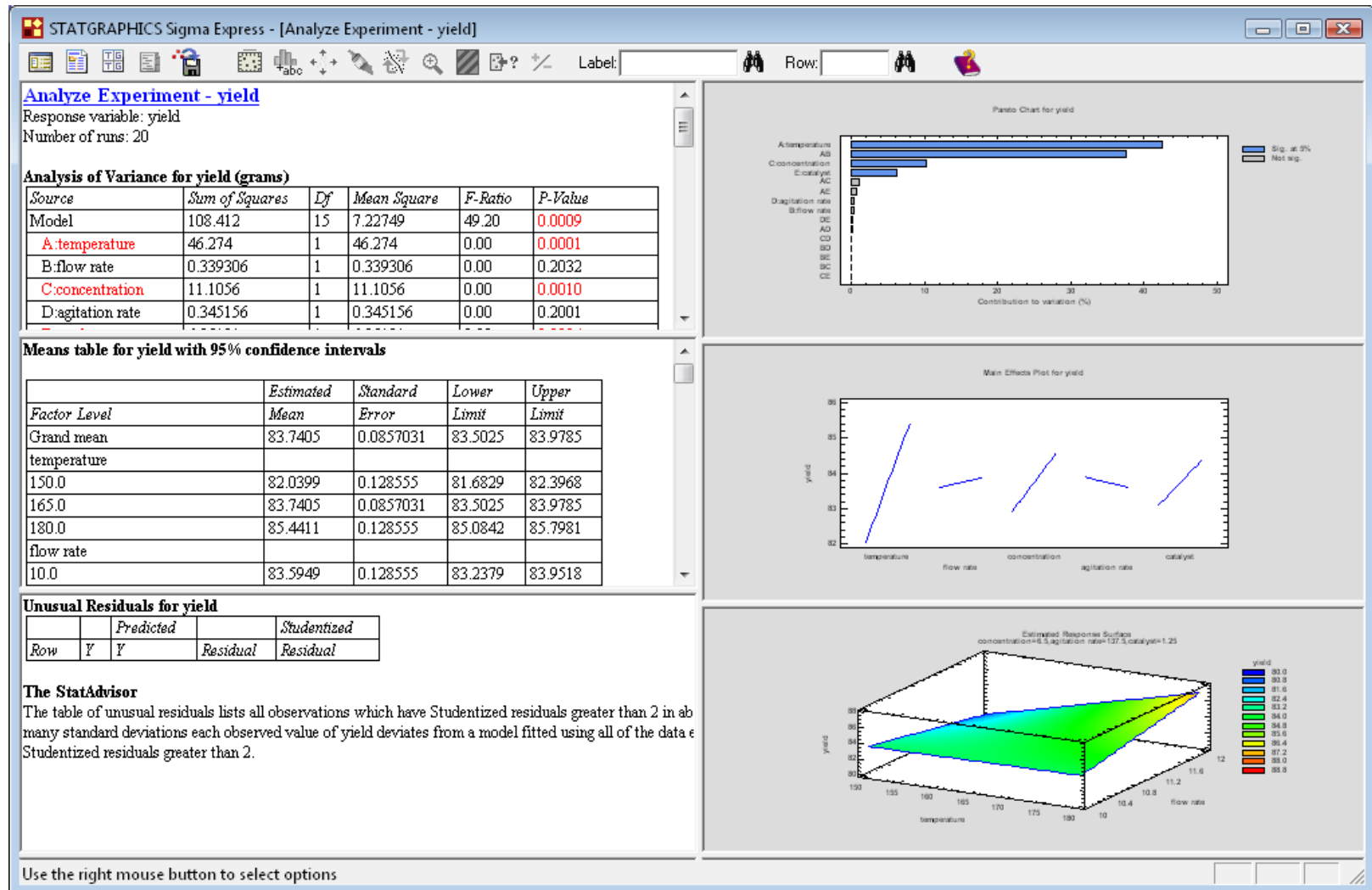
Tables and Graphs

Tables and Graphs

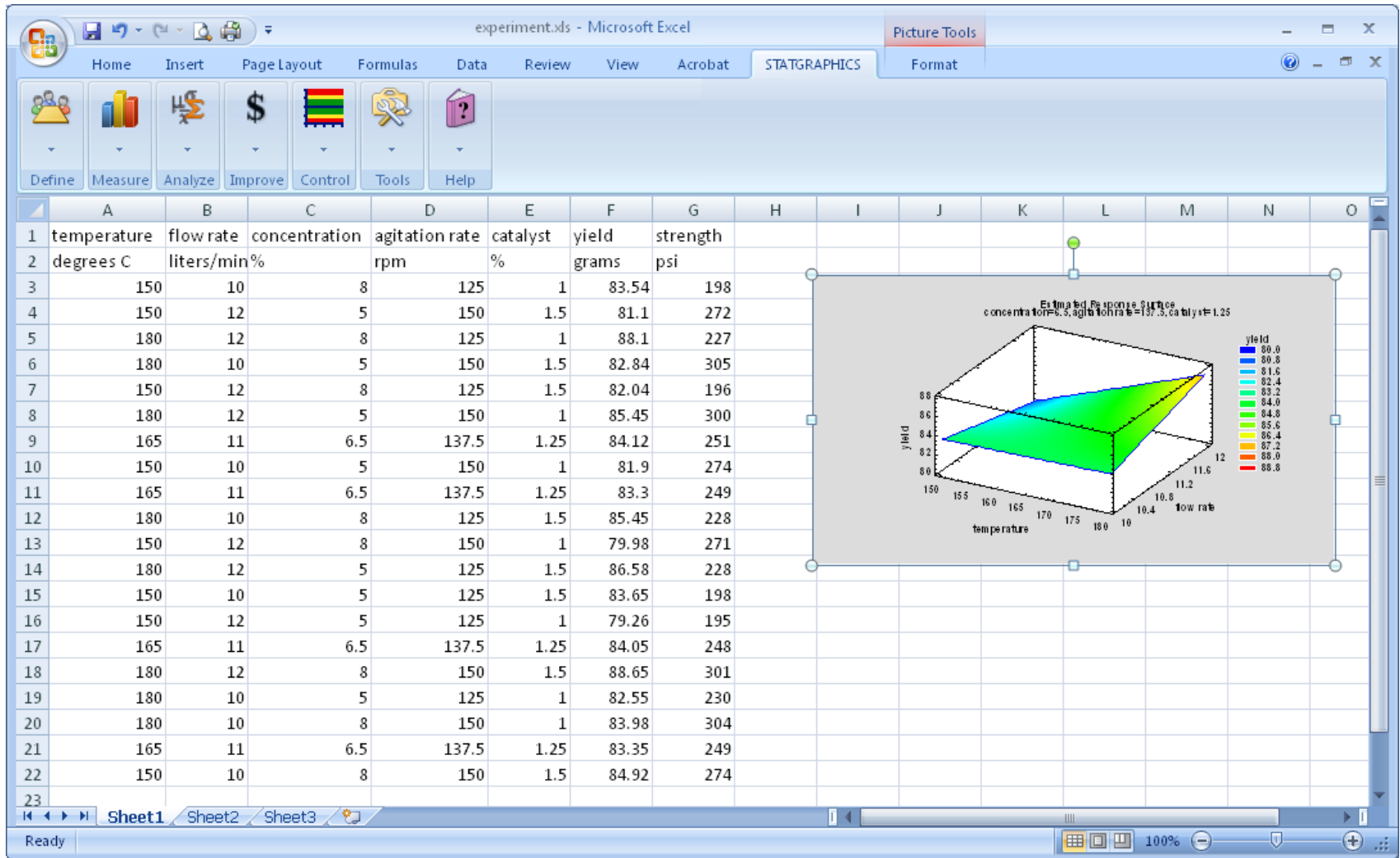
TABLES	GRAPHS
<input checked="" type="checkbox"/> Analysis Summary	<input checked="" type="checkbox"/> Pareto Chart
<input checked="" type="checkbox"/> Means Table	<input checked="" type="checkbox"/> Main Effects Plot
<input type="checkbox"/> Standardized Regression Coefficients	<input type="checkbox"/> Interaction Plot
<input type="checkbox"/> Unstandardized Regression Coefficients	<input type="checkbox"/> Trace Plot
<input type="checkbox"/> Predictions	<input checked="" type="checkbox"/> Surface Plot
<input checked="" type="checkbox"/> Unusual Residuals	<input type="checkbox"/> Contour Plot
<input type="checkbox"/> Optimization	<input type="checkbox"/> Diagnostic Plots

