DATA vs TIME

Look at Trend versus Time

Trend Chart

Model Distribution vs Time

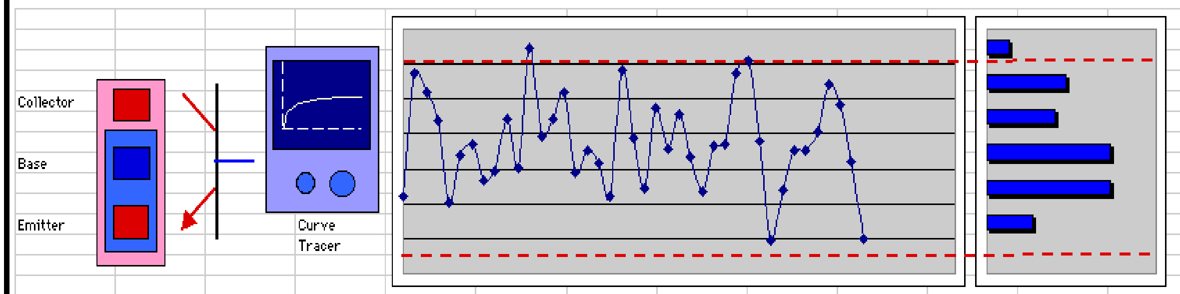
Time Series Modeling
Autocorrelation
Partial Autocorrelation
Moving Average
EWMA
AR
MA
ARIMA

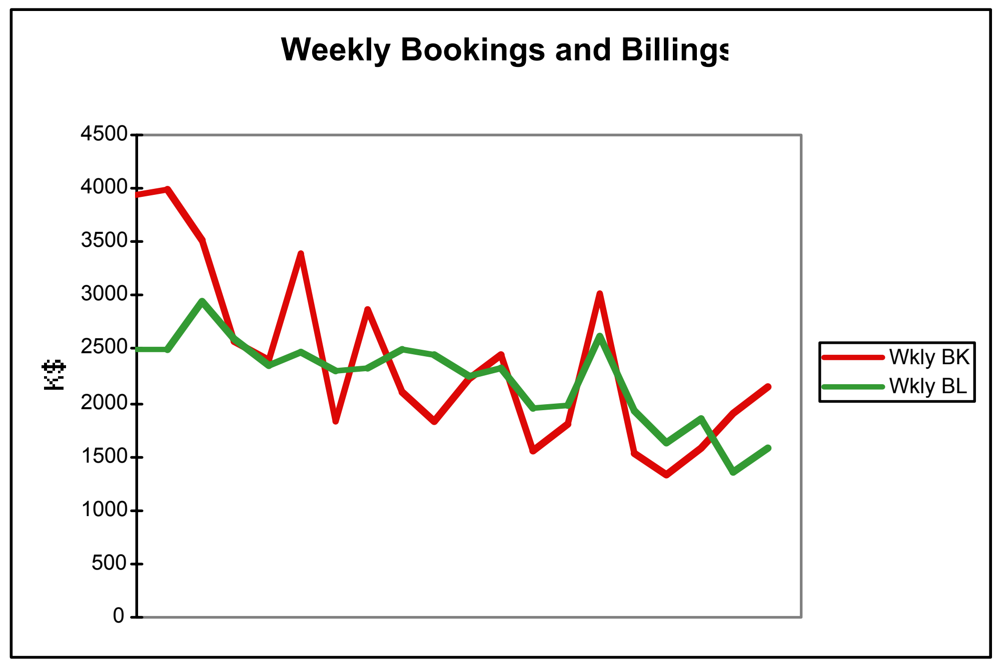
Study Sources -Time Variation

Gauge Capability
Variance Components Analysis

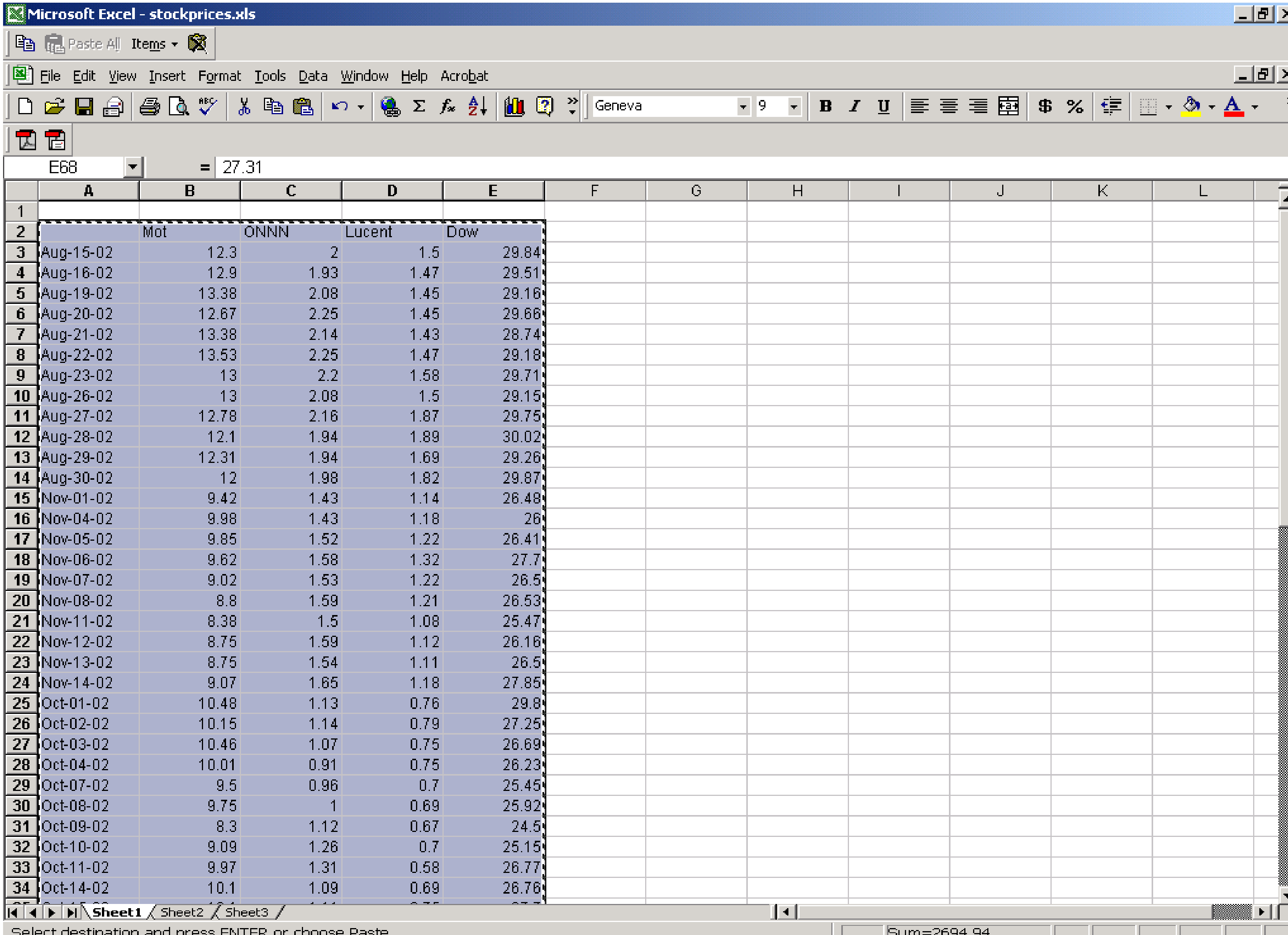
Compare Trend to Limits

Control Charts
X-Bar
R, S
Individuals
Moving R
EWMA



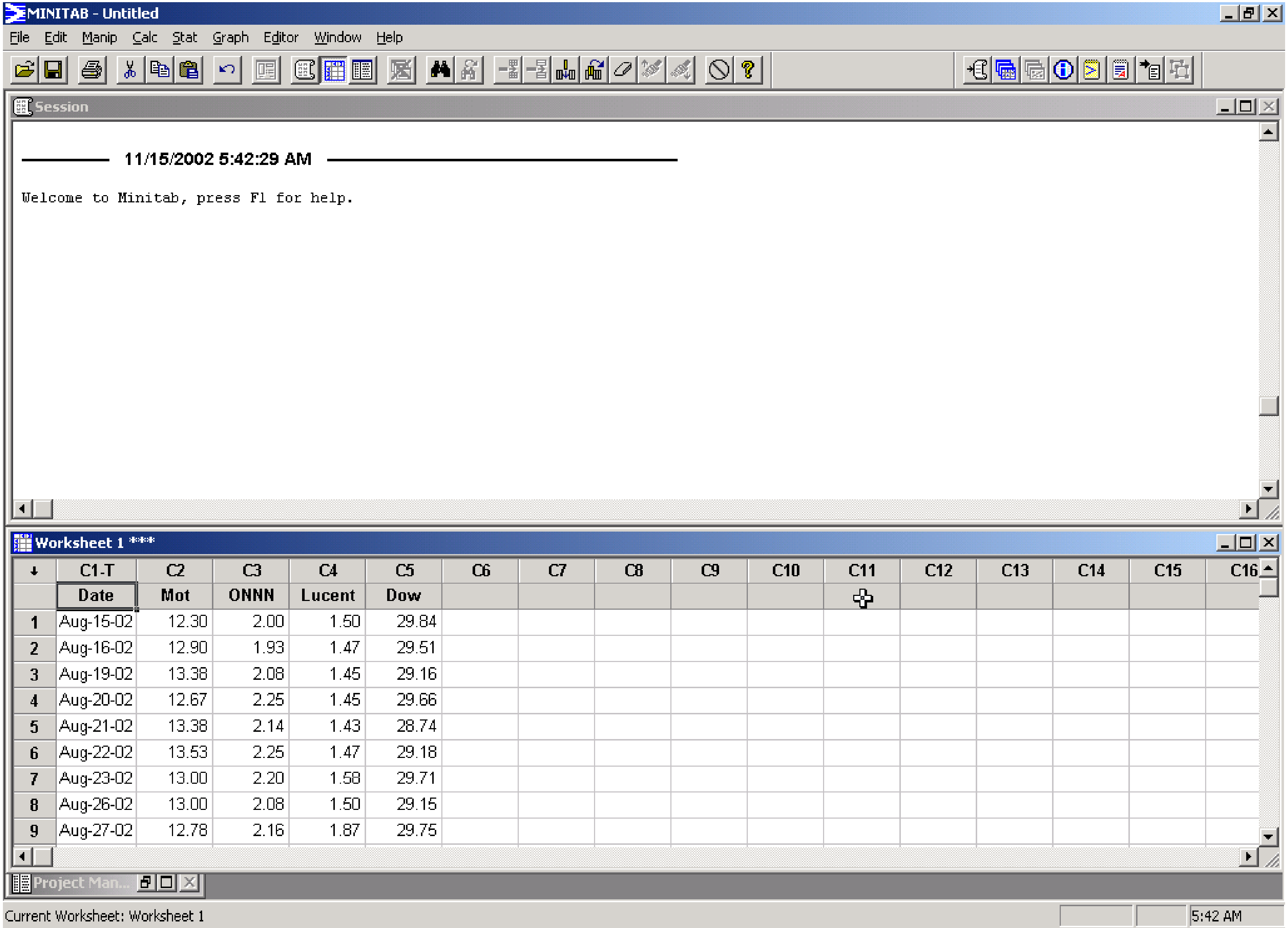


Open a New Worksheet / Type: Excel or Copy from Excel (stockprices.xls)



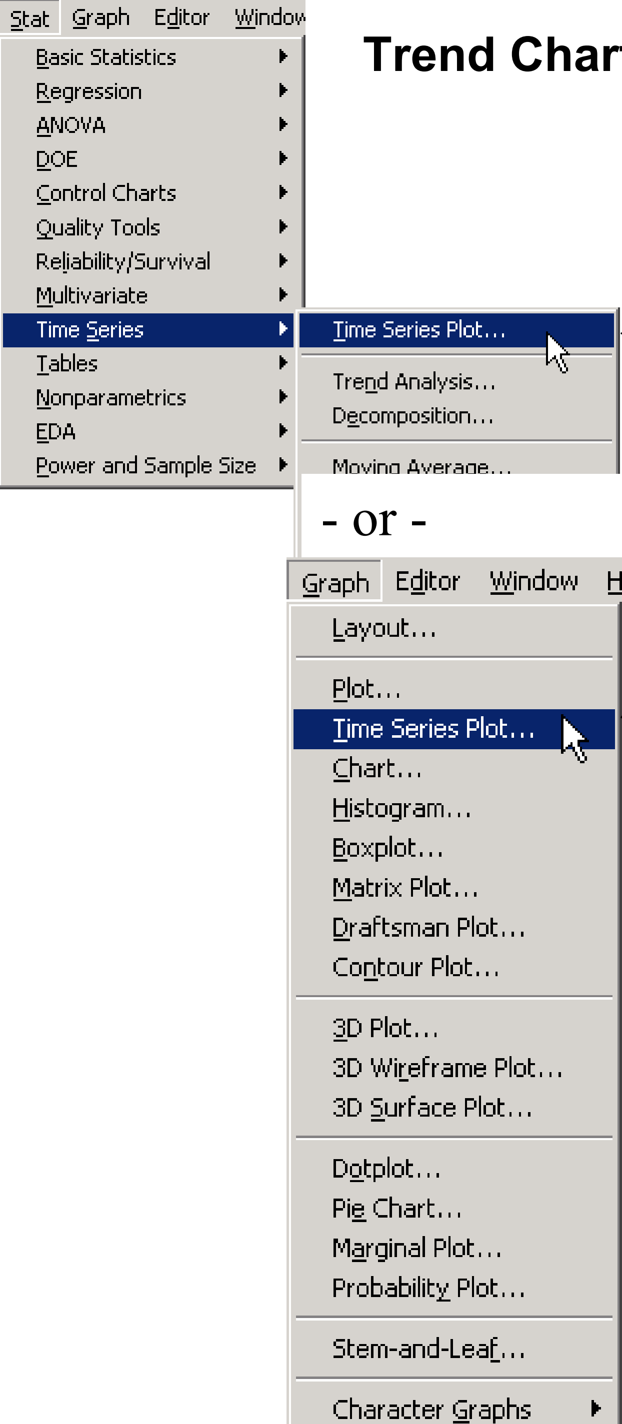
	Mot	ONNN	Lucent	Dow
Aug-15-02	12.3	2	1.5	29.84
Aug-16-02	12.9	1.93	1.47	29.51
Aug-19-02	13.38	2.08	1.45	29.16
Aug-20-02	12.67	2.25	1.45	29.66
Aug-21-02	13.38	2.14	1.43	28.74
Aug-22-02	13.53	2.25	1.47	29.18
Aug-23-02	13	2.2	1.58	29.71
Aug-26-02	13	2.08	1.5	29.15
Aug-27-02	12.78	2.16	1.87	29.75
Aug-28-02	12.1	1.94	1.89	30.02
Aug-29-02	12.31	1.94	1.69	29.26
Aug-30-02	12	1.98	1.82	29.87
Nov-01-02	9.42	1.43	1.14	26.48
Nov-04-02	9.98	1.43	1.18	26
Nov-05-02	9.85	1.52	1.22	26.41
Nov-06-02	9.62	1.58	1.32	27.7
Nov-07-02	9.02	1.53	1.22	26.5
Nov-08-02	8.8	1.59	1.21	26.53
Nov-11-02	8.38	1.5	1.08	25.47
Nov-12-02	8.75	1.59	1.12	26.16
Nov-13-02	8.75	1.54	1.11	26.5
Nov-14-02	9.07	1.65	1.18	27.85
Oct-01-02	10.48	1.13	0.76	29.8
Oct-02-02	10.15	1.14	0.79	27.25
Oct-03-02	10.46	1.07	0.75	26.69
Oct-04-02	10.01	0.91	0.75	26.23
Oct-07-02	9.5	0.96	0.7	25.45
Oct-08-02	9.75	1	0.69	25.92
Oct-09-02	8.3	1.12	0.67	24.5
Oct-10-02	9.09	1.26	0.7	25.15
Oct-11-02	9.97	1.31	0.58	26.77
Oct-14-02	10.1	1.09	0.69	26.76

