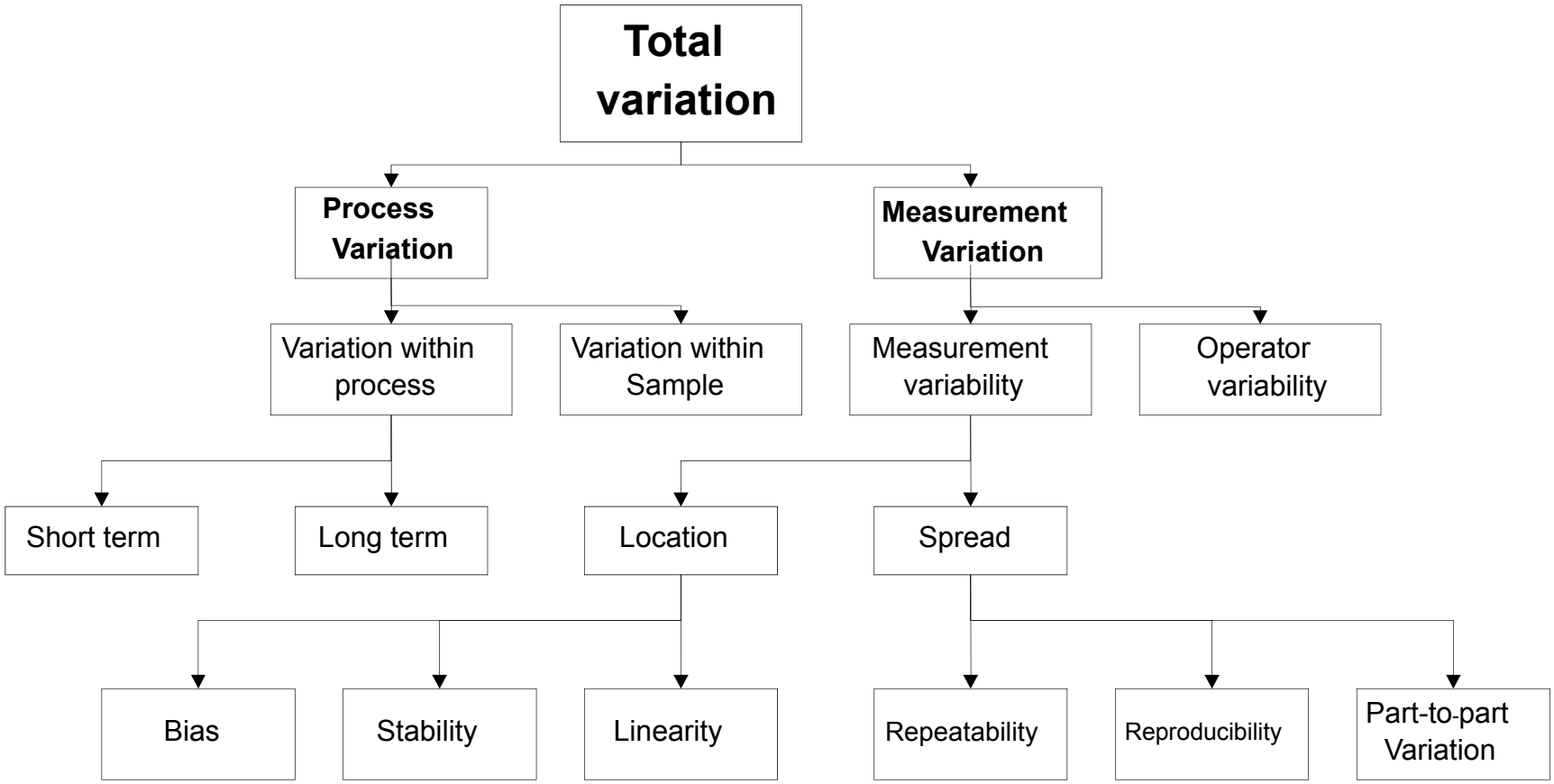
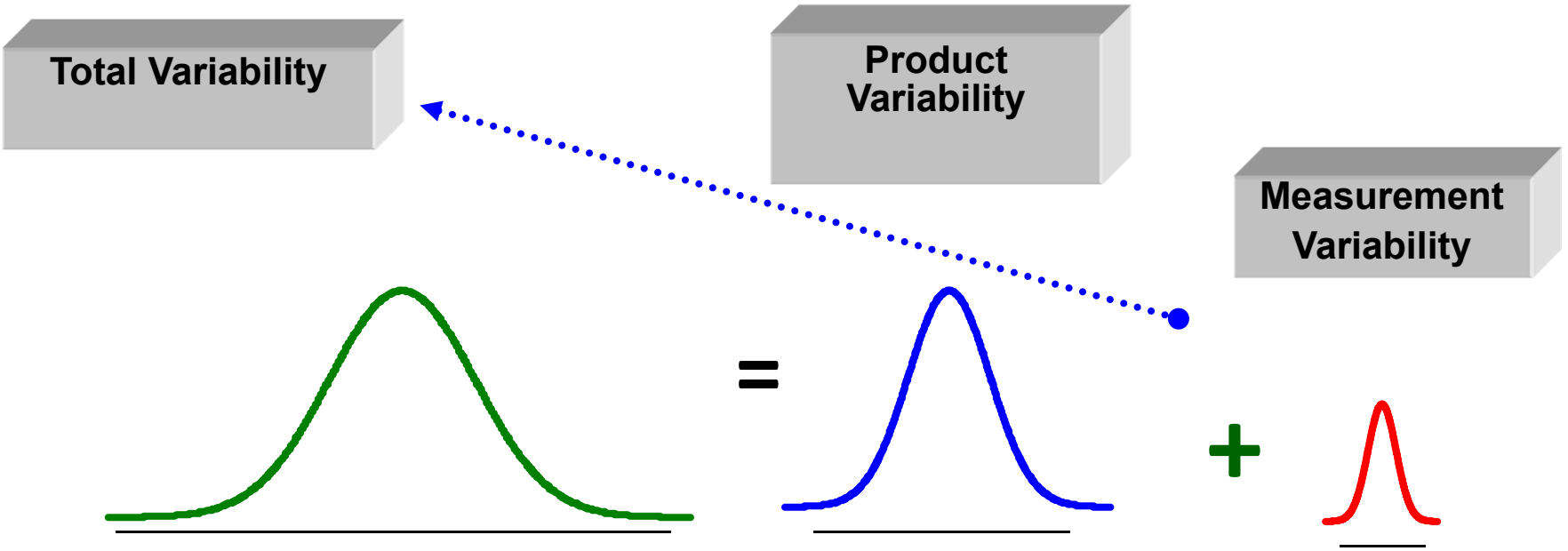
Measurement System Analysis (MSA) Using MINITAB

To reduce the total variation ‘Measurement Variation’ should be identified.