OK
Cancel
All
Store
Help

Analysis Window

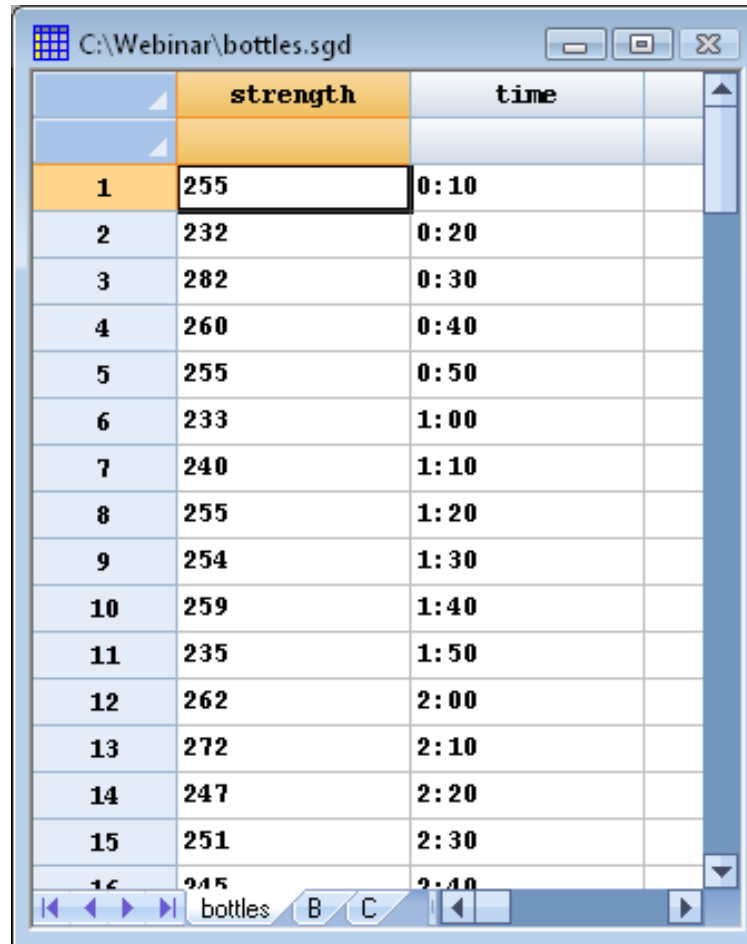


Paste Back to Excel



Example #5 (Control) – Individuals with EWMA

Suggested by Stu Hunter

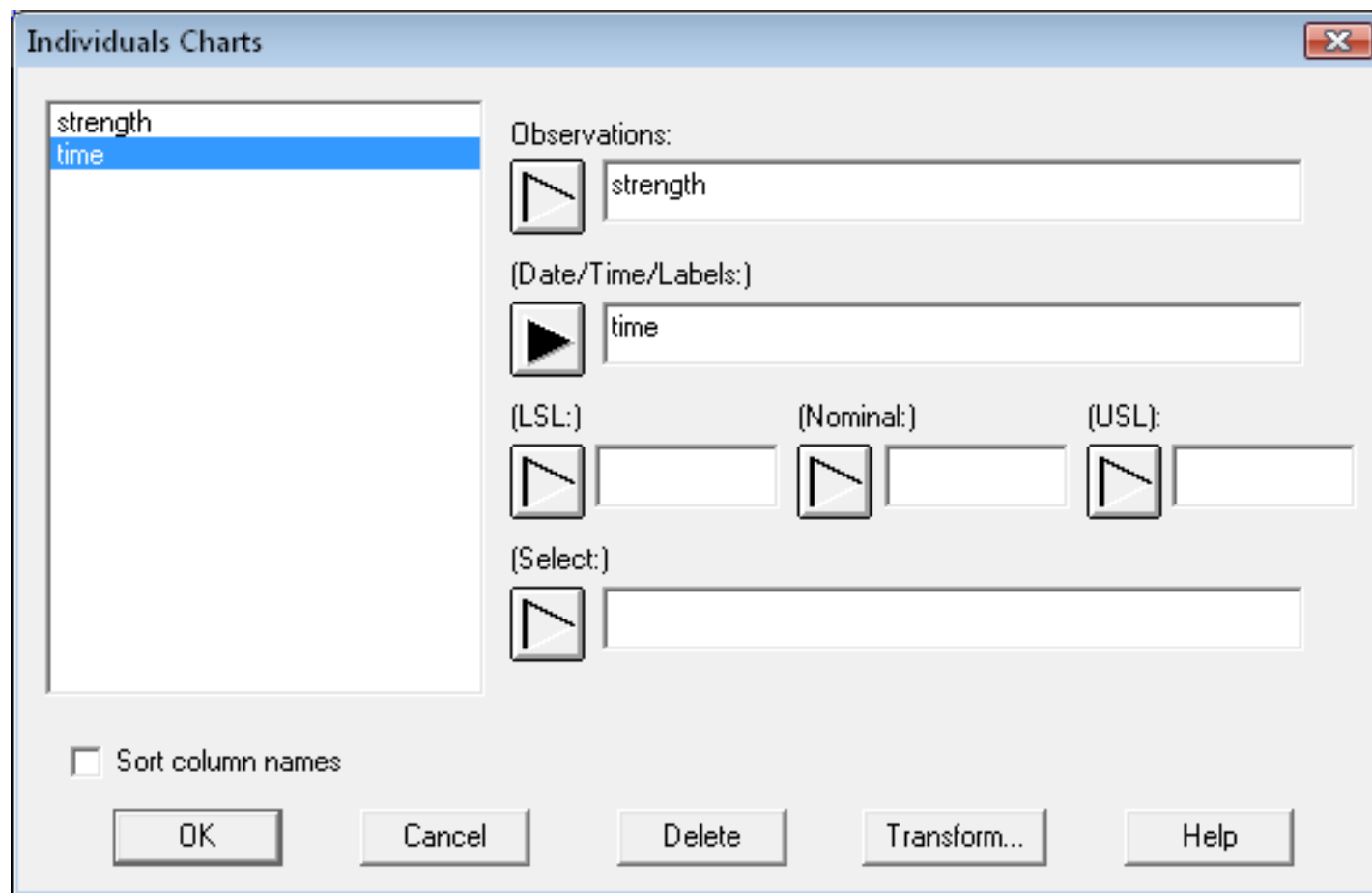


A screenshot of a data table window titled "C:\Webinar\bottles.sgd". The table has three columns: an index column, a "strength" column, and a "time" column. The first row (index 1) is highlighted in orange. The data is as follows:

	strength	time
1	255	0:10
2	232	0:20
3	282	0:30
4	260	0:40
5	255	0:50
6	233	1:00
7	240	1:10
8	255	1:20
9	254	1:30
10	259	1:40
11	235	1:50
12	262	2:00
13	272	2:10
14	247	2:20
15	251	2:30
16	245	2:40

The window includes a standard toolbar at the bottom with navigation buttons and sheet tabs labeled "bottles", "B", and "C".