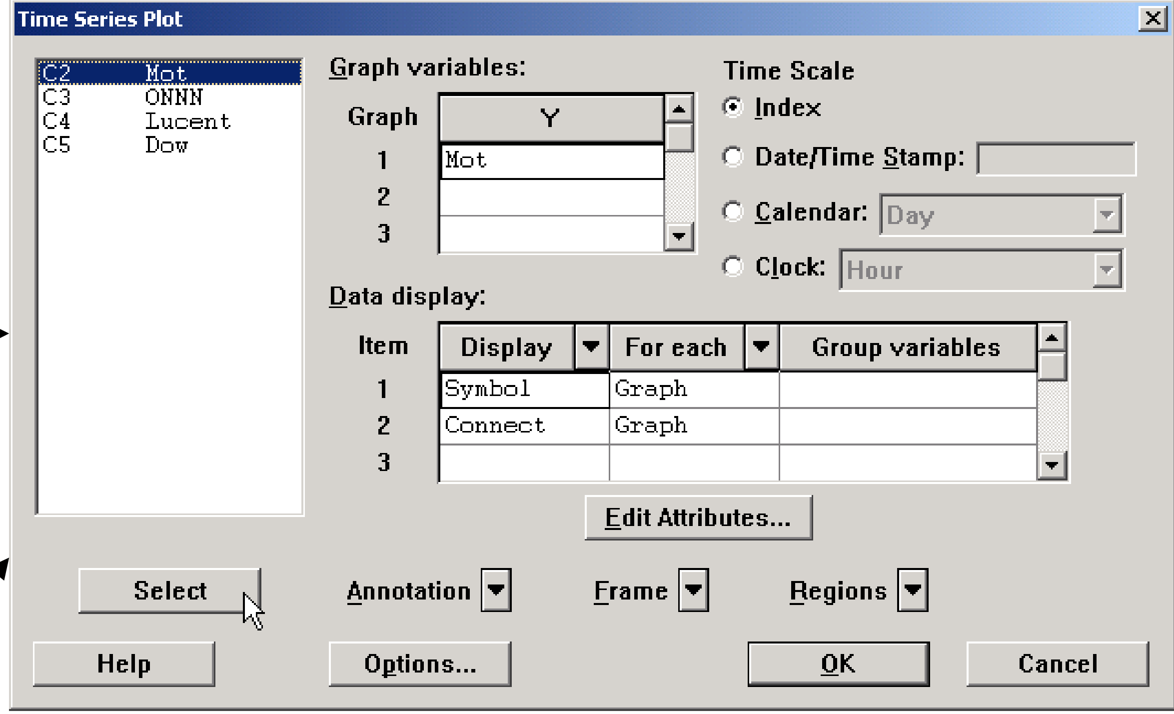
Paste into Minitab

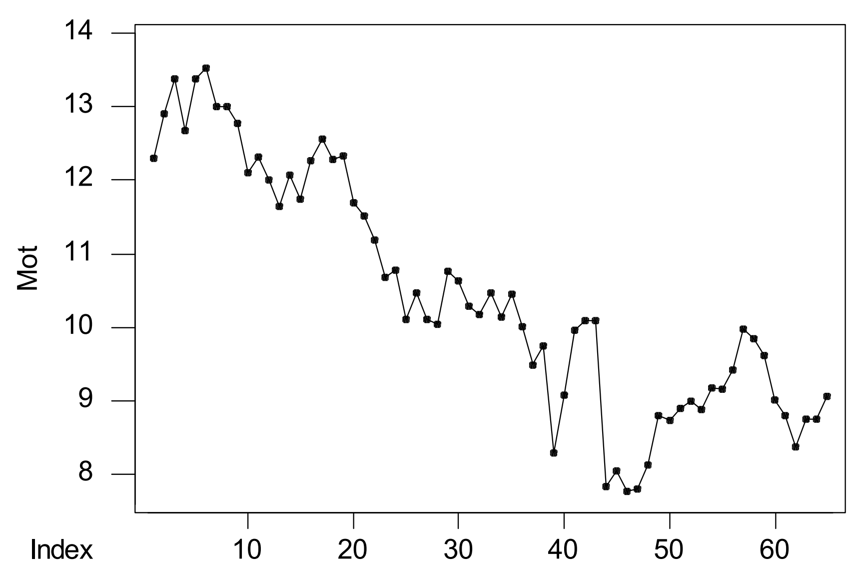


↓	C1-T	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
	Date	Mot	ONNN	Lucent	Dow											
1	Aug-15-02	12.30	2.00	1.50	29.84											
2	Aug-16-02	12.90	1.93	1.47	29.51											
3	Aug-19-02	13.38	2.08	1.45	29.16											
4	Aug-20-02	12.67	2.25	1.45	29.66											
5	Aug-21-02	13.38	2.14	1.43	28.74											
6	Aug-22-02	13.53	2.25	1.47	29.18											
7	Aug-23-02	13.00	2.20	1.58	29.71											
8	Aug-26-02	13.00	2.08	1.50	29.15											
9	Aug-27-02	12.78	2.16	1.87	29.75											

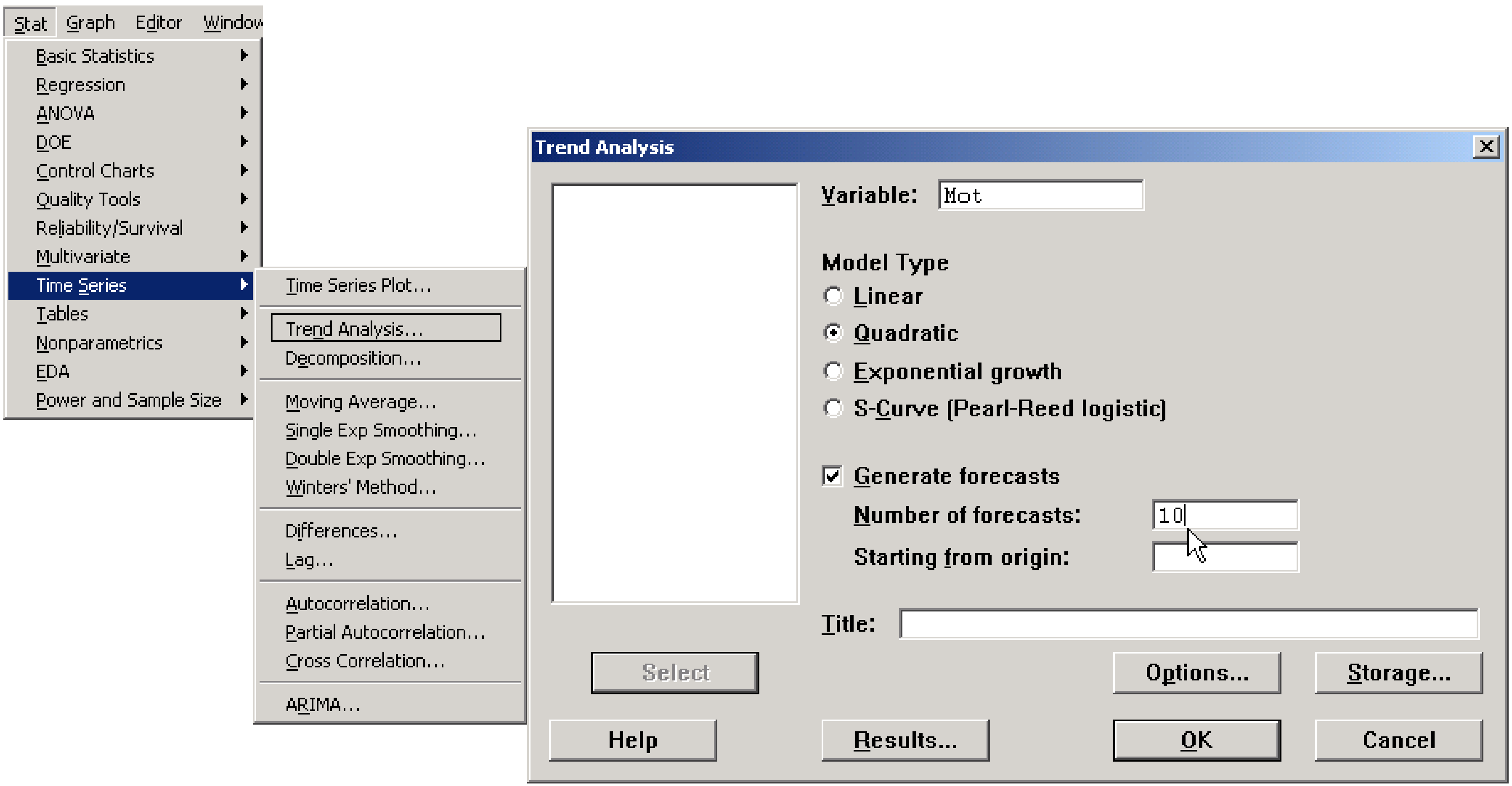
Trend Chart

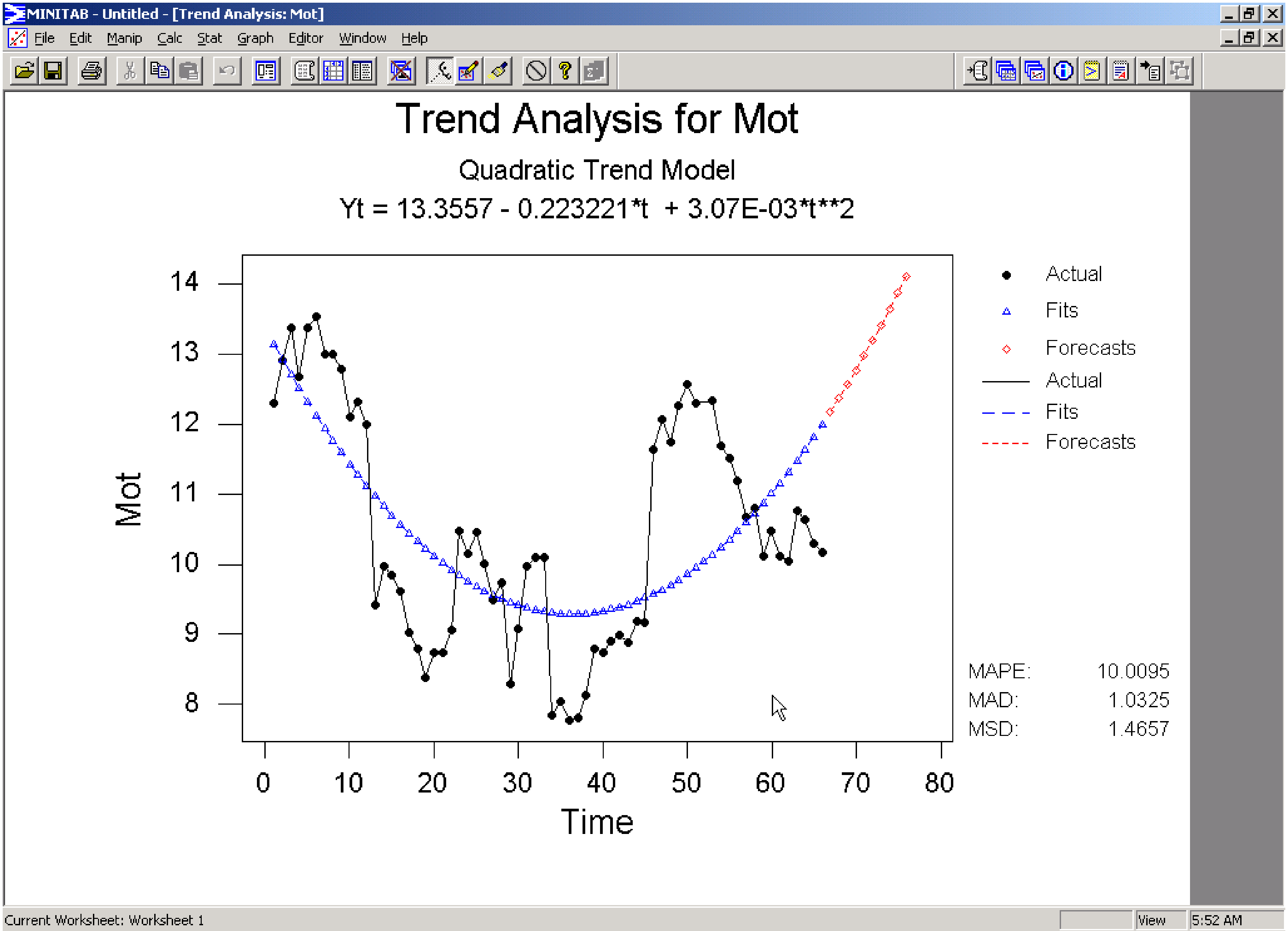

Stat Graph Editor Window
Basic Statistics
Regression
ANOVA
DOE
Control Charts
Quality Tools
Reliability/Survival
Multivariate
Time Series
Tables
Nonparametrics
EDA
Power and Sample Size
Time Series Plot...
Trend Analysis...
Decomposition...
Moving Average...
- or -
Graph Editor Window H
Layout...
Plot...
Time Series Plot...
Chart...
Histogram...
Boxplot...
Matrix Plot...
Draftsman Plot...
Contour Plot...
3D Plot...
3D Wireframe Plot...
3D Surface Plot...
Dotplot...
Pie Chart...
Marginal Plot...
Probability Plot...
Stem-and-Leaf...
Character Graphs