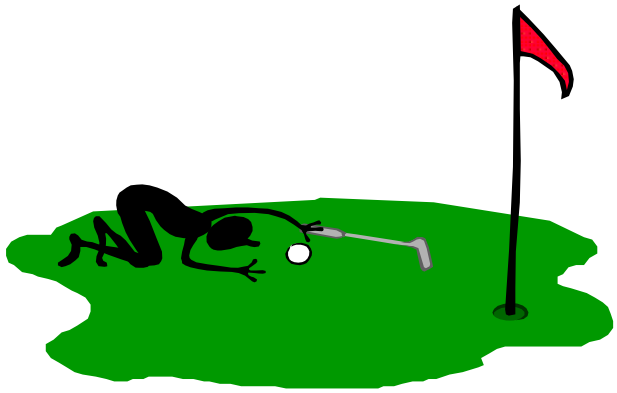




$$\sigma^2_{total} = \sigma^2_{product} + \sigma^2_{measurement\ system}$$

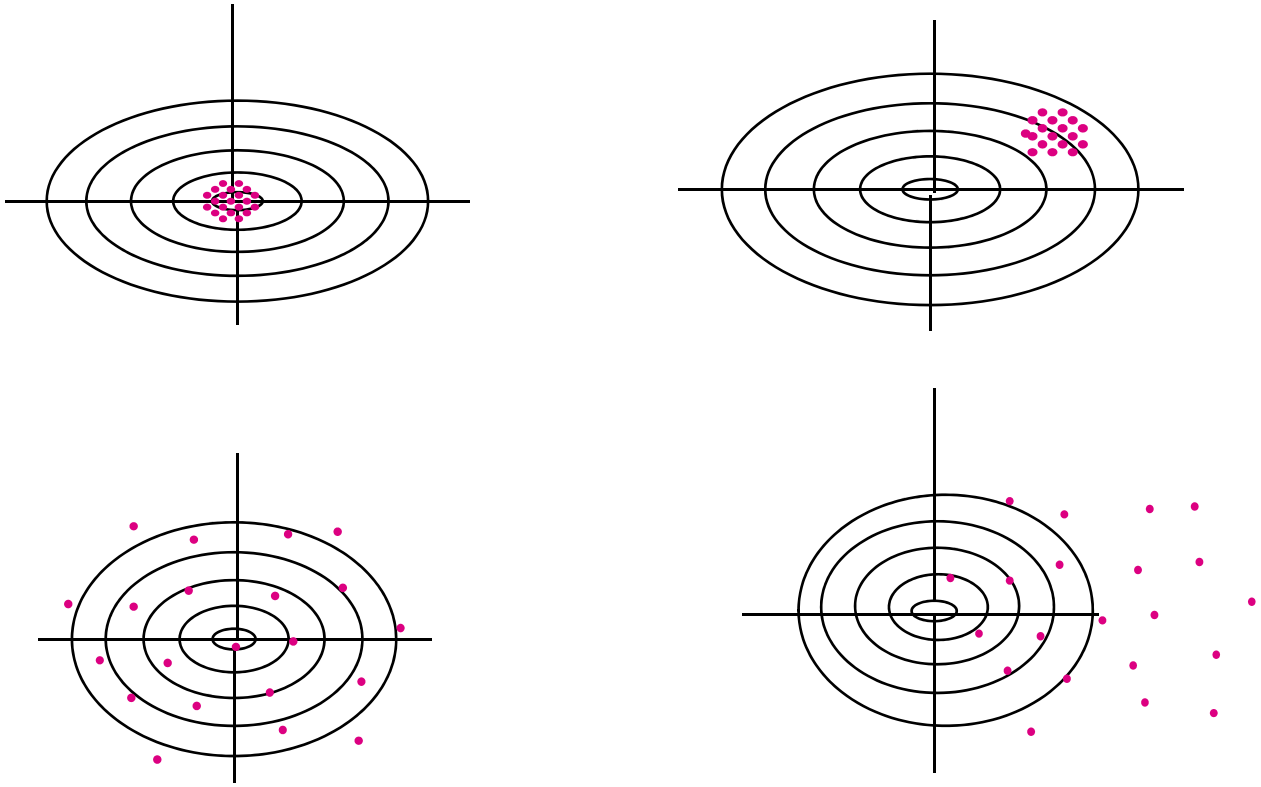
Measurement System Analysis

- ***Off Line***
- Resolution (Precision)
- Bias (Accuracy)
- Linearity



- ***On line***
- Repeatability
- Reproducibility
- Stability

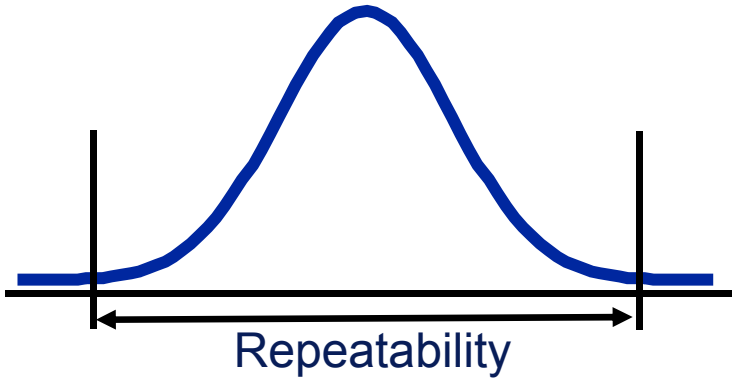
- Resolution (Precision)
- Bias (Accuracy)



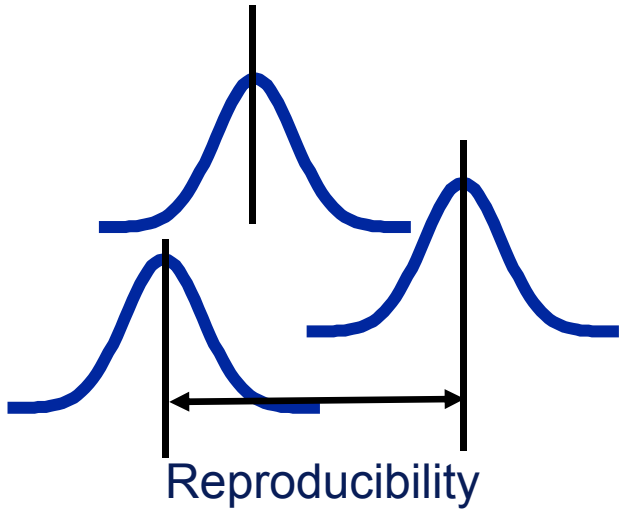
Gage R&R Evaluating

Type of measurement system variation : Width or Spread

- **Repeatability** : is the variation in measurements obtained with **one measurement instrument** when used several times by an appraiser while measuring the identical characteristic on the **same part / condition**.



- **Reproducibility** : is the variation in the average of the measurements made by **different appraisers** using the **same measurement instrument** when measure the identical characteristic on the **same part / condition**.



Ref. : MSA from Ford / GM 1990

Type of Data

• **Discrete (attribute) Data** : Qualitative data that can be counted and recorded to analysis.. Example, a shaft diameter measured by Go-no go gage.

X = Good or No Good,

X = Pass or Fail

• **Variable / Continuous data** : Quantitative data measured by measurement system.. Example, height or weight of student.

X = 150, 160, 170 cm,

X = 60, 65, 70 kg

Case Study

Scenario :

There was an issue feedback from HDD manufacturing plant in Singapore. Drives were facing HSA hit top cover. The FA reported that all units got cartridge height problem.

Possible Root Causes: Correlation, Cartridge installation or Both?