Data Input Dialog Box



The image shows the 'Individuals Charts' dialog box in Minitab. On the left, a list of variables includes 'strength' and 'time', with 'time' selected. On the right, the 'Observations:' field contains 'strength'. Below it, the '(Date/Time/Labels:)' field contains 'time'. Further down, there are three empty fields for '(LSL:)', '(Nominal:)', and '(USL:)', each preceded by a small icon. Below these is a '(Select:)' field, also preceded by a small icon. At the bottom left, there is a checkbox labeled 'Sort column names'. At the bottom, there are five buttons: 'OK', 'Cancel', 'Delete', 'Transform...', and 'Help'.

Individuals Charts

strength
time

Observations:
strength

(Date/Time/Labels:)
time

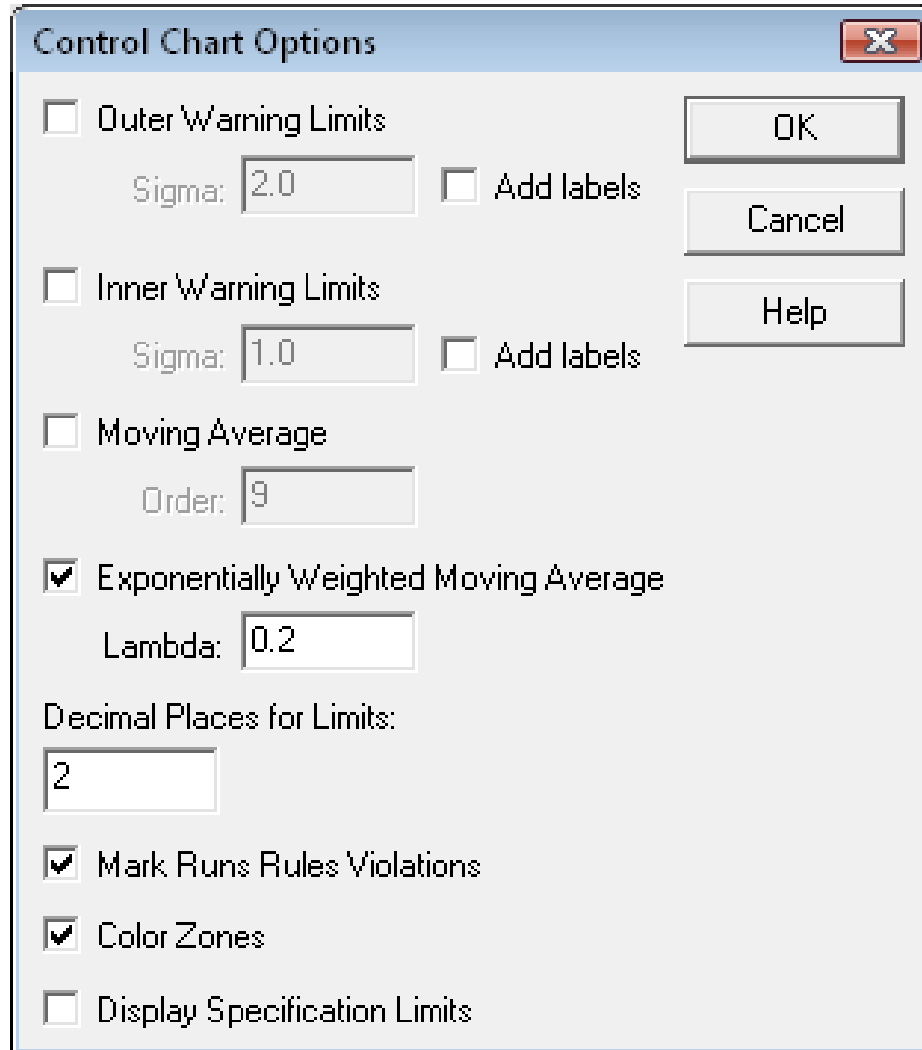
(LSL:) (Nominal:) (USL:)