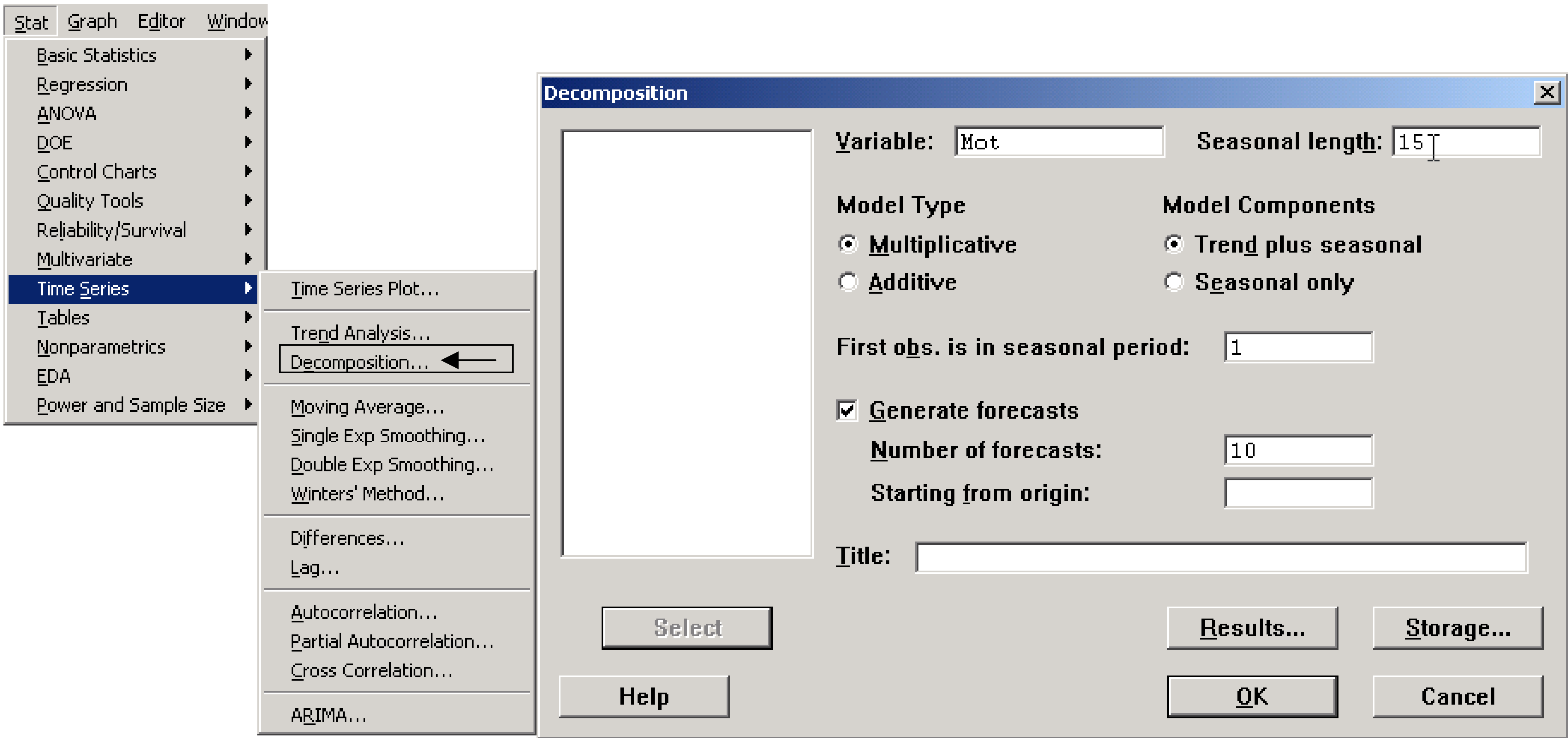

Time Series Plot
C2 Mot
C3 ONNN
C4 Lucent
C5 Dow
Graph variables:
Graph Y
1 Mot
2
3
Time Scale
Index
Date/Time Stamp:
Calendar: Day
Clock: Hour
Data display:
Item Display For each Group variables
1 Symbol Graph
2 Connect Graph
3
Edit Attributes...
Select
Annotation
Frame
Regions
Help
Options...
OK
Cancel

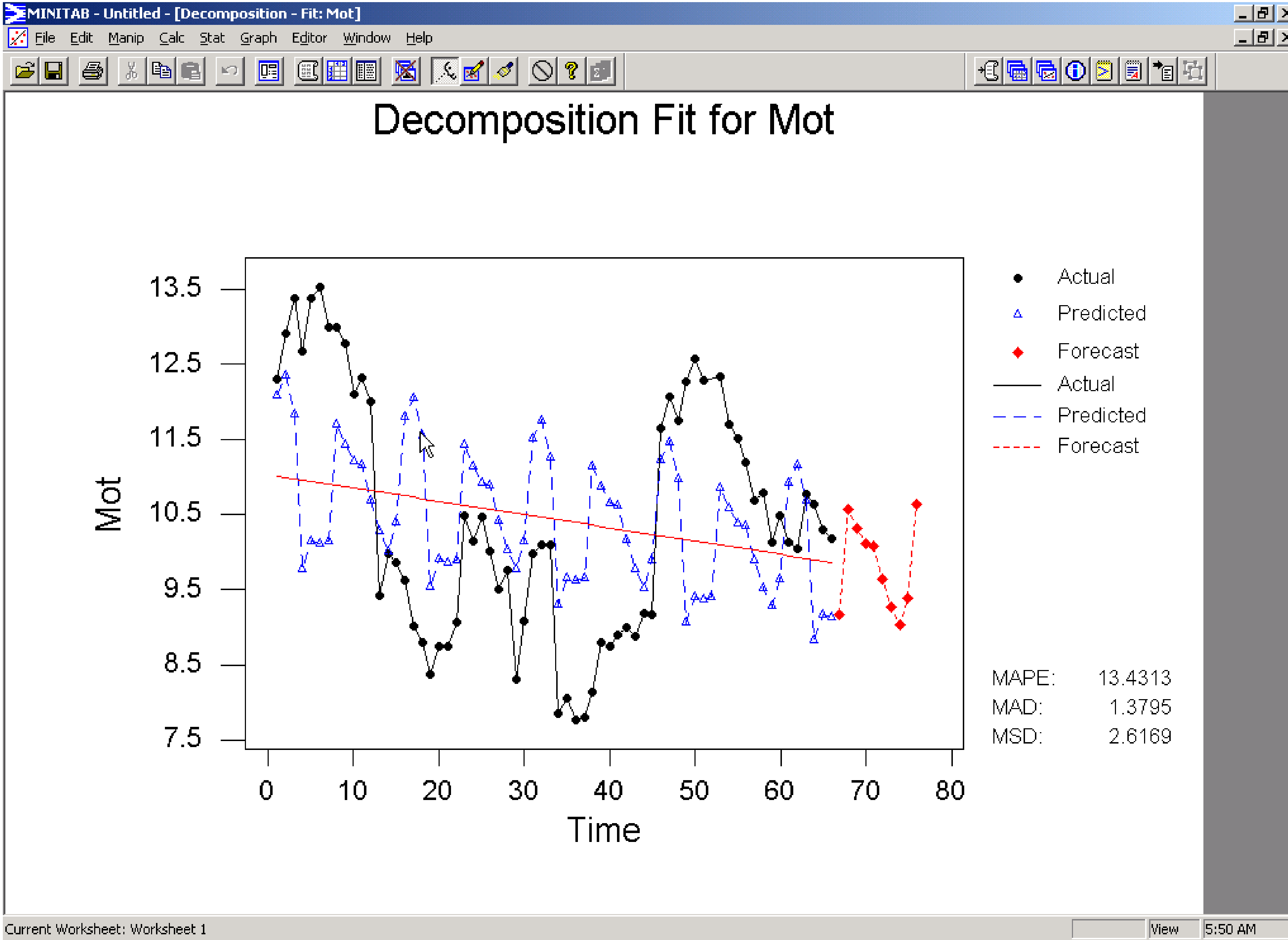

Mot
14
13
12
11
10
9
8
Index
10
20
30
40
50
60

Example – Stocks

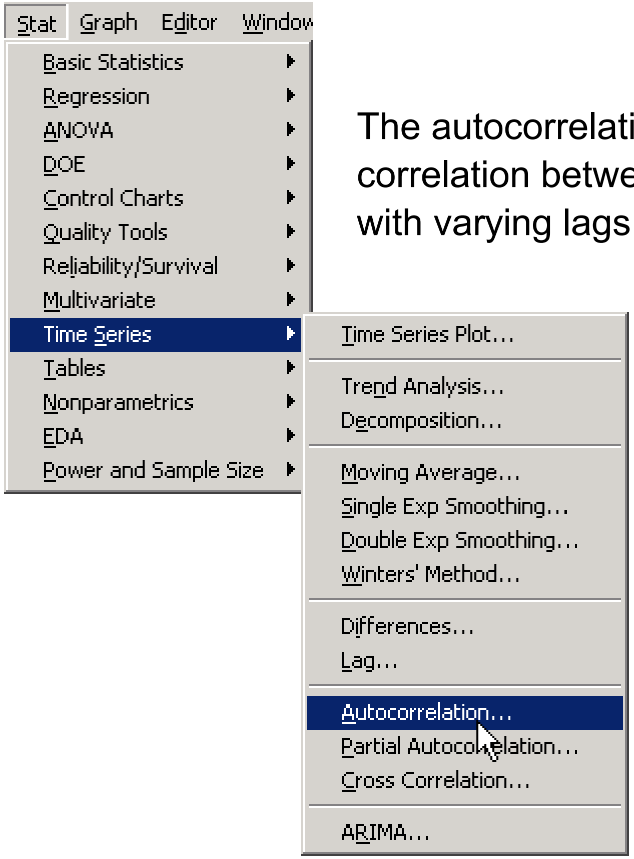



MINITAB - Untitled - [Trend Analysis: Mot]
File Edit Manip Calc Stat Graph Editor Window Help
Trend Analysis for Mot
Quadratic Trend Model
Yt = 13.3557 - 0.223221*t + 3.07E-03*t**2
Mot
Time
Actual
Fits
Forecasts
Actual
Fits
Forecasts
MAPE: 10.0095
MAD: 1.0325
MSD: 1.4657
Current Worksheet: Worksheet 1
View
5:52 AM


Stat Graph Editor Window
Basic Statistics
Regression
ANOVA
DOE
Control Charts
Quality Tools
Reliability/Survival
Multivariate
Time Series
Tables
Nonparametrics
EDA
Power and Sample Size
Time Series Plot...
Trend Analysis...
Decomposition...
Moving Average...
Single Exp Smoothing...
Double Exp Smoothing...
Winters' Method...
Differences...
Lag...
Autocorrelation...
Partial Autocorrelation...
Cross Correlation...
ARIMA...
Decomposition
Variable: Mot
Seasonal length: 15
Model Type
Multiplicative
Additive
Model Components
Trend plus seasonal
Seasonal only
First obs. is in seasonal period: 1
Generate forecasts
Number of forecasts: 10
Starting from origin:
Title:
Select
Results...
Storage...
Help
OK
Cancel

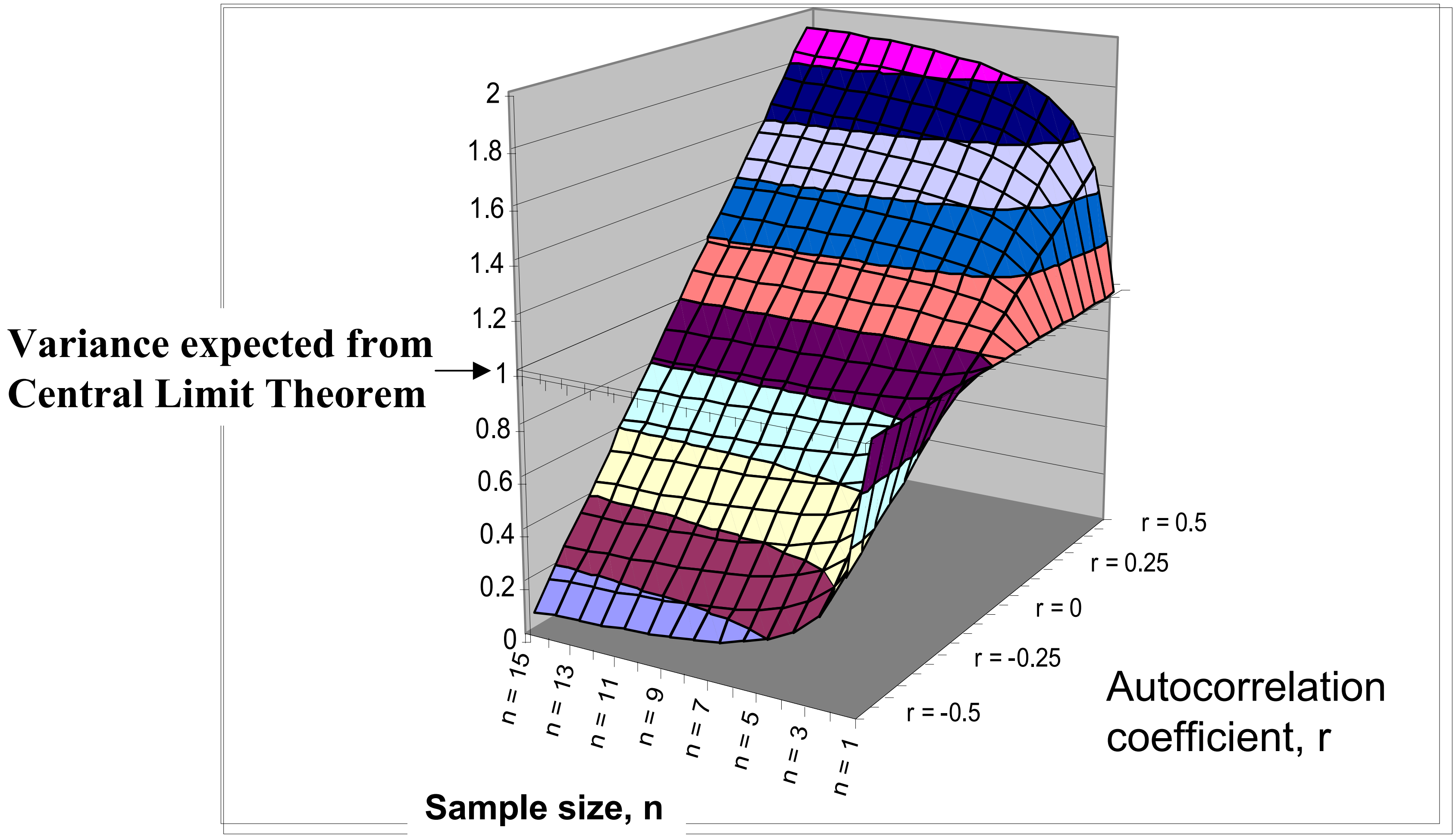

MINITAB - Untitled - [Decomposition - Fit: Mot]
File Edit Manip Calc Stat Graph Editor Window Help
Decomposition Fit for Mot
Mot
13.5
12.5
11.5
10.5
9.5
8.5
7.5
0
10
20
30
40
50
60
70
80
Time
Actual
Predicted
Forecast
Actual
Predicted
Forecast
MAPE: 13.4313
MAD: 1.3795
MSD: 2.6169
Current Worksheet: Worksheet 1
View
5:50 AM