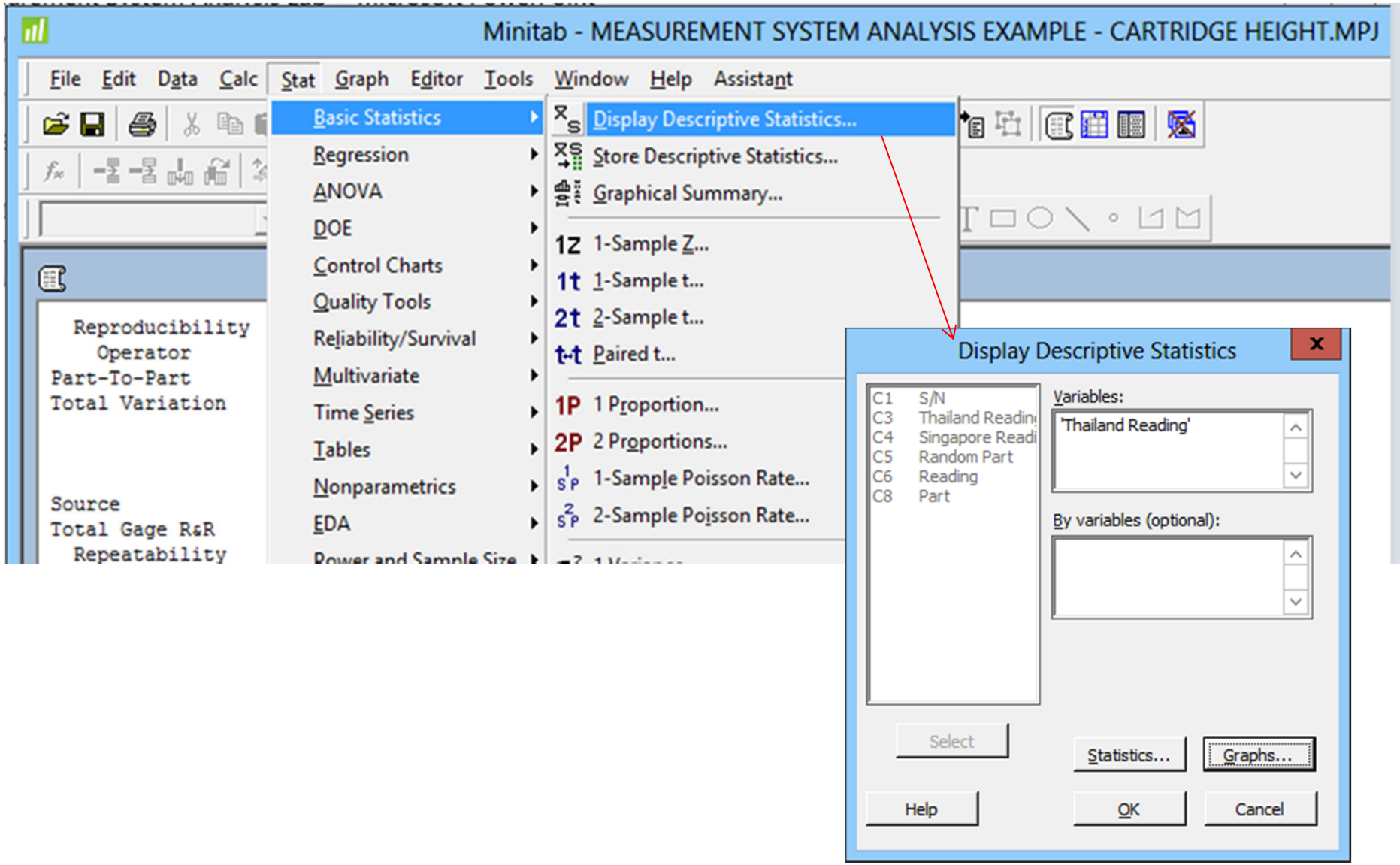
10 cartridges were randomly selected from assembly lines at SG plant. Cartridge heights were measured by 3 different tools (A, B and C) each measured 3 times then sent back to Thailand for investigation

Thailand Action Items :

1. MSA needed → Gauge R&R both TH and SG plants
2. Test Hypothesis → Paired T-test
3. Correlation → Linear Regression Analysis

Basic Information about the Data

Open MINITAB File “MEASUREMENT SYSTEM ANALYSIS EXAMPLE - CARTRIDGE HEIGHT.MPJ”



Basic Information about the Data

Descriptive Statistics: Thailand Reading

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Thailand Reading	90	0	15.097	0.128	1.210	13.762	14.118	14.681

Variable	Q3	Maximum
Thailand Reading	15.574	17.423

Descriptive Statistics: Singapore Reading

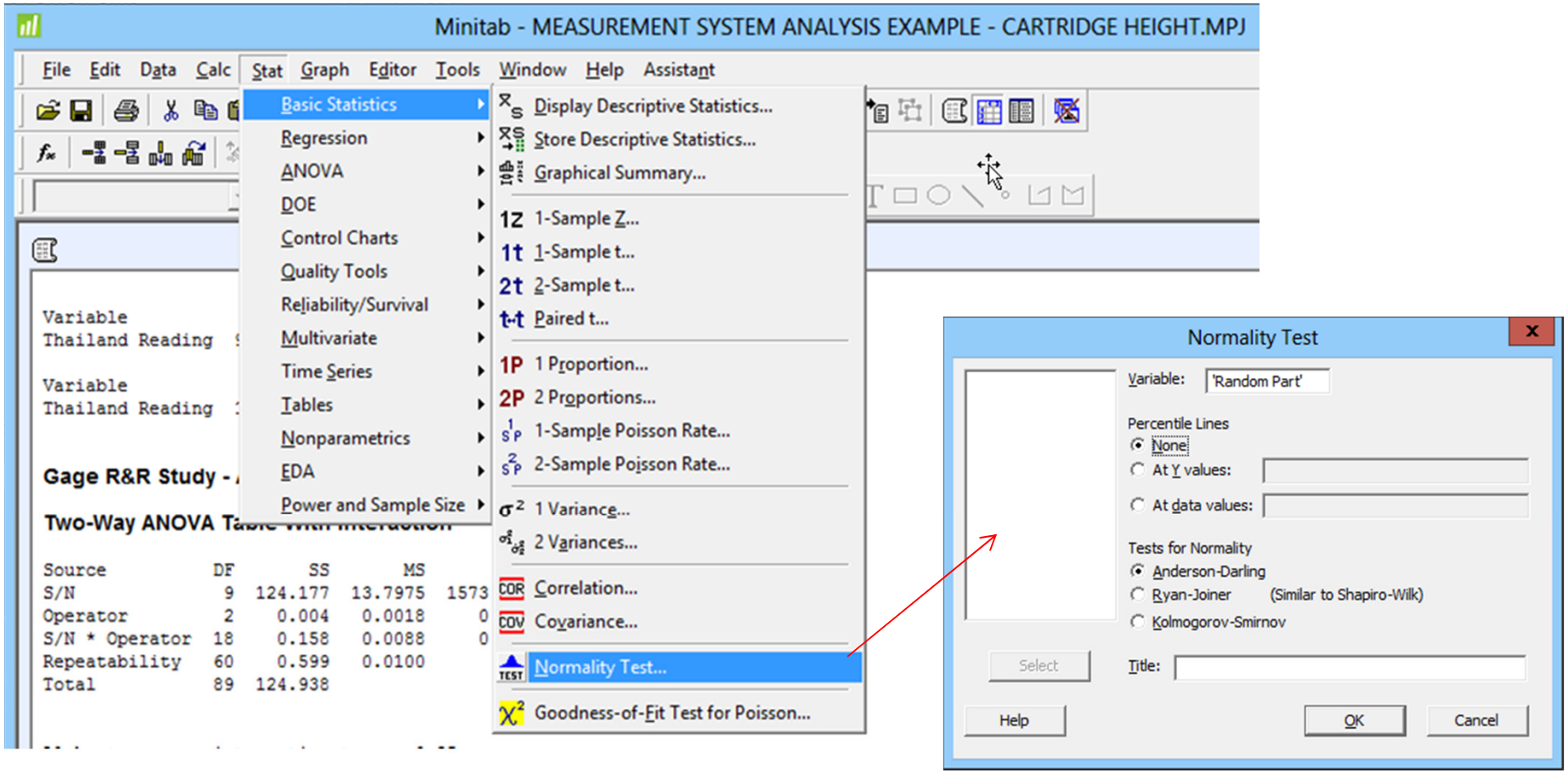
Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Singapore Reading	90	0	15.289	0.125	1.185	13.930	14.314	14.899