(Select:)

☐ Sort column names

OK Cancel Delete Transform... Help

X Chart – Pane Options



A screenshot of a software dialog box titled "Control Chart Options". The dialog box has a standard Windows-style title bar with a close button (X) in the top right corner. The main area contains several settings for a control chart. There are three sections for warning limits: "Outer Warning Limits" with a Sigma value of 2.0, "Inner Warning Limits" with a Sigma value of 1.0, and "Moving Average" with an Order value of 9. Each of these sections has an unchecked checkbox and an "Add labels" checkbox. The "Exponentially Weighted Moving Average" section is checked, with a Lambda value of 0.2. Below these is a "Decimal Places for Limits" field set to 2. At the bottom, there are three more checkboxes: "Mark Runs Rules Violations" (checked), "Color Zones" (checked), and "Display Specification Limits" (unchecked). On the right side of the dialog, there are three buttons: "OK", "Cancel", and "Help".

Control Chart Options

☐ Outer Warning Limits
Sigma: 2.0 ☐ Add labels

☐ Inner Warning Limits
Sigma: 1.0 ☐ Add labels

☐ Moving Average
Order: 9

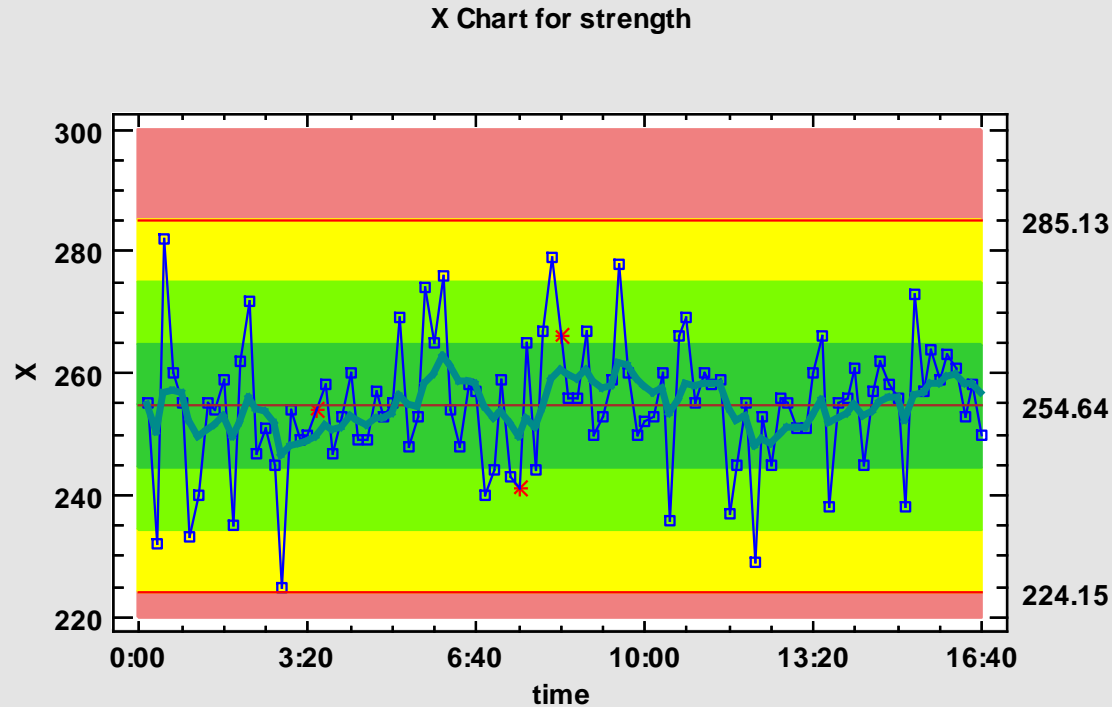
☒ Exponentially Weighted Moving Average
Lambda: 0.2