Autocorrelation

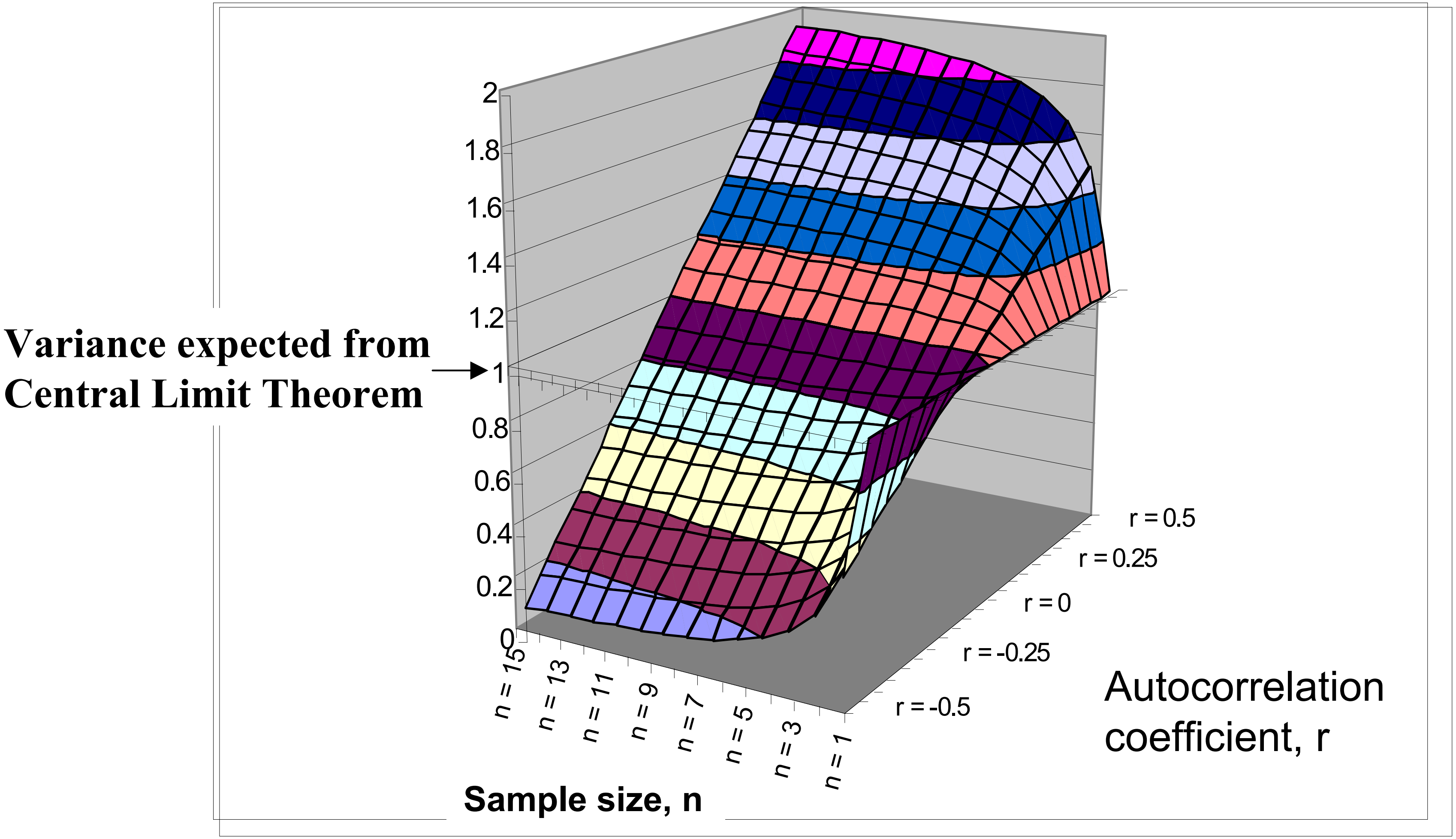


The autocorrelation correllogram shows the correlation between values that vary over time, with varying lags.

Autocorrelation of lag 1 is the correlation of each observation with the prior observation.
The Central Limit Theorem assumes independence, which relates to zero autocorrelation.
If there is autocorrelation, variance($\bar{y}$) = $C\sigma^2/n$ = C * (variance of means from C.L.T.).
C is the ratio of observed variance of means to that expected from the Central Limit Theorem
C can range from 0 to 2, depending on the autocorrelation and the sample size
The autocorrelation for lag of 1 can range from -.5 to +.5.



7 *Statistics for Experimenters*, George E.P. Box, William G Hunter, & J. Stuart Hunter, John Wiley & Sons, 1978, pg.62.


Variance expected from Central Limit Theorem
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
n = 15
n = 13
n = 11
n = 9
n = 7
n = 5
n = 3
n = 1
Sample size, n
r = 0.5
r = 0.25
r = 0
r = -0.25
r = -0.5
Autocorrelation coefficient, r

Overview
Data vs. Time

- Complications of S.P.C. in Semiconductor Processing
- Identifying and Prioritizing Critical Parameters
- Gauge Capability
- Levels of Variation
- Control Charting
- Times Series Modeling

Complications of S.P.C. in Semiconductor Processing

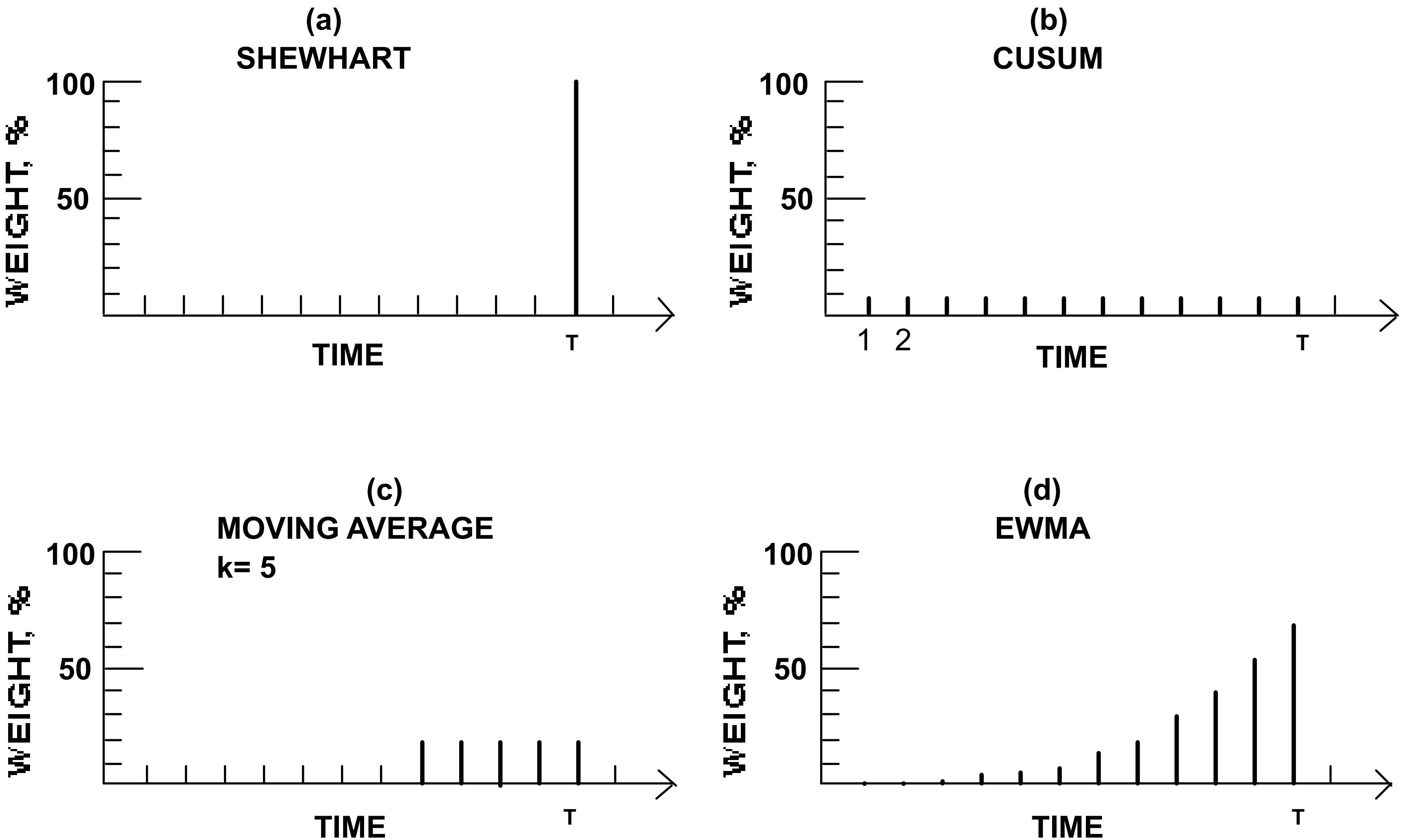
1. Indirect relationship of process parameters to device performance

   - Most IC fabrication operations involve chemical inputs and outputs, that relate indirectly to device performance (electrical outputs)
   - Effects on SPC - in many cases, spec limits were set somewhat arbi trarily (that is, not based upon the effect on device performance)

2. Quantity of process operations, input and output parameters

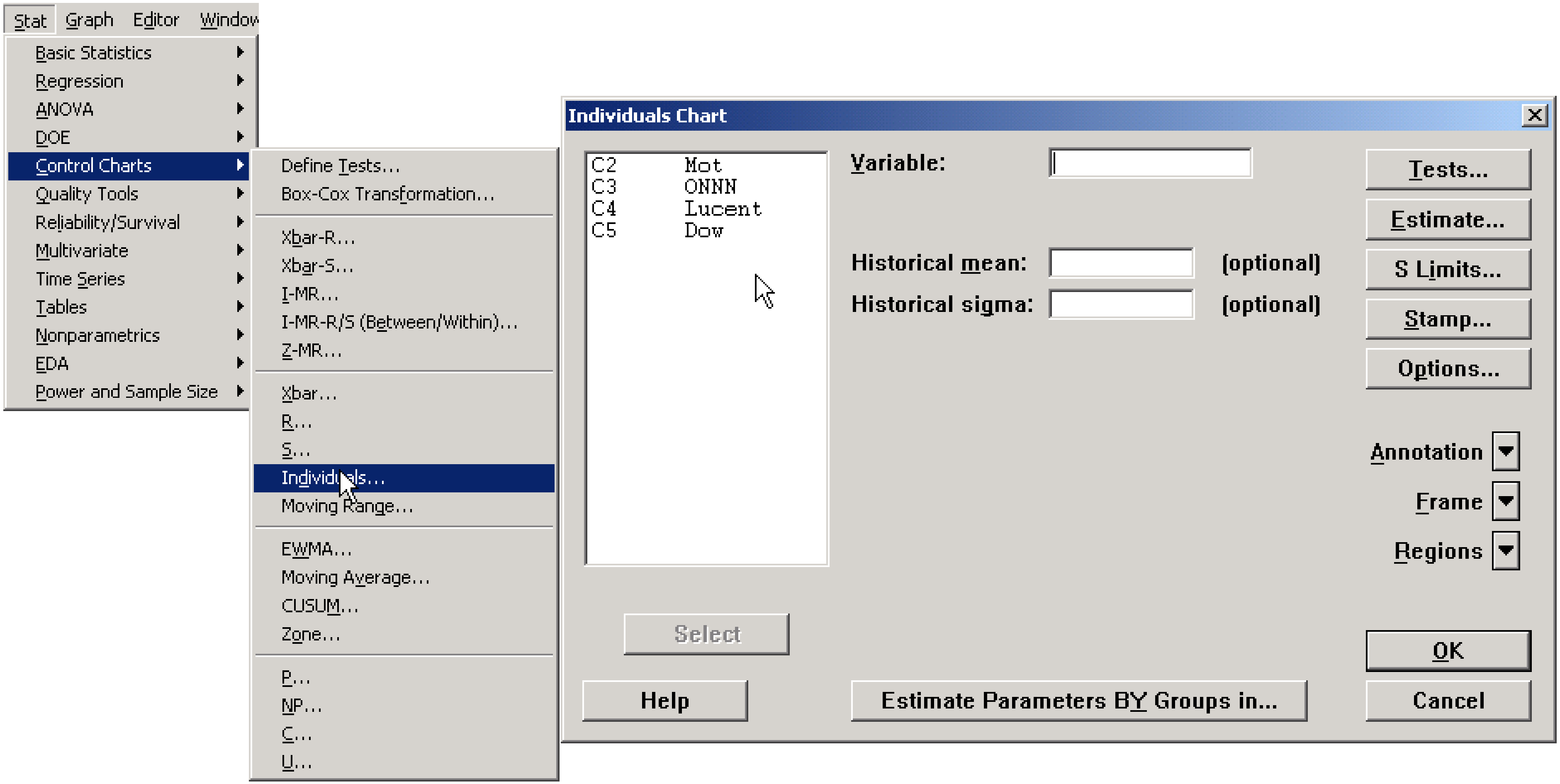
   - There are literally hundreds or thousands of process parameters (input and output) that can effect the product
   - Effects on SPC - there are insufficient resources to completely characterize each parameter

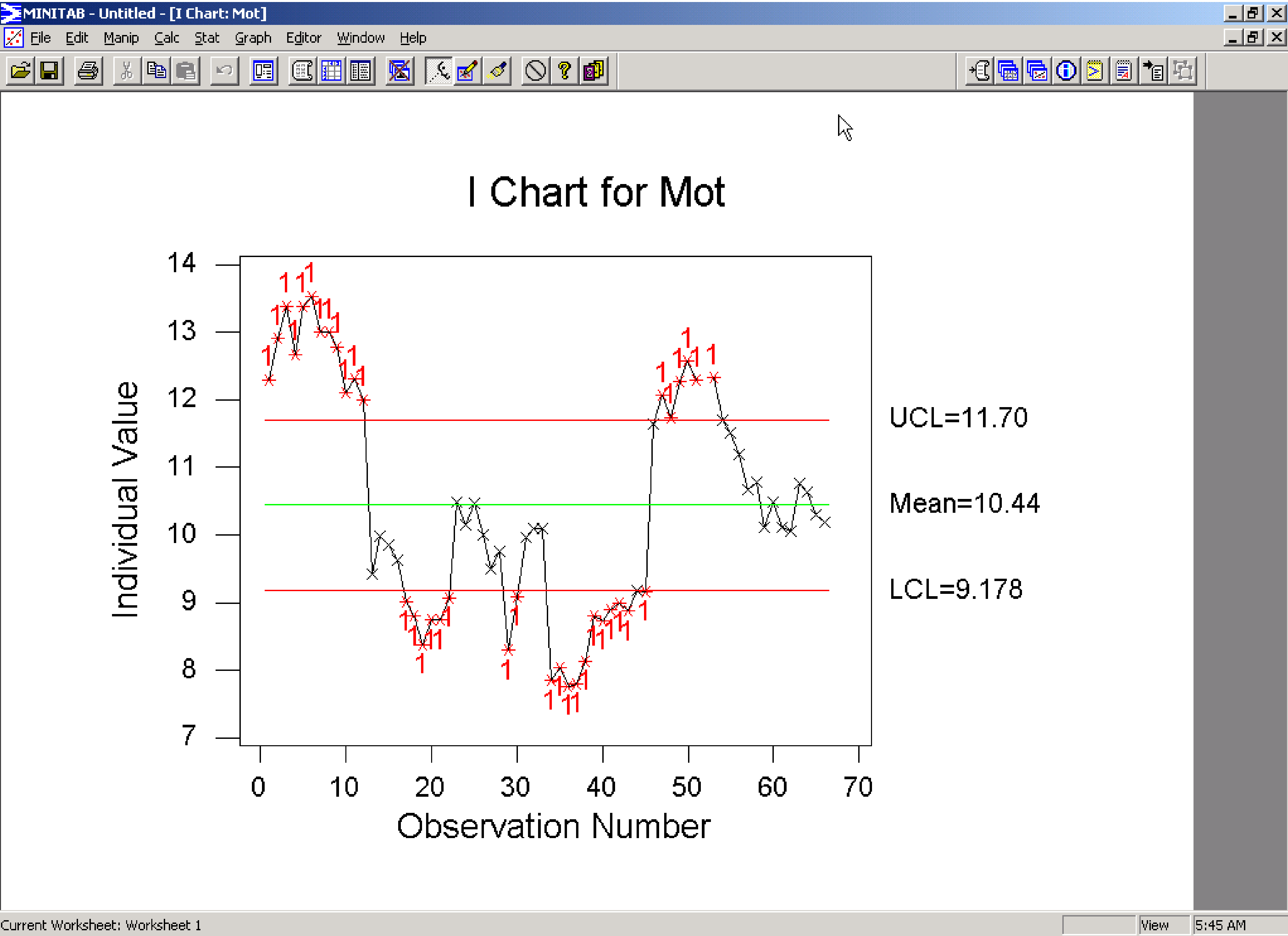
THE EXPONENTIALLY WEIGHTED MOVING AVERAGE



SPC – Individuals Chart

(Applied to stock prices…)