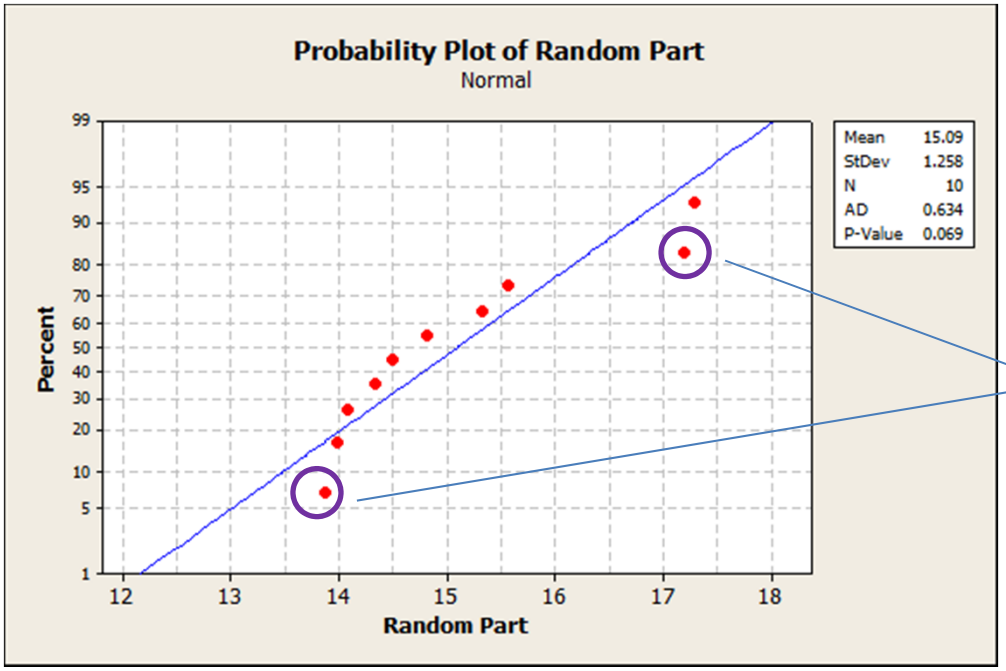
Variable	Q3	Maximum
Singapore Reading	15.756	17.633

Normality Test of Data

Most of the statistical tools, except for non-parametric test, require that the data distribute normally. So before we can use these tools, the normality of data must be validated.

10 parts were randomly selected and cartridge height data were already available for Normality Test.





These two data points are likely outliners (the rare and extreme). They can be discarded and replaced with new samples.

Ideally, all data points should lie on the straight line, if they were distributed normally. In practice, due to random nature of the data, they will not.

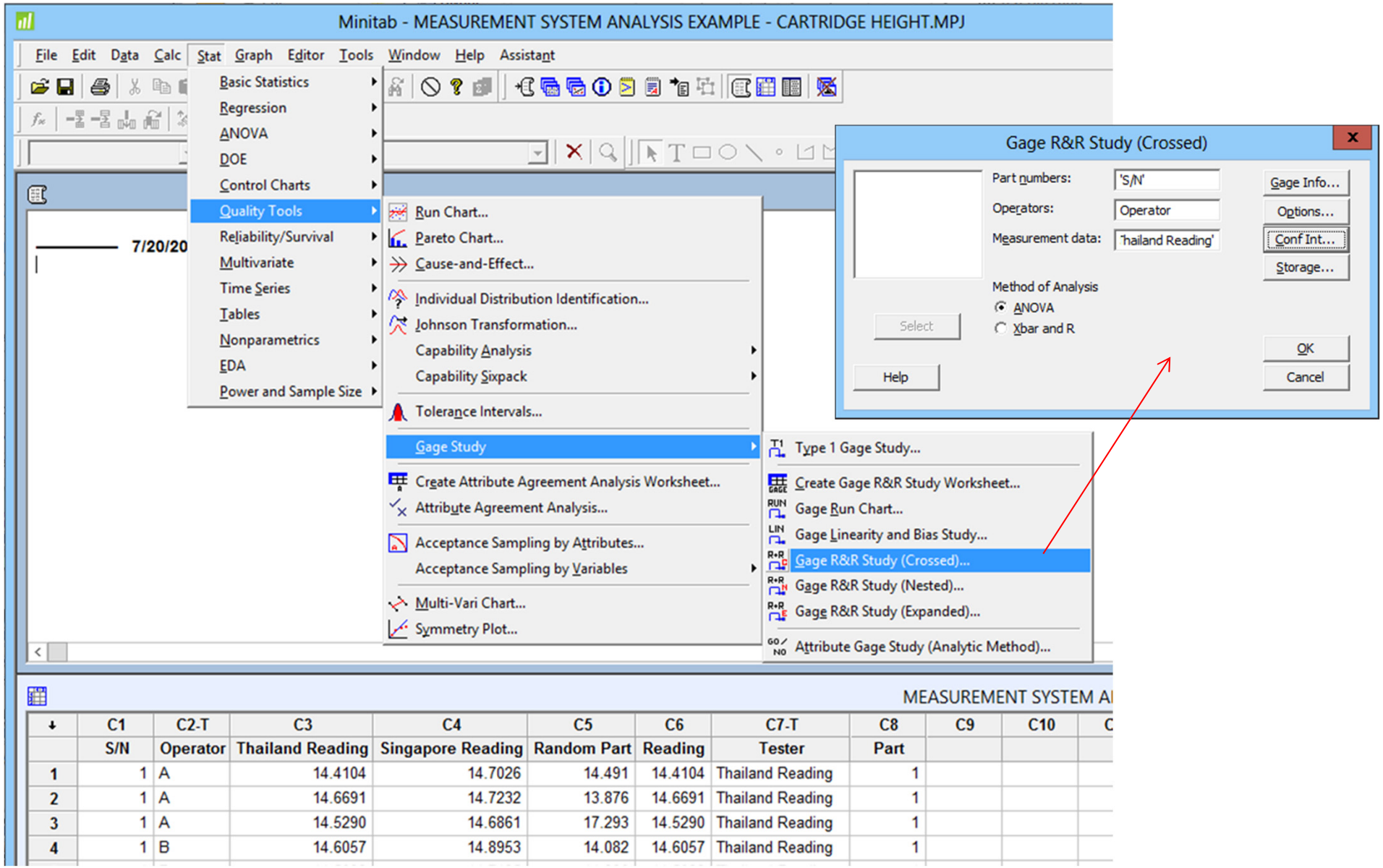
We then test the hypothesis of normality of data by looking at the P-value. The null hypothesis is “data distribute normally”. Typically, If the P-value is less than 5% we can reject the null hypothesis.

In this case the null hypothesis cannot be rejected and we can say that “the data probably distribute normally”.

If the P-value is less than 5%, we can discard a few samples, recollect and test again until pass.

Action 1: Gauge R&R

Open MINITAB File “MEASUREMENT SYSTEM ANALYSIS EXAMPLE - CARTRIDGE HEIGHT.MPJ”



	C1	C2-T	C3	C4	C5	C6	C7-T	C8	C9	C10	C
	S/N	Operator	Thailand Reading	Singapore Reading	Random Part	Reading	Tester	Part			
1	1	A	14.4104	14.7026	14.491	14.4104	Thailand Reading	1			
2	1	A	14.6691	14.7232	13.876	14.6691	Thailand Reading	1			
3	1	A	14.5290	14.6861	17.293	14.5290	Thailand Reading	1			
4	1	B	14.6057	14.8953	14.082	14.6057	Thailand Reading	1			

Gauge R&R Thailand

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
S/N	9	129.556	14.3951	1567.93	0.000
Operator	2	0.009	0.0043	0.47	0.626
Repeatability	78	0.716	0.0092		
Total	89	130.281			

If the P-value is less than 5%, the parameter (source) contribution to total variation (sum squared SS) is considered significant.

Part-to-part variation is significant.