Decimal Places for Limits:
2

☒ Mark Runs Rules Violations
☒ Color Zones
☐ Display Specification Limits

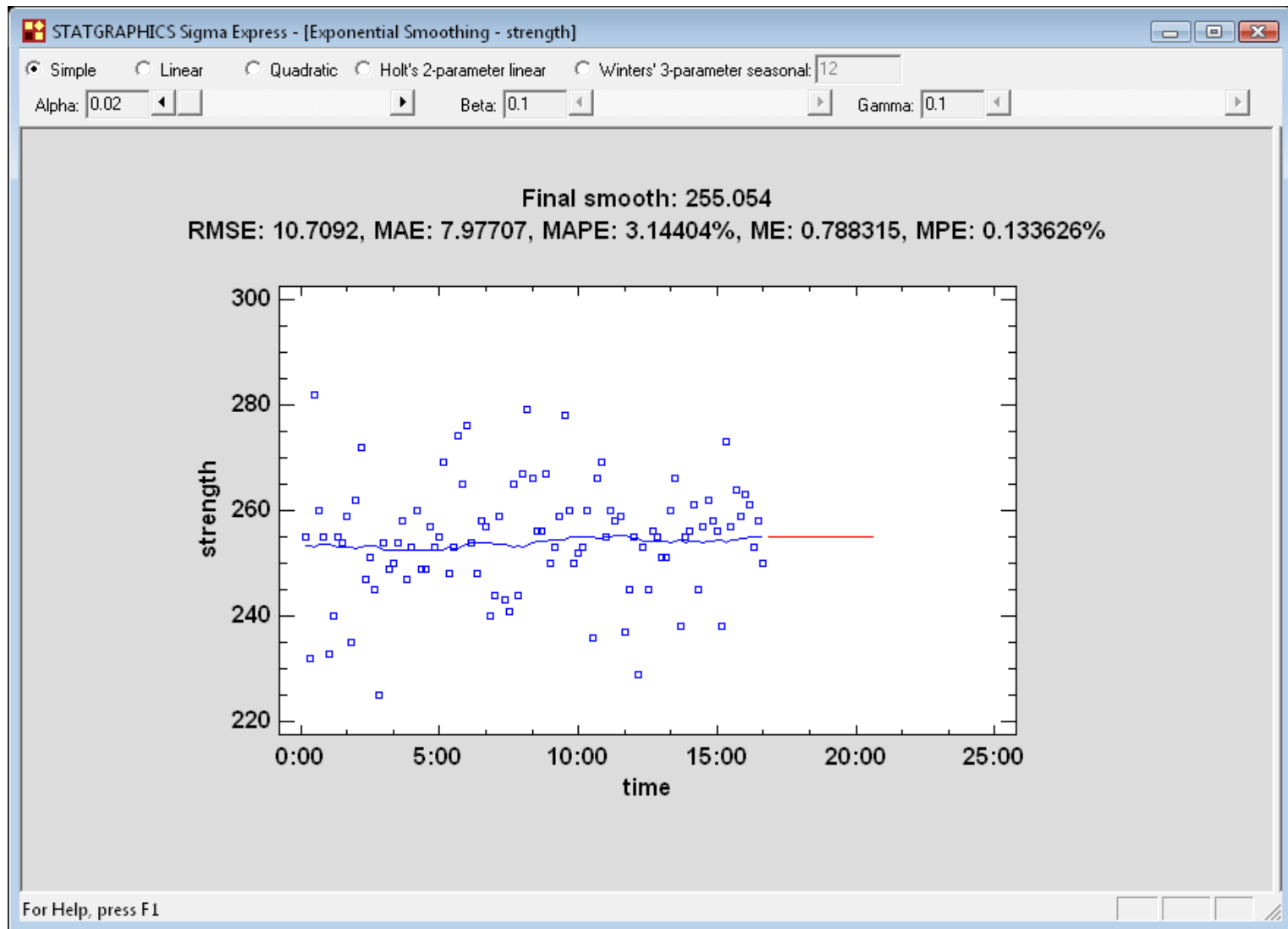
OK
Cancel
Help

X Chart with EWMA ($\lambda = 0.2$)



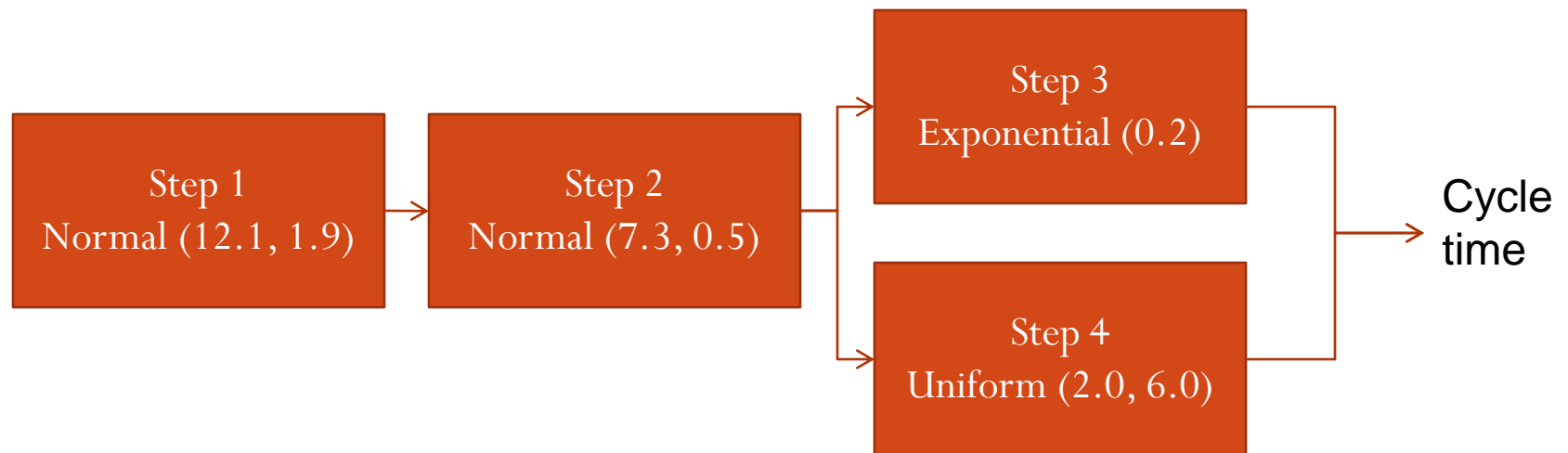
Note: inner zone provides 3-sigma limits for the EWMA.