MINITAB - Untitled - [I Chart: Mot]
File Edit Manip Calc Stat Graph Editor Window Help
I Chart for Mot
Individual Value
14
13
12
11
10
9
8
7
0 10 20 30 40 50 60 70
Observation Number
UCL=11.70
Mean=10.44
LCL=9.178
Current Worksheet: Worksheet 1
View
5:45 AM

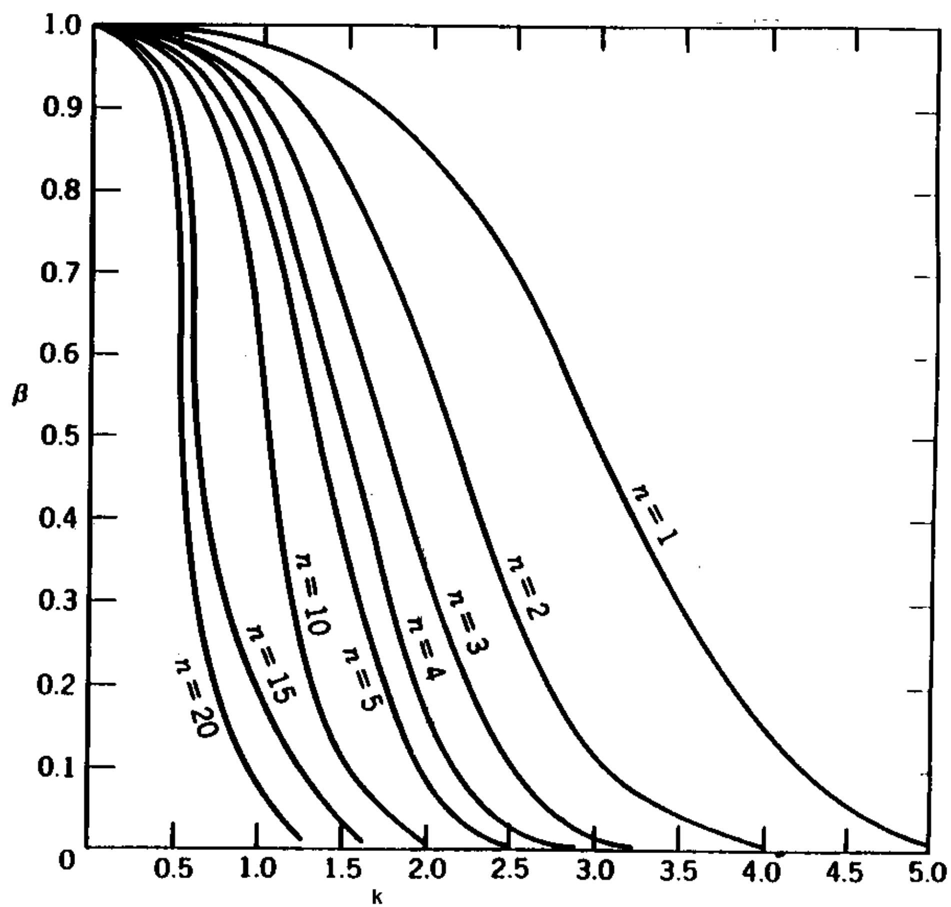
SPC is an ongoing Statistical Test

Risks

Reality

Your Conclusion	There is a difference	There is not a difference
There is a difference	**(WAY TO GO!!!)**	α **- RISK (TYPE I ERROR)**
There is not a difference	β **- RISK (TYPE II ERROR)**	**(WAY TO GO!!!)**

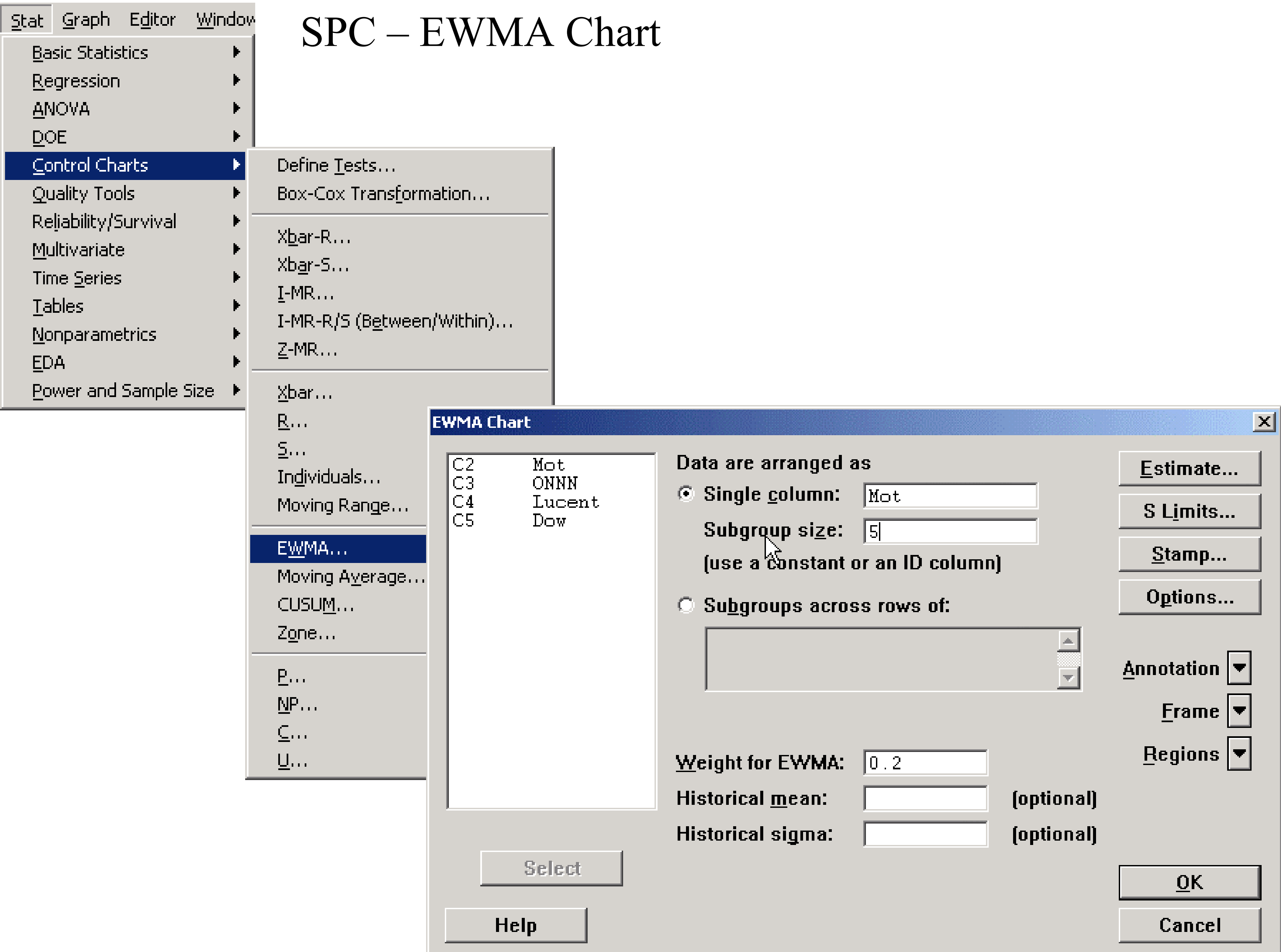
BETA RISK FOR $\overline{X}$ CONTROL CHART

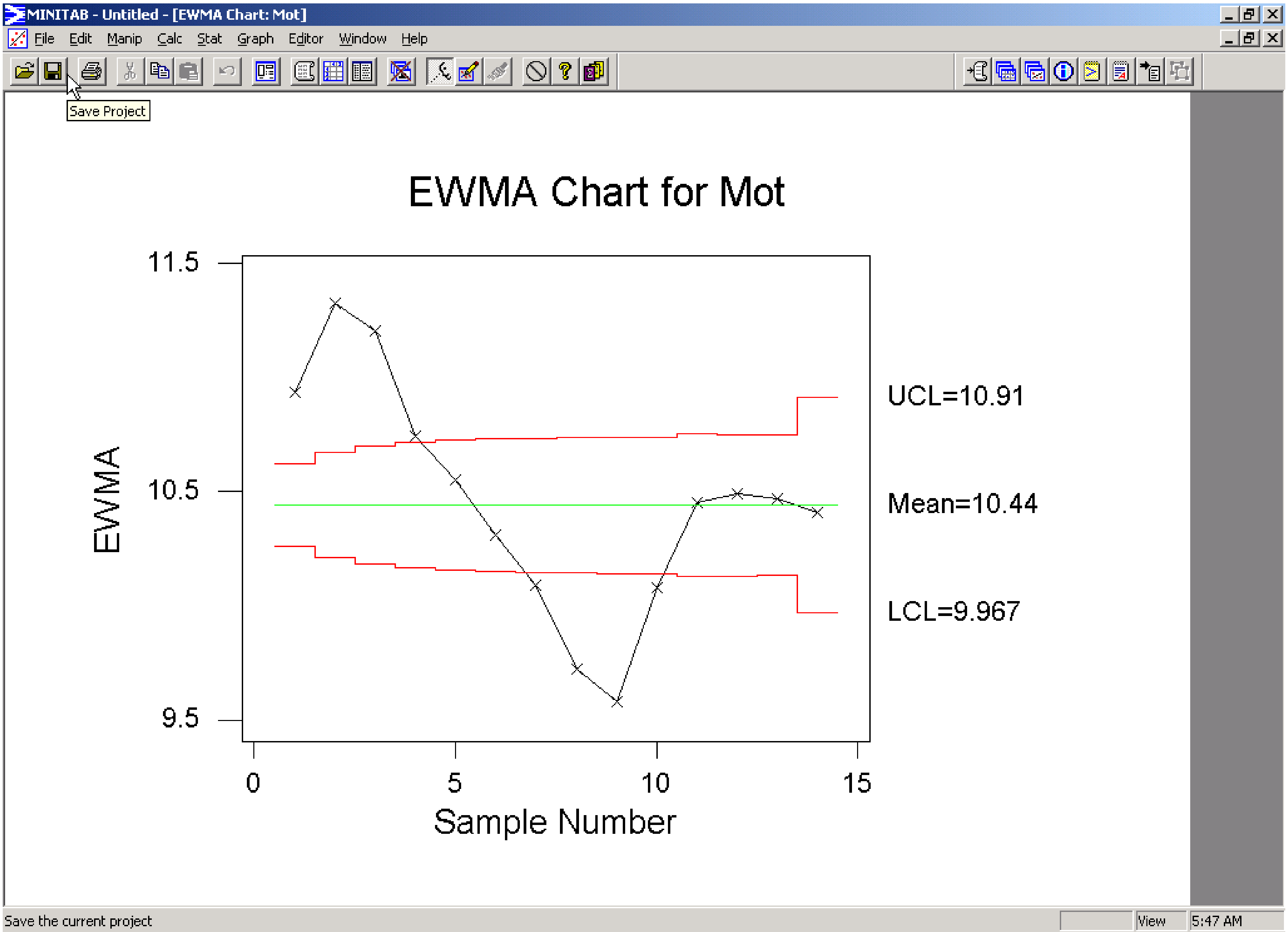


Operating characteristic curves for the $\overline{x}$ chart with 3–sigma limits. ß = p (not detecting a shift of kσ in the mean on the first sample following the shift).

Note: Over time, the beta risk decreases.

SPC – EWMA Chart




MINITAB - Untitled - [EWMA Chart: Mot]
File Edit Manip Calc Stat Graph Editor Window Help
Save Project
EWMA Chart for Mot
11.5
10.5
9.5
EWMA
UCL=10.91
Mean=10.44
LCL=9.967
0
5
10
15
Sample Number
Save the current project
View
5:47 AM

Complications of S.P.C. in Semiconductor Processing

3. Nested variance

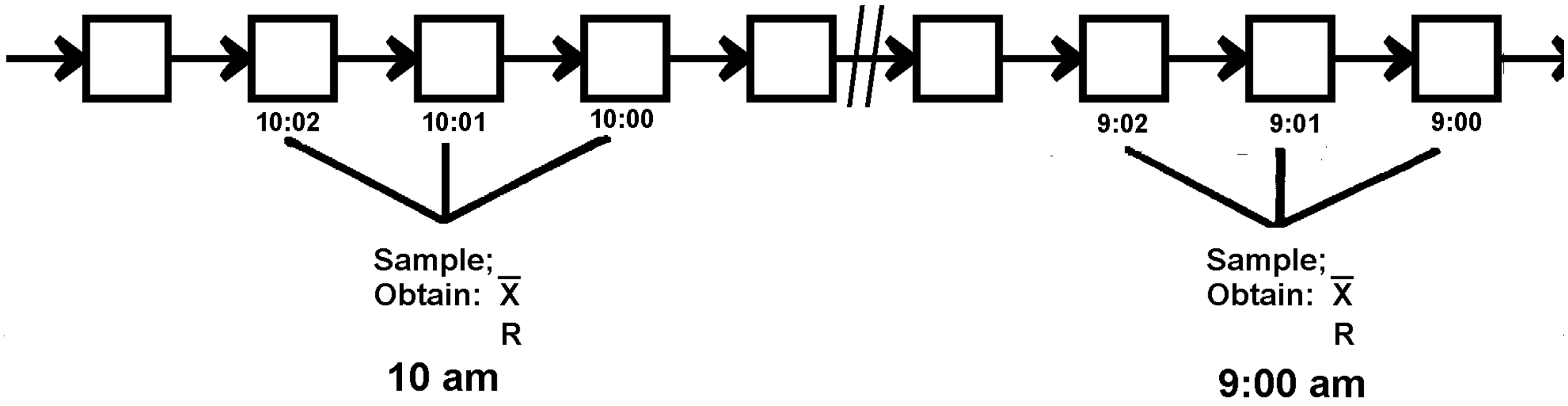
   - There are at least three levels of variation (lot-lot, wafer–wafer, within–wafer)
   - Effects on SPC - requirement to control multiple levels of variation; complications in establishing control limits. (Advantage: can provide clues to cause of out–of–control condition; can use to establish response procedures)

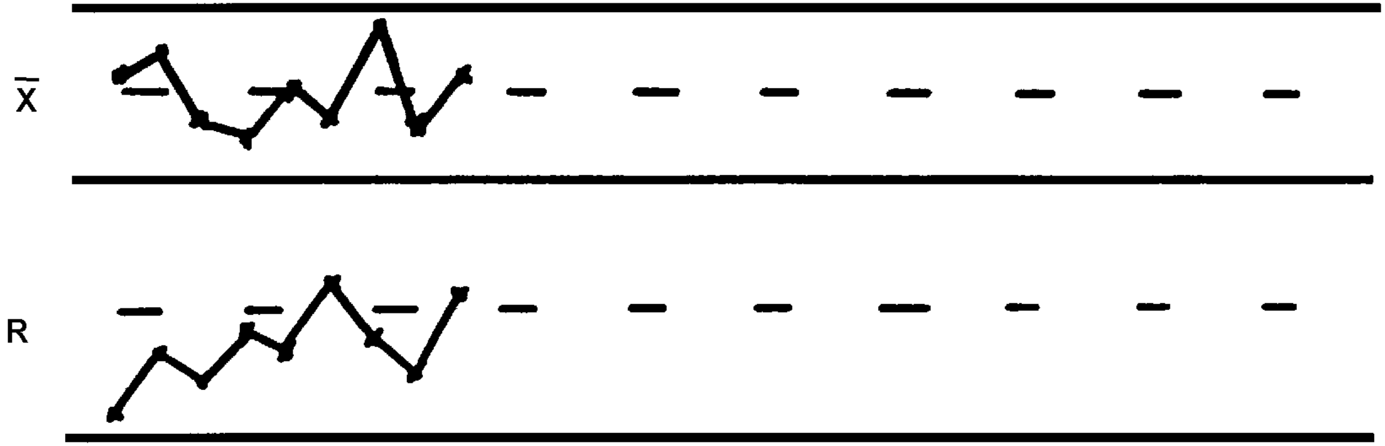
4. Non-normal distributions

   - Several key parameters have non-normal distributions (examples: HFE, contact resistance, sheet resistance)
   - Effects on SPC - "X-bar" (lot means) may not approach normality (central limit theorem), because lot-lot is often the only level of variation with respect to time