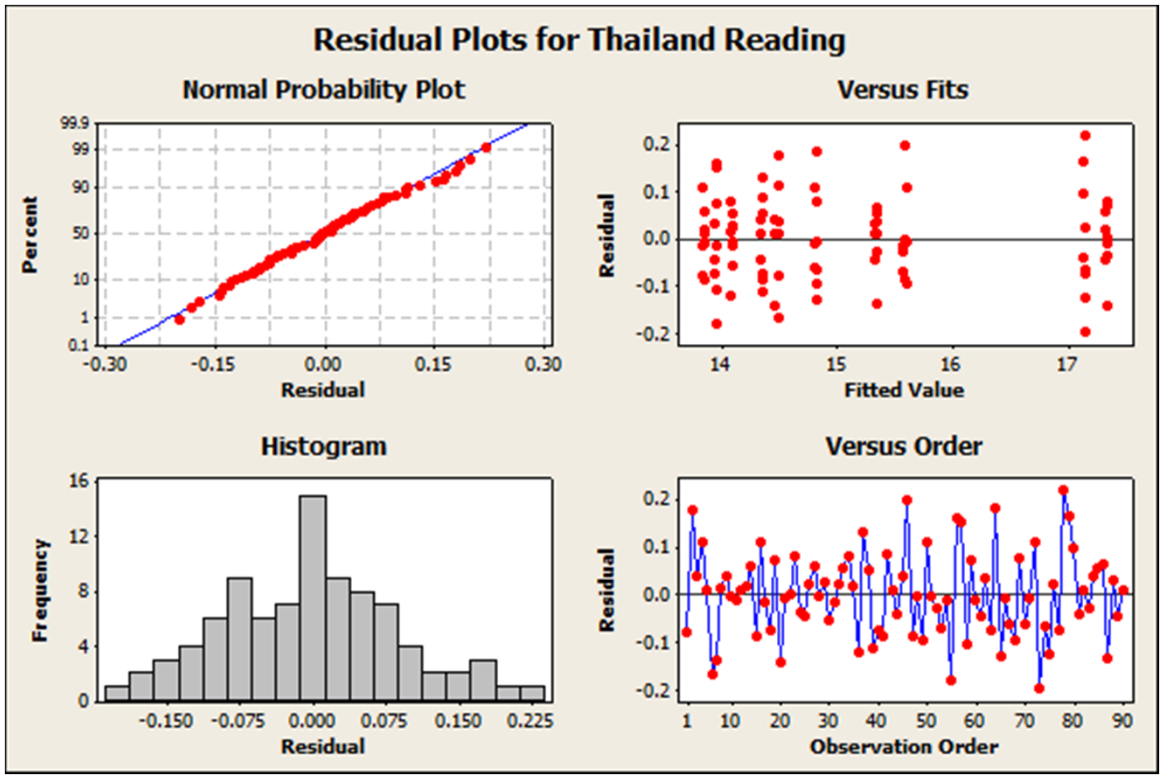
Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.00918	0.57
Repeatability	0.00918	0.57
Reproducibility	0.00000	0.00
Operator	0.00000	0.00
Part-To-Part	1.59844	99.43
Total Variation	1.60762	100.00

Repeatability of tools is good, only 0.57%
Reproducibility (different among tools) is too small to measure.

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0.09582	0.57490	7.56
Repeatability	0.09582	0.57490	7.56
Reproducibility	0.00000	0.00000	0.00
Operator	0.00000	0.00000	0.00
Part-To-Part	1.26429	7.58577	99.71
Total Variation	1.26792	7.60752	100.00

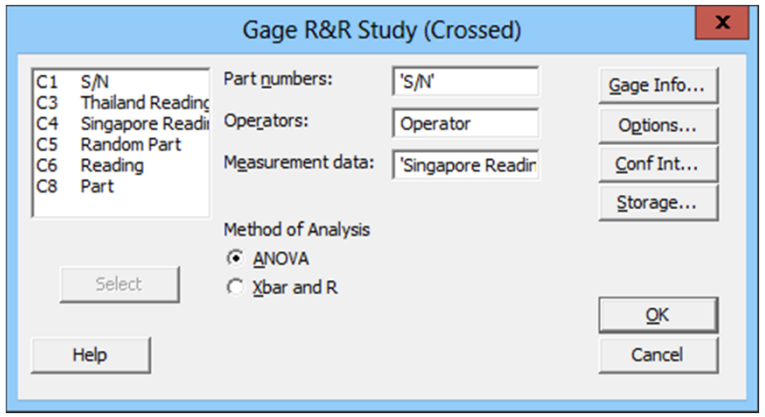
The residual error must distribute normally: $e = NID(0,\sigma^2)$



Gauge R&R Singapore

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
S/N	9	124.177	13.7975	1422.24	0.000
Operator	2	0.004	0.0018	0.18	0.834
Repeatability	78	0.757	0.0097		
Total	89	124.938			



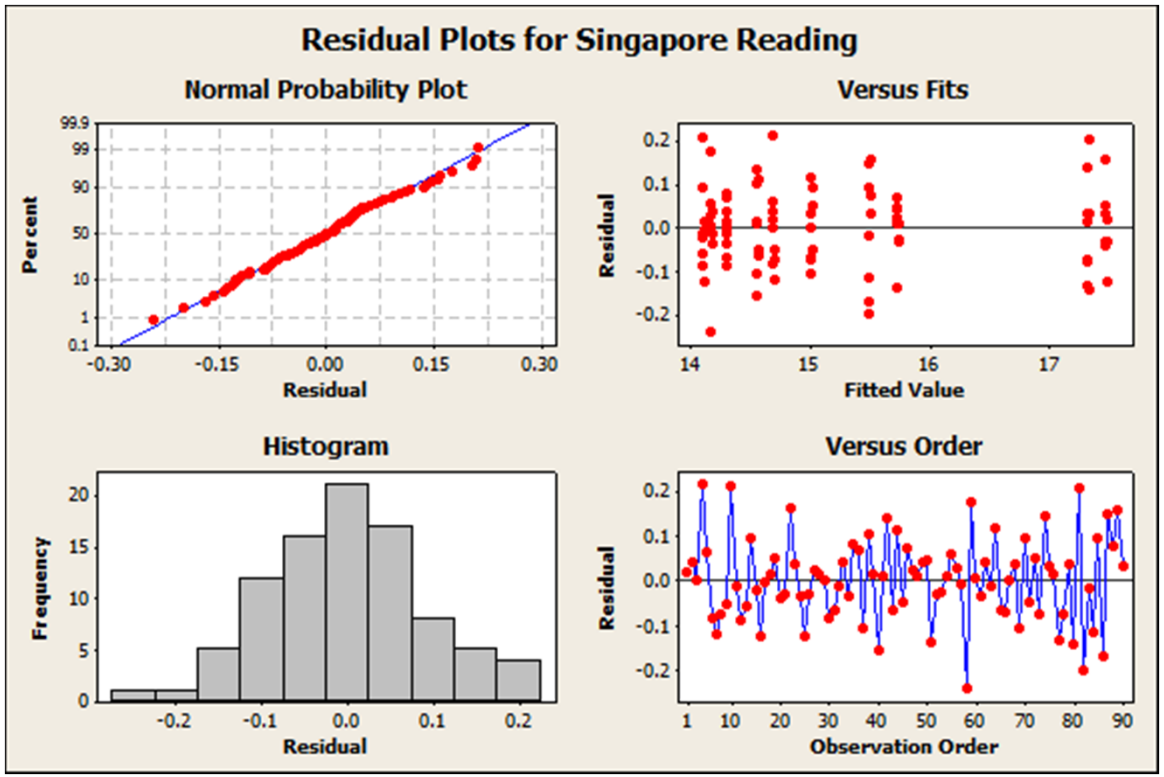
Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.00970	0.63
Repeatability	0.00970	0.63
Reproducibility	0.00000	0.00
Operator	0.00000	0.00
Part-To-Part	1.53198	99.37
Total Variation	1.54168	100.00

Repeatability of tools is good, only 0.63%
Reproducibility (different among tools) is too small to measure.