Exponential Smoothing Statlet



Example #6 - Monte Carlo Simulation

Cycle time = Step 1 + Step 2 + MAX(Step 3, Step 4)



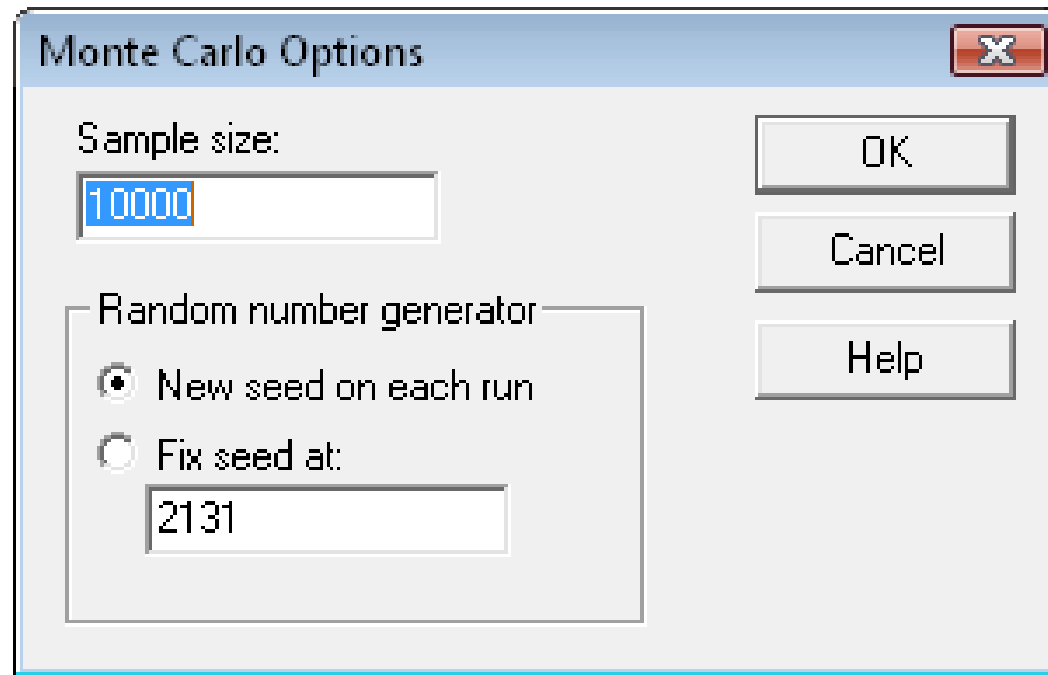
Data Input Dialog Box

Monte Carlo Simulation

Number of variables:

	Variable	Type	Definition	
1	Step 1	Normal r.v.	NORMAL(12.1,1.9)	Edit
2	Step 2	Normal r.v.	NORMAL(7.3,0.5)	Edit
3	Step 3	Exponential r.v.	EXPONENTIAL(0.2,0.0)	Edit
4	Step 4	Uniform r.v.	UNIFORM(2.0,6.0)	Edit
5	Longer of 3,4	Function	Step3*(Step3>=Step4)+Step4*(Step4>Step3)	Edit
6	Cycle time	Function	Step 1+Step 2+Longer of 3,4	Edit
7				Edit
8				Edit
9				Edit
10				Edit
11				Edit
12				Edit
13				Edit
14				Edit
15				Edit

Analysis Options



A screenshot of a software dialog box titled "Monte Carlo Options". The dialog has a standard Windows-style title bar with a close button (X) in the top right corner. The main content area is light gray. On the left, there is a "Sample size:" label followed by a text input field containing the number "10000". Below this, there is a section titled "Random number generator" which contains two radio button options: "New seed on each run" (which is selected) and "Fix seed at:" followed by a text input field containing the number "2131". On the right side of the dialog, there are three buttons stacked vertically: "OK", "Cancel", and "Help".