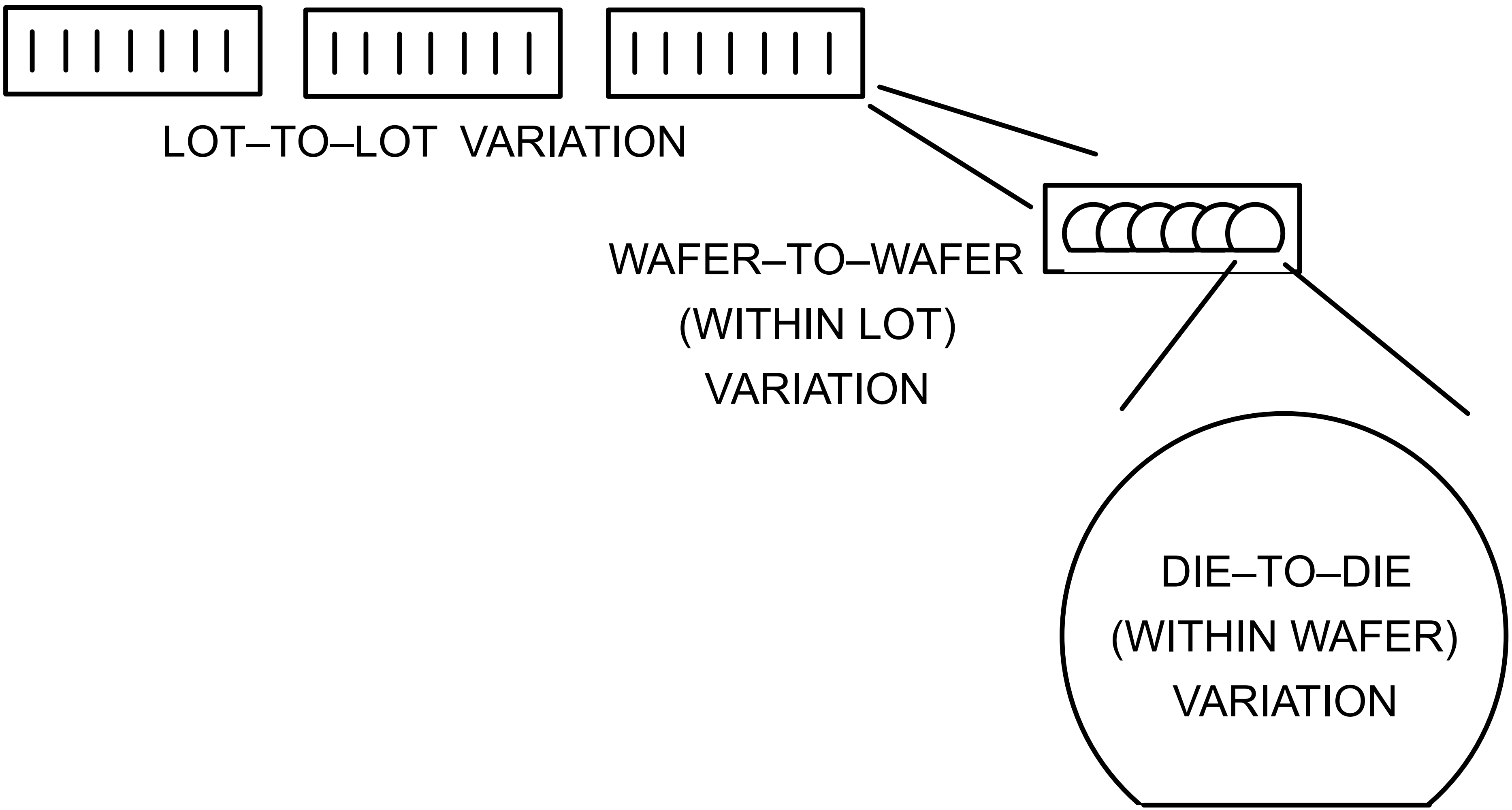
Shewhart Control Chart Model

Assembly Line:

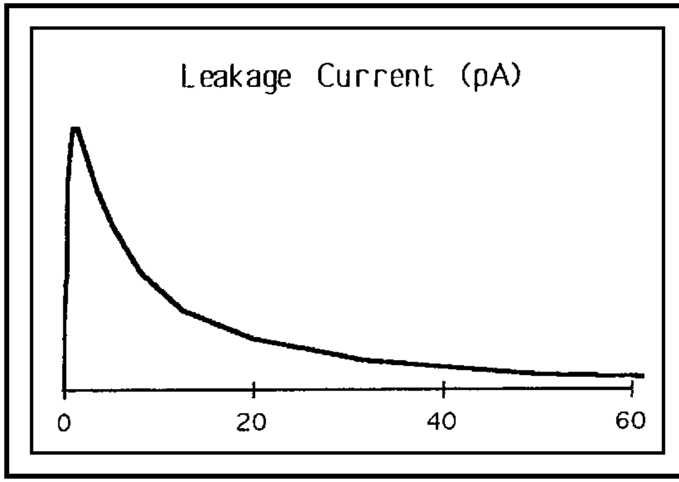




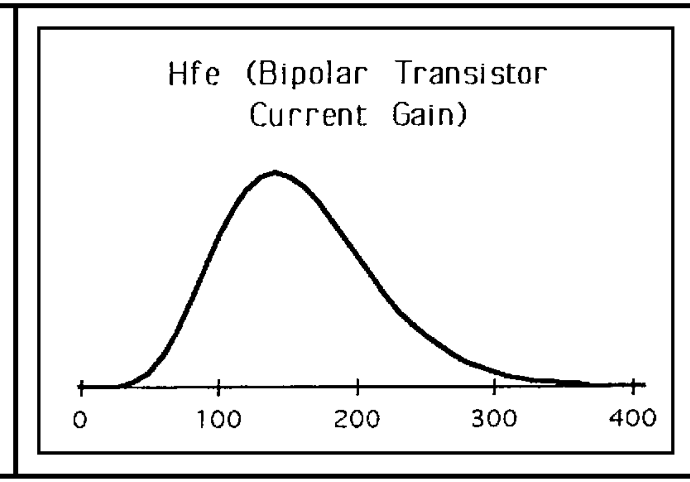
Nested Variance in I.C. Manufacturing:



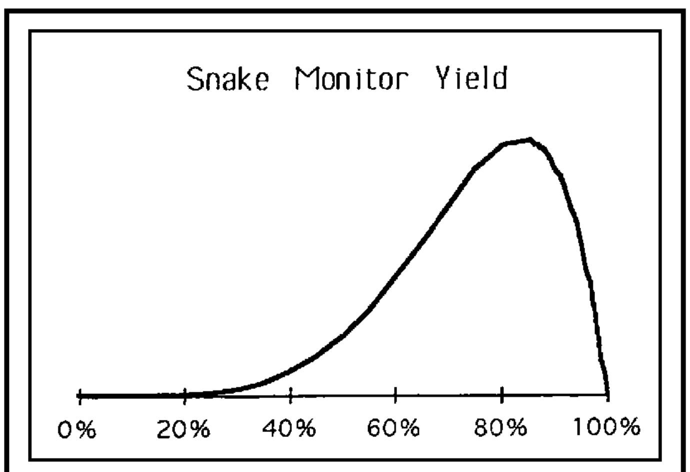
Non-Normal Distribution in Semiconductor Processing



LOG-NORMAL DISTRIBUTION

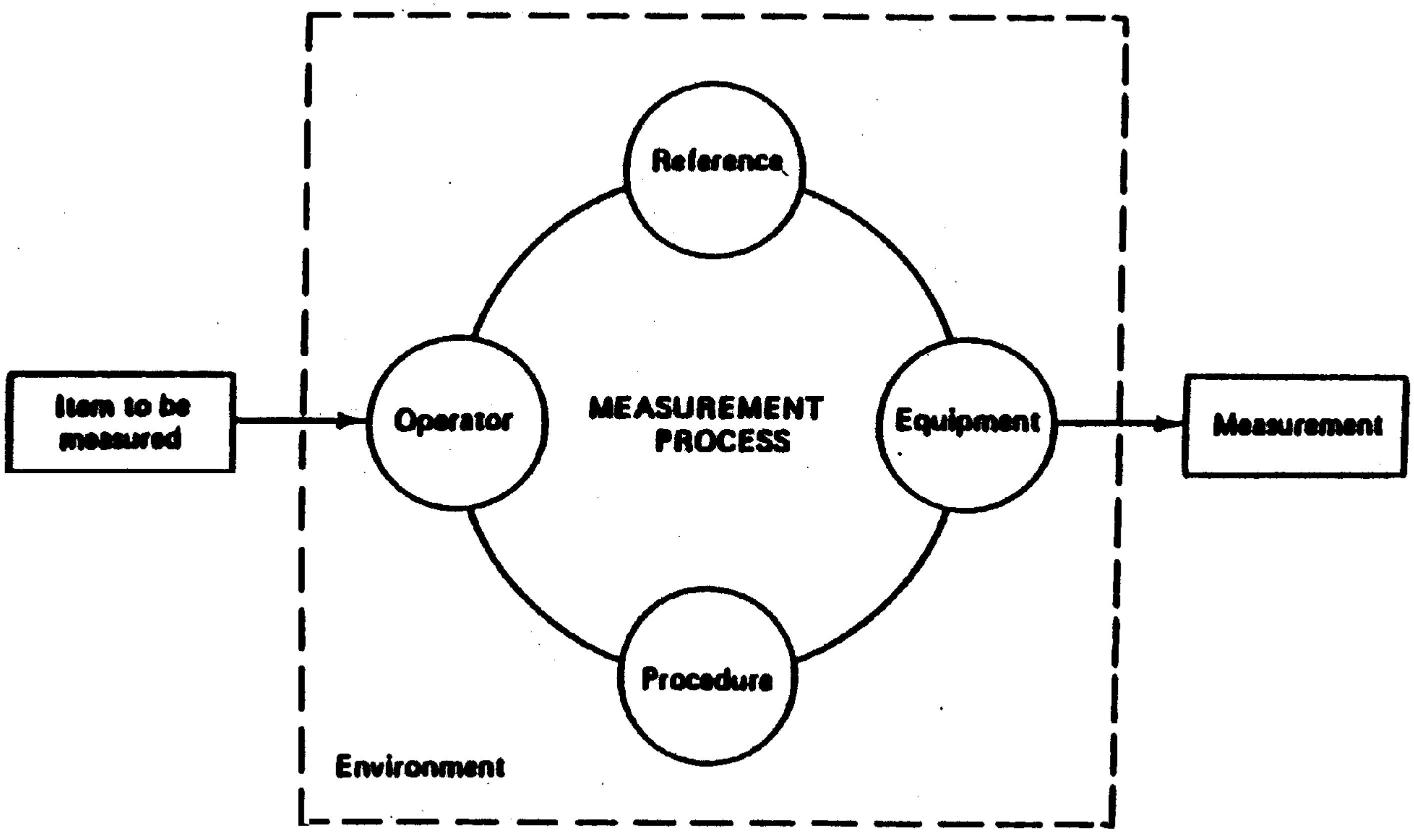


GAMMA DISTRIBUTION



BETA DISTRIBUTION

Measurement as a Production Process Concept



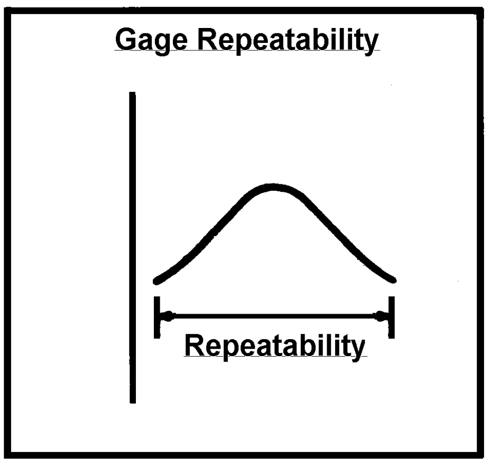
Accuracy and Precision

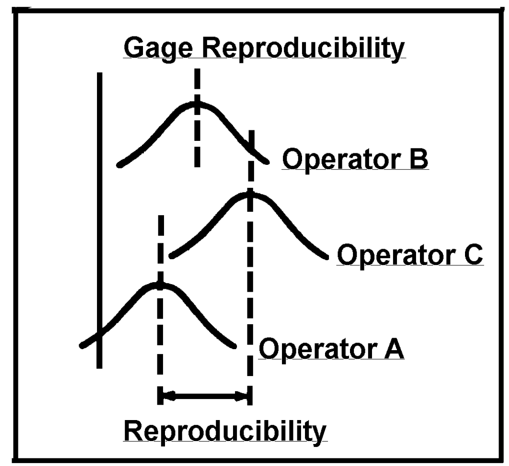
Accuracy = Closeness to the truth

Precision = Closeness of replicate measurements

Precision: Repeatability and Reproducibility

Precision — The degree of agreement among individual measurements of the same sample





Gage Repeatability

Gage Repeatability is the variation in measurements obtained when one operator uses the same gage for measuring the identical characteristics of the same parts.

Gage Reproducibility

Gage Reproducibility is the variation in the average of measurements made by different operators using the same gage when measuring identical characteristics of the same parts.

Precision/Tolerance Ratio
P/T Ratio

The P/T value is the ratio between the measurement precision estimate and the tolerance of the characteristic begin measured.

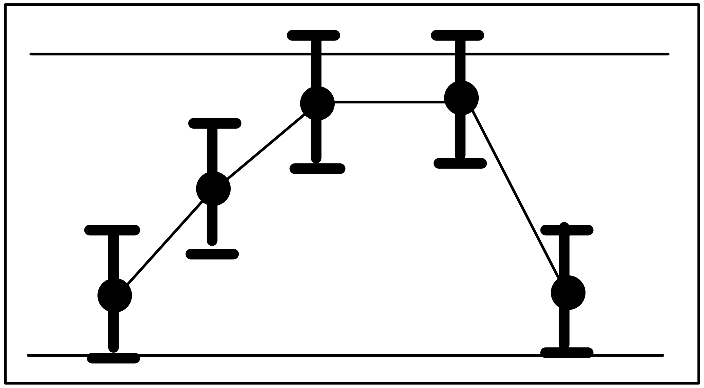
$$\text{P/T Ratio} = \frac{6\,\sigma_E}{\text{Total Tolerance}}$$

Where σ_E is the standard deviation due to measurment variability.