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0.09849	0.59097	7.93
Repeatability	0.09849	0.59097	7.93
Reproducibility	0.00000	0.00000	0.00
Operator	0.00000	0.00000	0.00
Part-To-Part	1.23773	7.42638	99.68
Total Variation	1.24164	7.44986	100.00

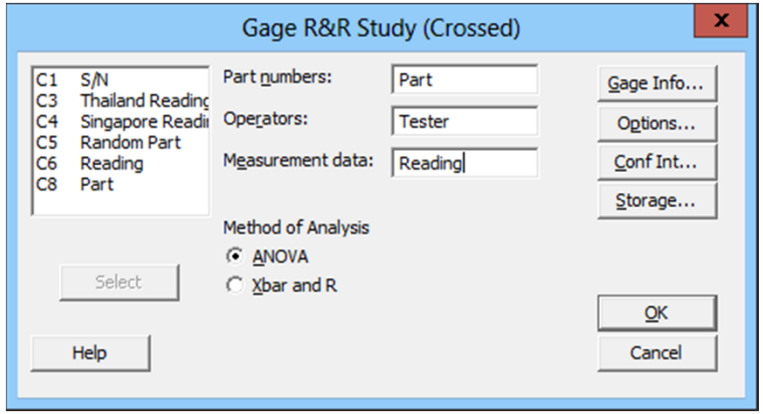
The residual error must distribute normally: $e = NID(0,\sigma^2)$



Gage R&R Combined
(to see the effects of measurement locations)

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	9	253.681	28.1867	3097.44	0.000
Tester	1	1.662	1.6623	182.67	0.000
Repeatability	169	1.538	0.0091		
Total	179	256.881			



Now we can see that plant measurements differ significantly, statistically speaking.

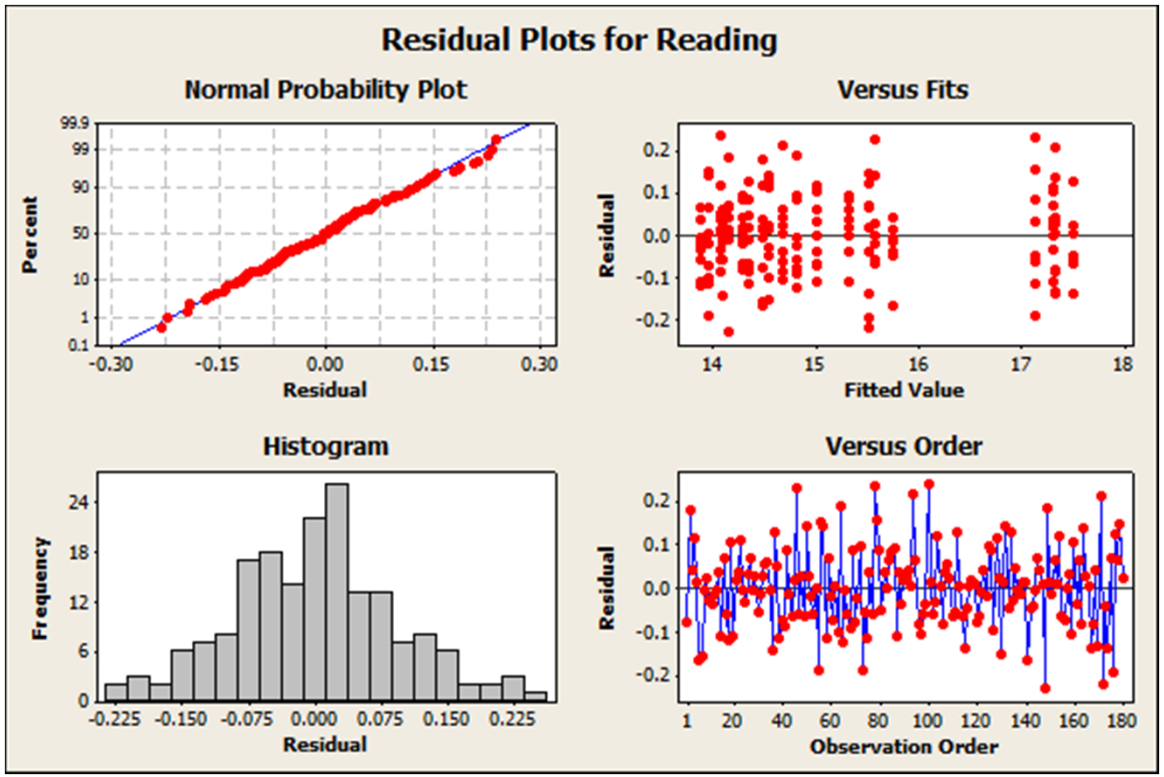
Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.02747	1.72
Repeatability	0.00910	0.57
Reproducibility	0.01837	1.15
Tester	0.01837	1.15
Part-To-Part	1.56542	98.28
Total Variation	1.59289	100.00

The reading differences between TH&SG plants (1.15%) is statistically significant (P-value = 0.000 above) which need to be investigated further.

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0.16574	0.99443	13.13
Repeatability	0.09539	0.57236	7.56
Reproducibility	0.13553	0.81320	10.74
Tester	0.13553	0.81320	10.74
Part-To-Part	1.25117	7.50702	99.13
Total Variation	1.26210	7.57259	100.00

The residual error must distribute normally: $e = NID(0,\sigma^2)$



Action 2: Test of Hypothesis

Test Hypothesis is required to check both Mean and Variation.

Remark : We are using the exactly same parts for both Thailand and Singapore.

This allows us to use the paired T-test technique for hypothesis testing. This technique is much less sensitive to part-to-part variation than the T-test and Z-test.

Note that the paired T-test requires data be distributed normally and collected (or measured) in pair.

Hypothesis Test of Equal Variances

Referring to the basic info of data, we can see that it is likely that the variances of both data sets are the same. If this is true, we can use pooled variance for subsequent analysis.

Basic Information about the Data

Descriptive Statistics: Thailand Reading

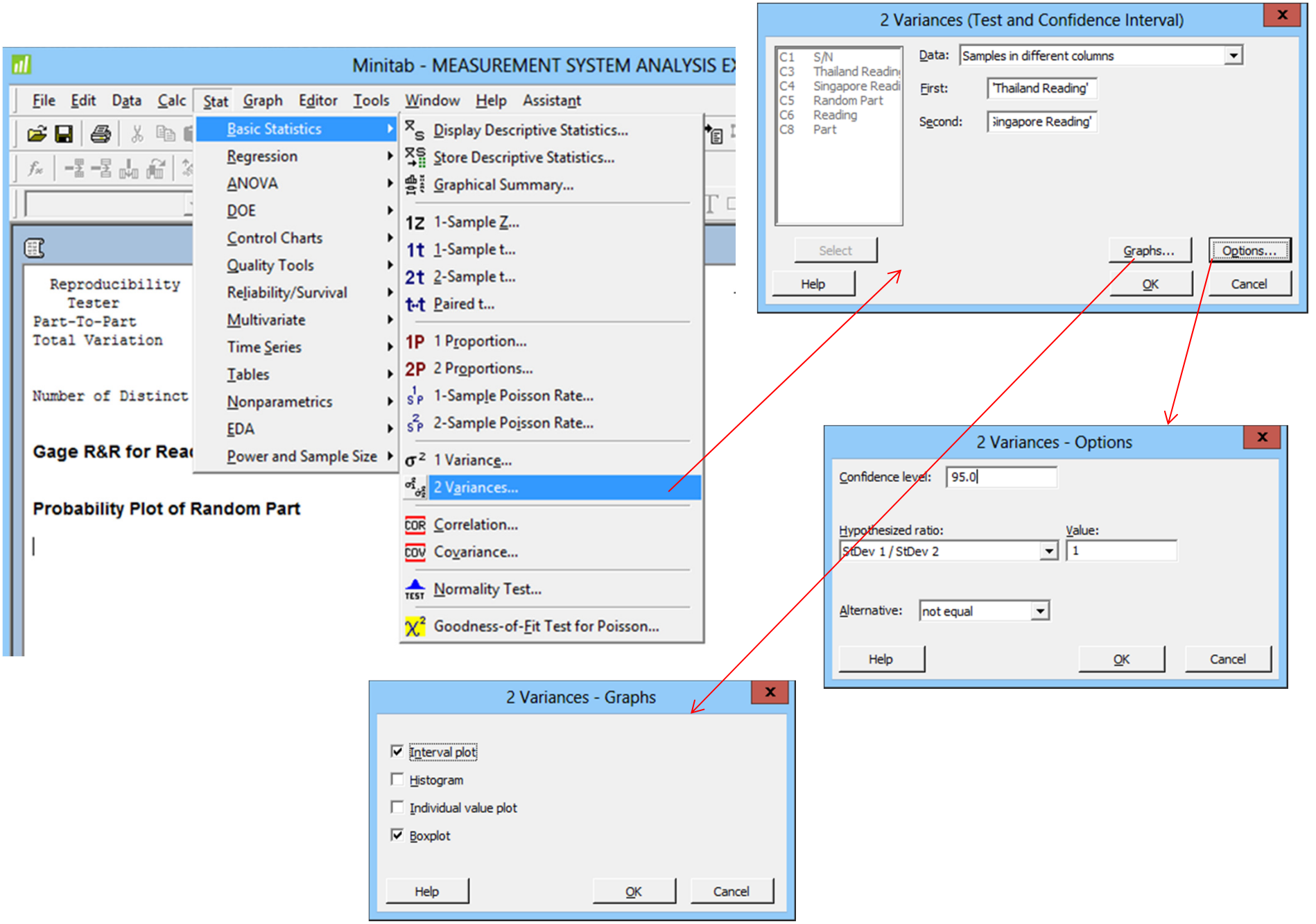
Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Thailand Reading	90	0	15.097	0.128	1.210	13.762	14.118	14.681