Monte Carlo Options

Sample size:

10000

Random number generator

☒ New seed on each run

☐ Fix seed at:

2131

OK

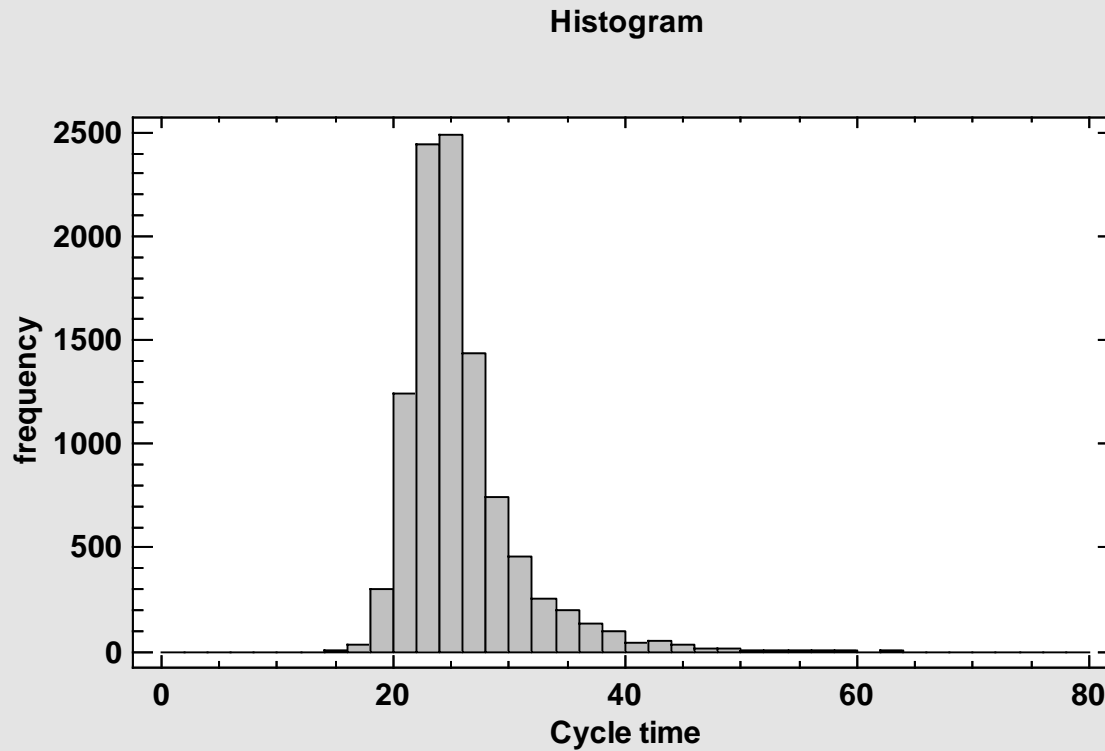
Cancel

Help

Results

	Step 1	Step 2	Step 3	Step 4	Longer of 3,4	Cycle time
1	8.74647	6.92289	9.10541	5.4555	9.10541	24.7748
2	12.2499	7.75773	0.584659	4.92922	4.92922	24.9369
3	15.3852	6.95049	0.861326	2.38812	2.38812	24.7238
4	13.5535	7.10579	1.62776	2.67132	2.67132	23.3306
5	12.4184	7.97465	2.67824	3.26676	3.26676	23.6598
6	12.5518	7.79287	0.226421	2.76604	2.76604	23.1107
7	14.0215	7.2574	0.269444	2.57698	2.57698	23.8559
8	12.3127	6.47419	0.987392	3.66773	3.66773	22.4546
9	11.6138	7.67422	1.94213	2.8533	2.8533	22.1413
10	11.6337	7.78204	18.5557	3.04468	18.5557	37.9714
11	13.5279	7.57129	2.099	2.58311	2.58311	23.6823
12	10.7113	7.47557	6.87714	3.86512	6.87714	25.064
13	12.2368	8.50403	2.9599	5.53983	5.53983	26.2807
14	8.94834	7.61052	4.74446	3.57031	4.74446	21.3033
15	12.3489	8.336	0.18726	2.74818	2.74818	23.4331
16	12.8097	6.65332	17.9887	2.91263	17.9887	37.4517
17	10.7898	6.36124	3.9373	4.13587	4.13587	21.2869
18	13.9608	7.09202	2.62326	3.02066	3.02066	24.0735

Histogram of cycle time



More Information

Go to www.statgraphics.com

Or send e-mail to info@statgraphics.com