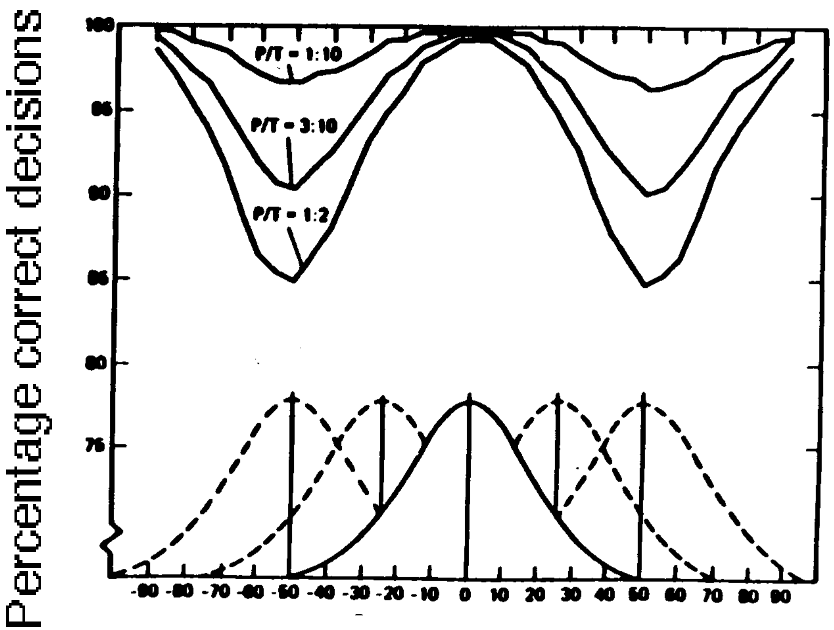
Assumption:

Measurement errors are independent
Measurement errors are normally distributed
Measurement error is independent of part size

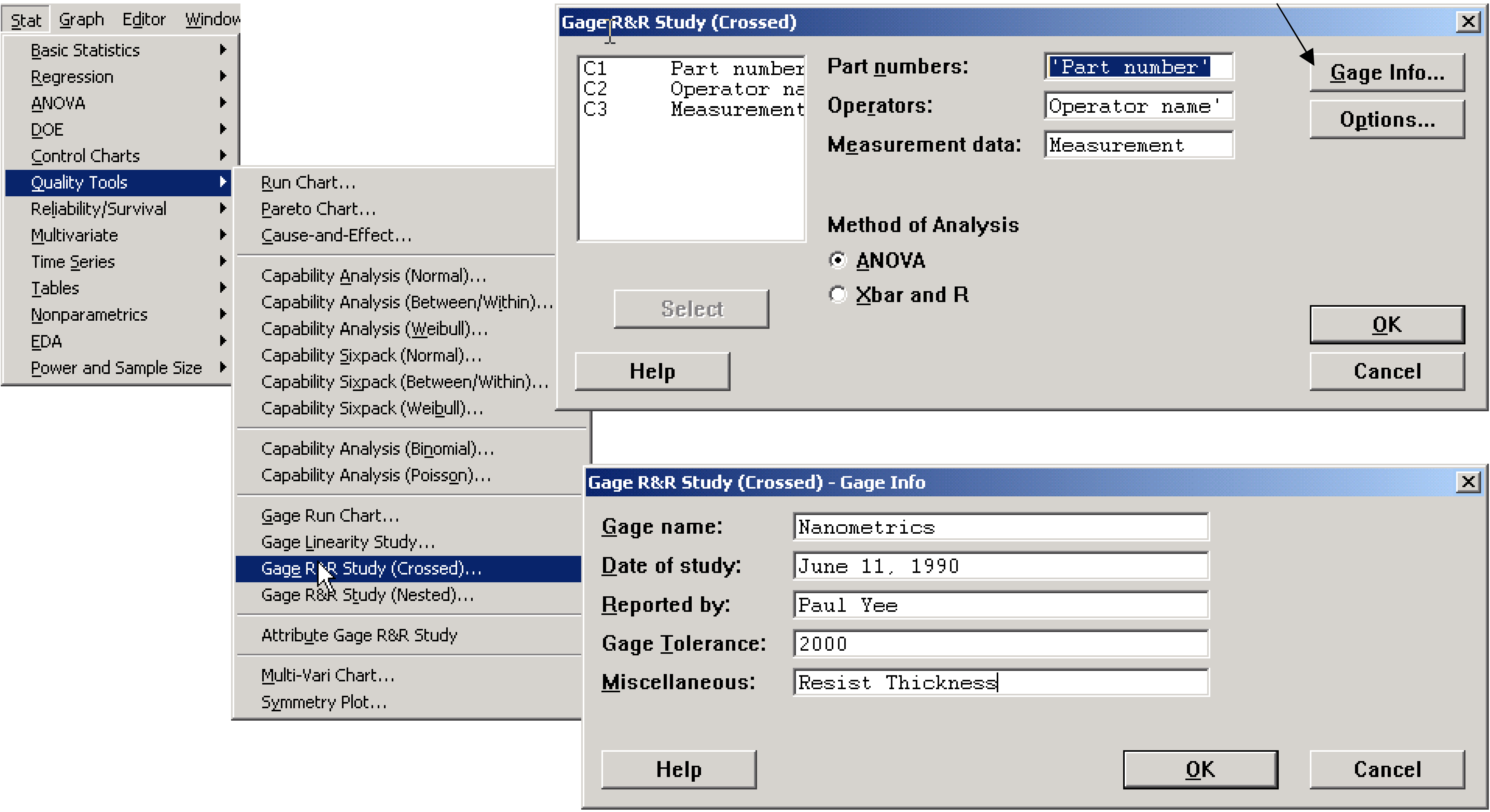
EFFECT OF P/T RATIO ON DECISION MAKING



Control chart with measurement error.



Position of parts distribution where
6o parts = total tolerance
scale units = percentage from aim


Stat
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Basic Statistics
Regression
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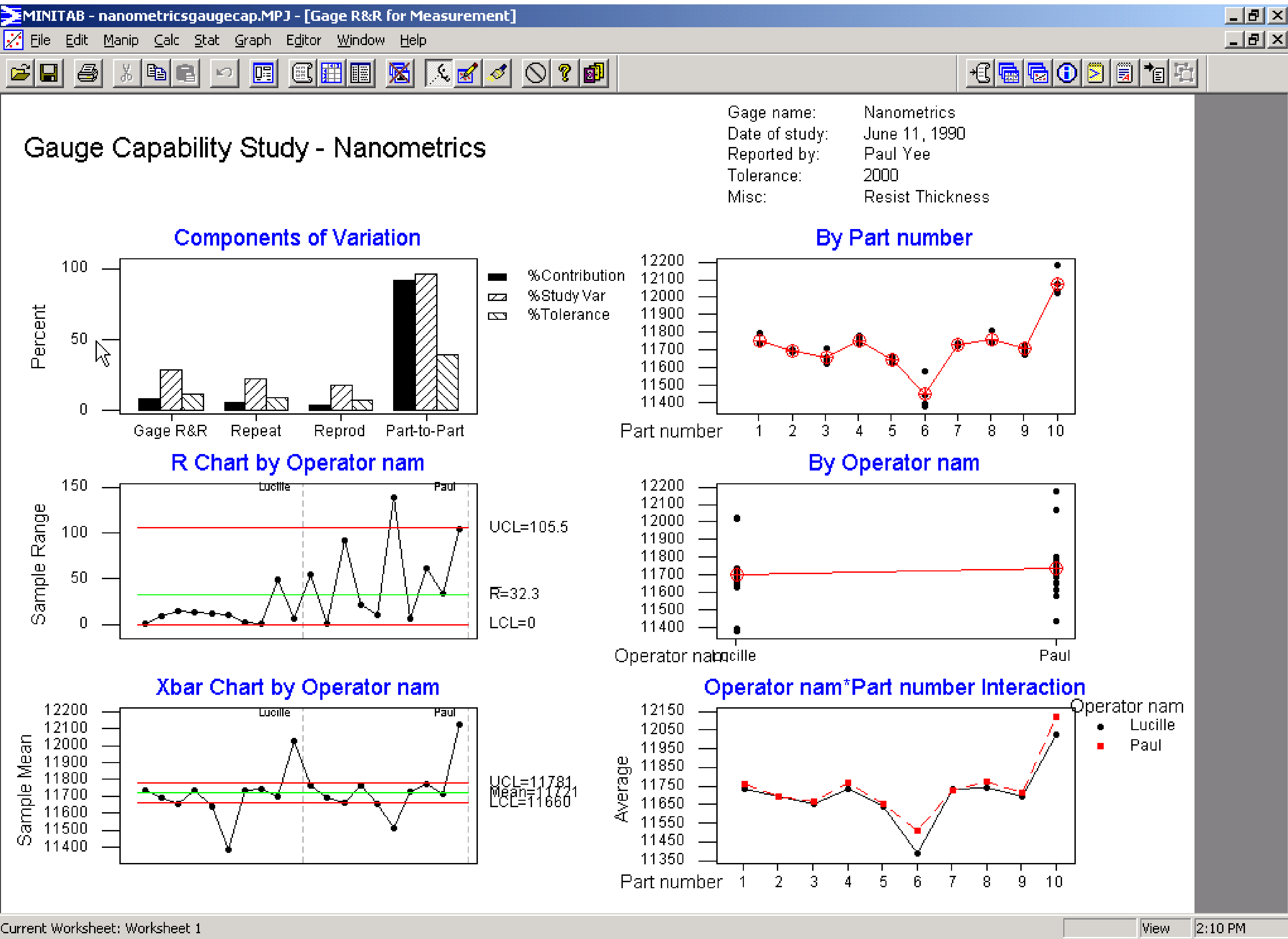
Nonparametrics
EDA
Power and Sample Size
Run Chart...
Pareto Chart...
Cause-and-Effect...
Capability Analysis (Normal)...
Capability Analysis (Between/Within)...
Capability Analysis (Weibull)...
Capability Sixpack (Normal)...
Capability Sixpack (Between/Within)...
Capability Sixpack (Weibull)...
Capability Analysis (Binomial)...
Capability Analysis (Poisson)...
Gage Run Chart...
Gage Linearity Study...
Gage R&R Study (Crossed)...
Gage R&R Study (Nested)...
Attribute Gage R&R Study
Multi-Vari Chart...
Symmetry Plot...
Gage R&R Study (Crossed)
C1 Part number
C2 Operator na
C3 Measurement
Part numbers: 'Part number'
Operators: Operator name'
Measurement data: Measurement
Gage Info...
Options...
Method of Analysis
ANOVA
Xbar and R
Select
Help
OK
Cancel
Gage R&R Study (Crossed) - Gage Info
Gage name: Nanometrics
Date of study: June 11, 1990
Reported by: Paul Yee
Gage Tolerance: 2000
Miscellaneous: Resist Thickness
Help
OK
Cancel



MINITAB - nanometricsgaugecap.MPJ - [Gage R&R for Measurement]
File Edit Manip Calc Stat Graph Editor Window Help
Gauge Capability Study - Nanometrics
Gage name: Nanometrics
Date of study: June 11, 1990
Reported by: Paul Yee
Tolerance: 2000
Misc: Resist Thickness
Components of Variation
Percent
%Contribution
%Study Var
%Tolerance
Gage R&R
Repeat
Reprod
Part-to-Part
By Part number
Part number
R Chart by Operator nam
Sample Range
Lucille
Paul
UCL=105.5
R=32.3
LCL=0
By Operator nam
Operator nam
Lucille
Paul
Xbar Chart by Operator nam
Sample Mean
UCL=11781
Mean=11721
LCL=11660
Operator nam*Part number Interaction
Average
Operator nam
Lucille
Paul
Part number
Current Worksheet: Worksheet 1
View
2:10 PM

Gage R&R Study - ANOVA Method

Gage R&R for Measurement

Gage name: Nanometrics
Date of study: June 11, 1990
Reported by: Paul Yee
Tolerance: 2000
Misc: Resist Thickness

Two -Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part number	9	858523	95391.5	50.6934	0.00000
Operator nam	1	12461	12460.9	6.6220	0.03002
Operator nam*Part number	9	16936	1881.7	1.4865	0.21961
Repeatability	20	25318	1265.9		
Total	39	913238			