Variable	Q3	Maximum
Thailand Reading	15.574	17.423

Descriptive Statistics: Singapore Reading

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Singapore Reading	90	0	15.289	0.125	1.185	13.930	14.314	14.899

Variable	Q3	Maximum
Singapore Reading	15.756	17.633


Minitab - MEASUREMENT SYSTEM ANALYSIS EX
File Edit Data Calc Stat Graph Editor Tools Window Help Assistant
Basic Statistics
Regression
ANOVA
DOE
Control Charts
Quality Tools
Reliability/Survival
Multivariate
Time Series
Tables
Nonparametrics
EDA
Power and Sample Size
Display Descriptive Statistics...
Store Descriptive Statistics...
Graphical Summary...
1-Sample Z...
1-Sample t...
2-Sample t...
Paired t...
1 Proportion...
2 Proportions...
1-Sample Poisson Rate...
2-Sample Poisson Rate...
1 Variance...
2 Variances...
Correlation...
Covariance...
Normality Test...
Goodness-of-Fit Test for Poisson...
Reproducibility
Tester
Part-To-Part
Total Variation
Number of Distinct
Gage R&R for Rea
Probability Plot of Random Part
2 Variances (Test and Confidence Interval)
C1 S/N
C3 Thailand Readin
C4 Singapore Readi
C5 Random Part
C6 Reading
C8 Part
Data: Samples in different columns
First: 'Thailand Reading'
Second: ingapore Reading'
Select
Graphs...
Options...
Help
OK
Cancel
2 Variances - Options
Confidence level: 95.0
Hypothesized ratio:
StDev 1 / StDev 2
Value: 1
Alternative: not equal
Help
OK
Cancel
2 Variances - Graphs
Interval plot
Histogram
Individual value plot
Boxplot
Help
OK
Cancel

Test and CI for Two Variances: Thailand Reading, Singapore Reading

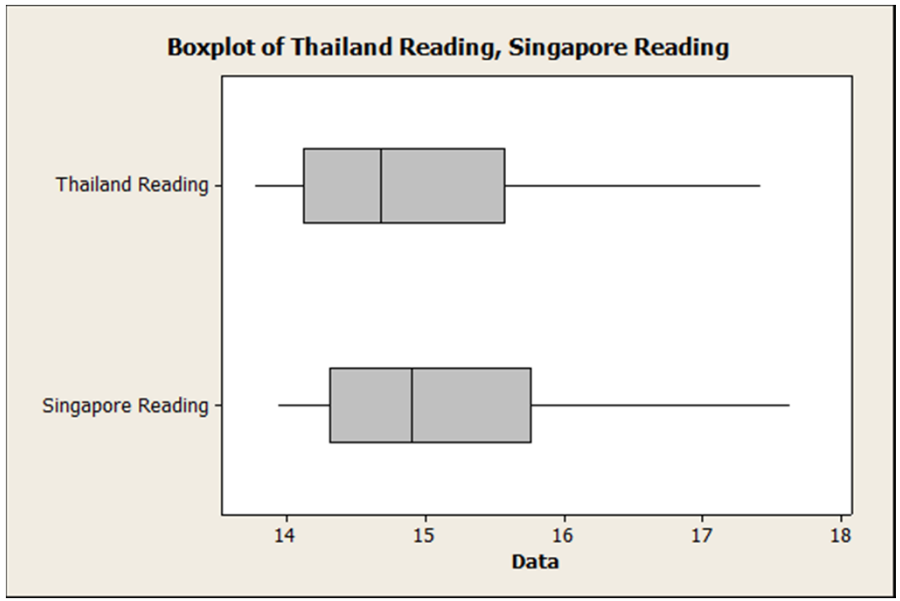
Method

Null hypothesis	Sigma(Thailand Reading) / Sigma(Singapore Reading) = 1
Alternative hypothesis	Sigma(Thailand Reading) / Sigma(Singapore Reading) not = 1
Significance level	Alpha = 0.05

Statistics

Variable	N	StDev	Variance
Thailand Reading	90	1.210	1.464
Singapore Reading	90	1.185	1.404

Ratio of standard deviations = 1.021
Ratio of variances = 1.043



95% Confidence Intervals

Distribution of Data	CI for StDev Ratio	CI for Variance Ratio
Normal	(0.828, 1.259)	(0.686, 1.584)
Continuous	(0.787, 1.348)	(0.620, 1.817)

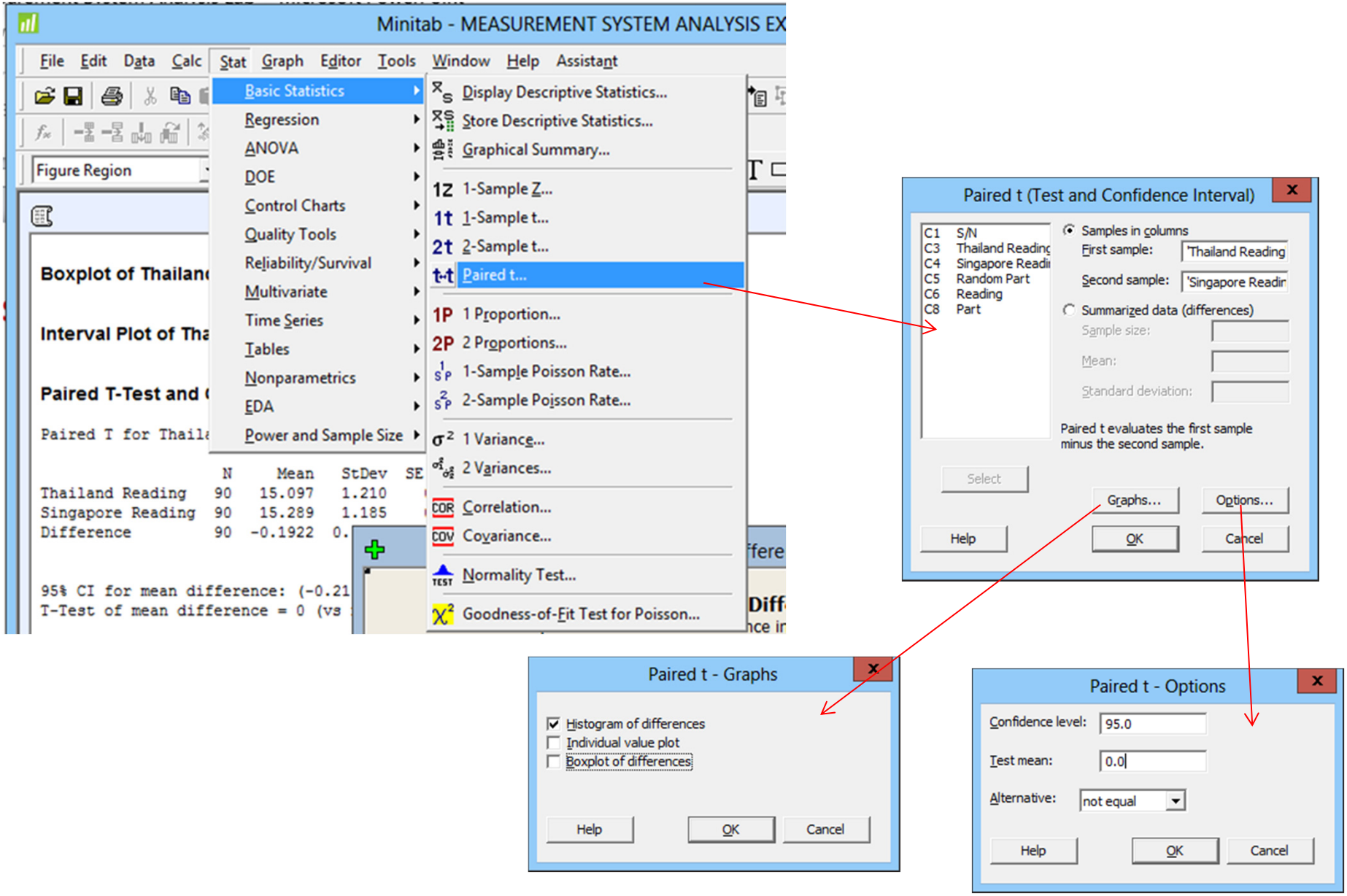
This said “variances could be equal”.