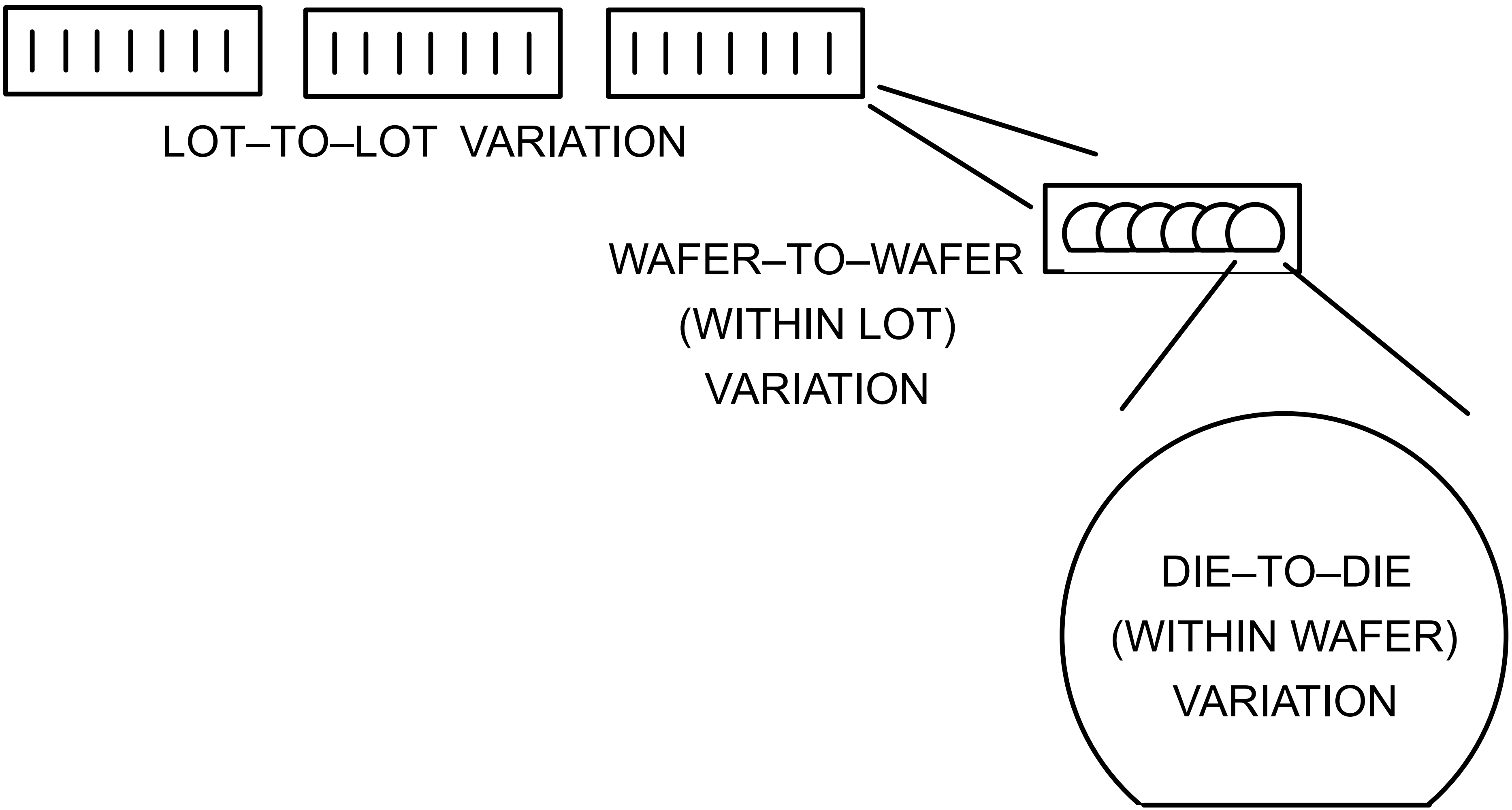
Gage R&R

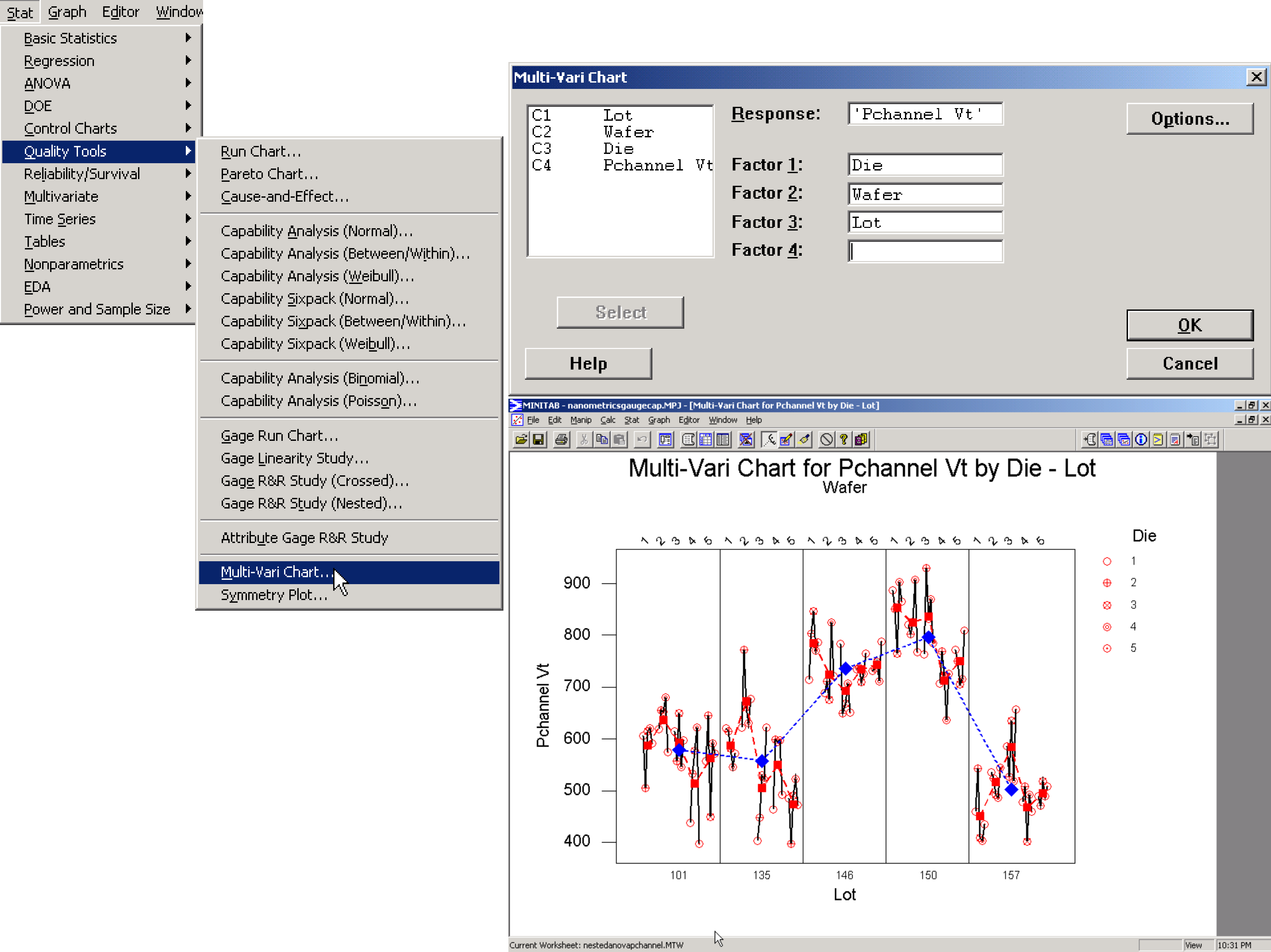
Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	2103	8.25
Repeatability	1266	4.97
Reproducibility	8 37	3.28
Operator nam	529	2.08
Operator nam*Part number	308	1.21
Part - To - Part	23377	91.75
Total Variation	25480	100.00

Source	StdDev (SD)	Study Var (5.15*SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	45.856	236.159	28.73	11.81
Repeatability	35.579	183.234	22.29	9.16
Reproducibility	28.929	148.983	18.12	7.45
Operator nam	22.999	118.445	14.41	5.92
Operator nam*Part number	17.548	90.370	10.99	4.52
Part - To - Part	152.897	787.419	95.78	39.37
Total Variation	159.625	822.070	100.00	41.10

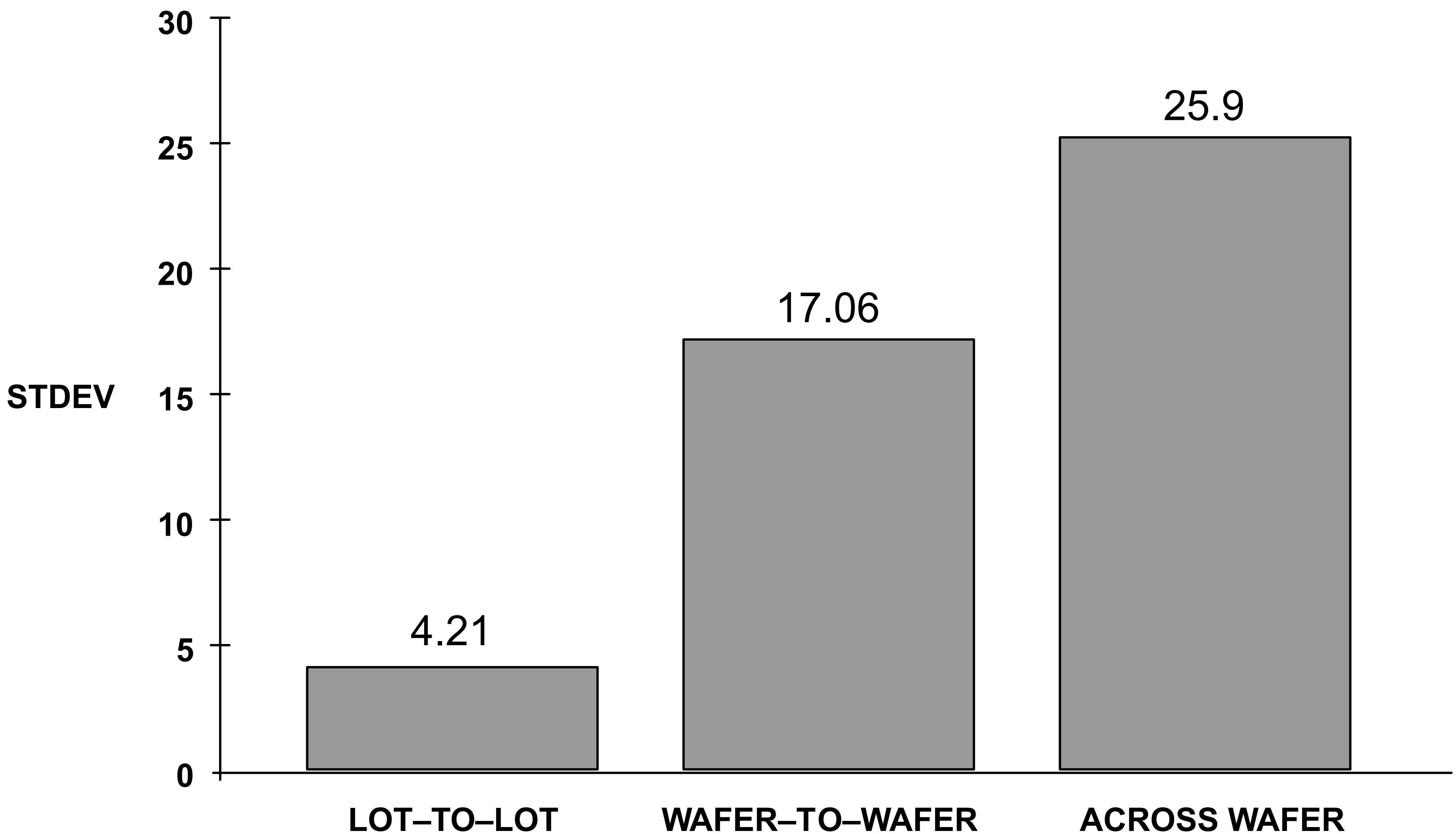
Number of Distinct Categories = 5

Nested Variance in I.C. Manufacturing:




Stat
Graph
Editor
Window
Basic Statistics
Regression
ANOVA
DOE
Control Charts
Quality Tools
Reliability/Survival
Multivariate
Time Series
Tables
Nonparametrics
EDA
Power and Sample Size
Run Chart...
Pareto Chart...
Cause-and-Effect...
Capability Analysis (Normal)...
Capability Analysis (Between/Within)...
Capability Analysis (Weibull)...
Capability Sixpack (Normal)...
Capability Sixpack (Between/Within)...
Capability Sixpack (Weibull)...
Capability Analysis (Binomial)...
Capability Analysis (Poisson)...
Gage Run Chart...
Gage Linearity Study...
Gage R&R Study (Crossed)...
Gage R&R Study (Nested)...
Attribute Gage R&R Study
Multi-Vari Chart...
Symmetry Plot...
Multi-Vari Chart
C1 Lot
C2 Wafer
C3 Die
C4 Pchannel Vt
Response: 'Pchannel Vt'
Factor 1: Die
Factor 2: Wafer
Factor 3: Lot
Factor 4:
Options...
Select
Help
OK
Cancel
MINITAB - nanometricsgaugecap.MPJ - [Multi-Vari Chart for Pchannel Vt by Die - Lot]
File Edit Manip Calc Stat Graph Editor Window Help
Multi-Vari Chart for Pchannel Vt by Die - Lot
Wafer
Pchannel Vt
900
800
700
600
500
400
101
135
146
150
157
Lot
Die
1
2
3
4
5
Current Worksheet: nestedanovapchannel.MTW
View
10:31 PM

63W HFE VARIANCE COMPONENTS ANALYSIS



VARIANCE COMPONENTS ANALYSIS

DIE–TO–DIE VARIANCE:

DIE–TO–DIE VARIANCE = AVERAGE (VARIANCE ACROSS EACH WAFER)

WAFER–TO–WAFER VARIANCE:

If measurements on the same wafer are averaged repeatibly,
Variance of means = (Die–to–die variance) / N_D (Center Limit Theorem)

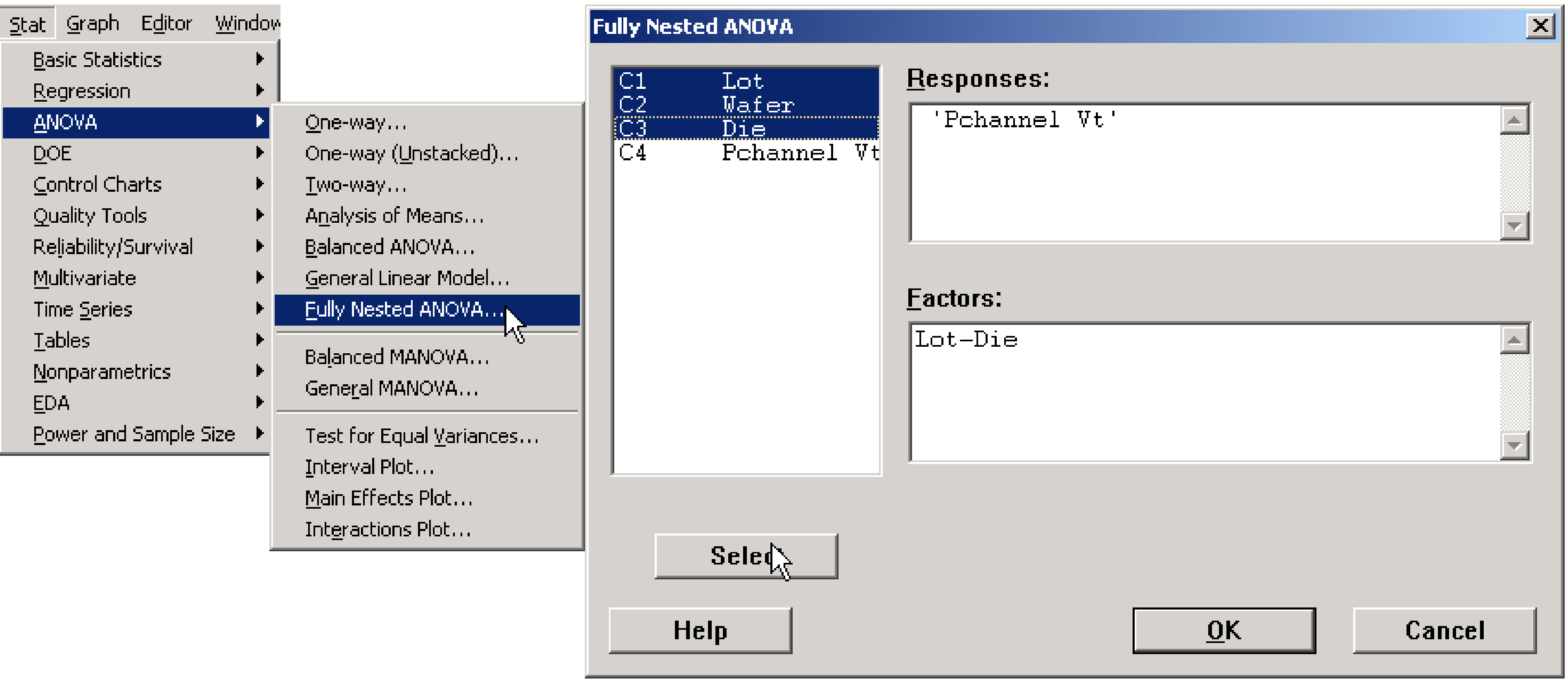
Wafer–To–Wafer Variance = (Average of the variances of wafer means)
– (Die–to–die variance) / N_D

LOT–TO–LOT VARIANCE:

Lot–to–lot Variance = (Variance of lot means)
– (Average of the variances of wafer means) / Nw

TOTAL VARIANCE = DIE–TO–DIE VARIANCE
+ WAFER–TO–WAFER VARIANCE
+ LOT–TO–LOT VARIANCE

Nested Analysis of Variance– Minitab Example



Nested ANOVA: Pchannel Vt versus Lot, Wafer, Die

Analysis of Variance for Pchannel

Source	DF	SS	MS	F	P
Lot	4	1568342.4642	392085.6160	25.071	0.000
Wafer	20	312782.2958	15639.1148	5.407	0.000
Die	100	289251.9864	2892.5199		
Total	124	2170376.7464			

Variance Components

Source	Var Comp.	% of Total	StDev
Lot	15057.860	73.45	122.710
Wafer	2549.319	12.44	50.491
Die	2892.520	14.11	53.782
Total	20499.699		143.177