Tests

Method	DF1	DF2	Test Statistic	P-Value
F Test (normal)	89	89	1.04	0.844
Levene's Test (any continuous)	1	178	0.05	0.827

This said “the null hypothesis H_o (equal variance) cannot be rejected at 5% risk”. The risk of being wrong is 84.4% to reject it.

Hypothesis Test of Difference in Means using Paired T-test



Paired T-Test and CI: Thailand Reading, Singapore Reading

Paired T for Thailand Reading - Singapore Reading

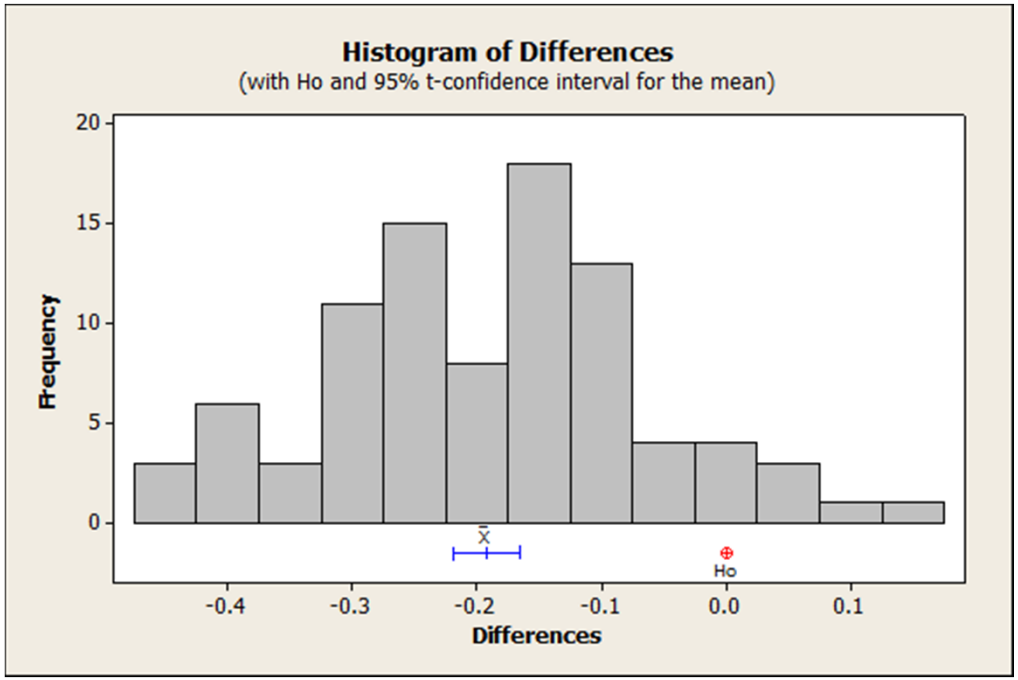
	N	Mean	StDev	SE Mean
Thailand Reading	90	15.097	1.210	0.128
Singapore Reading	90	15.289	1.185	0.125
Difference	90	-0.1922	0.1267	0.0134

95% CI for mean difference: (-0.2187, -0.1657)

T-Test of mean difference = 0 (vs not = 0): T-Value = -14.39 P-Value = 0.000

This said "we can reject the null hypothesis H_o (equal reading) at 5% risk".

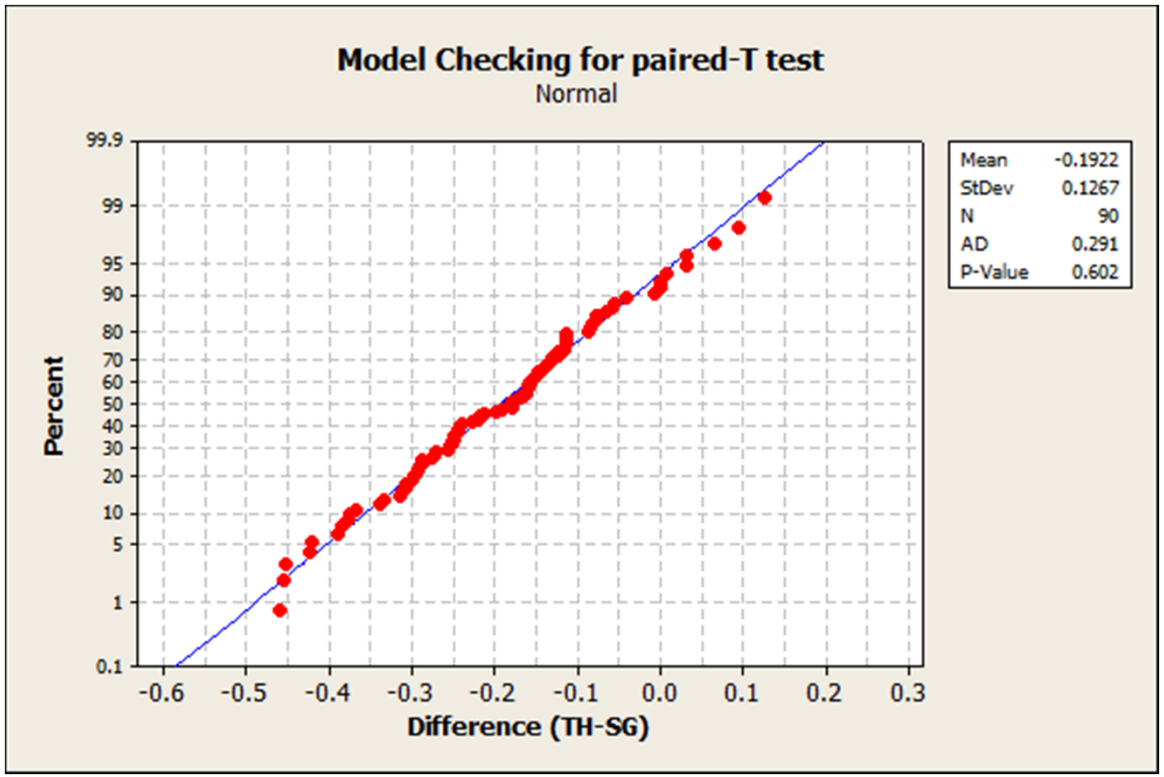
This said "the mean readings of cartridge heights between TH & SG plants is likely to be different, 95% confident".



Conclusion may be something like this:

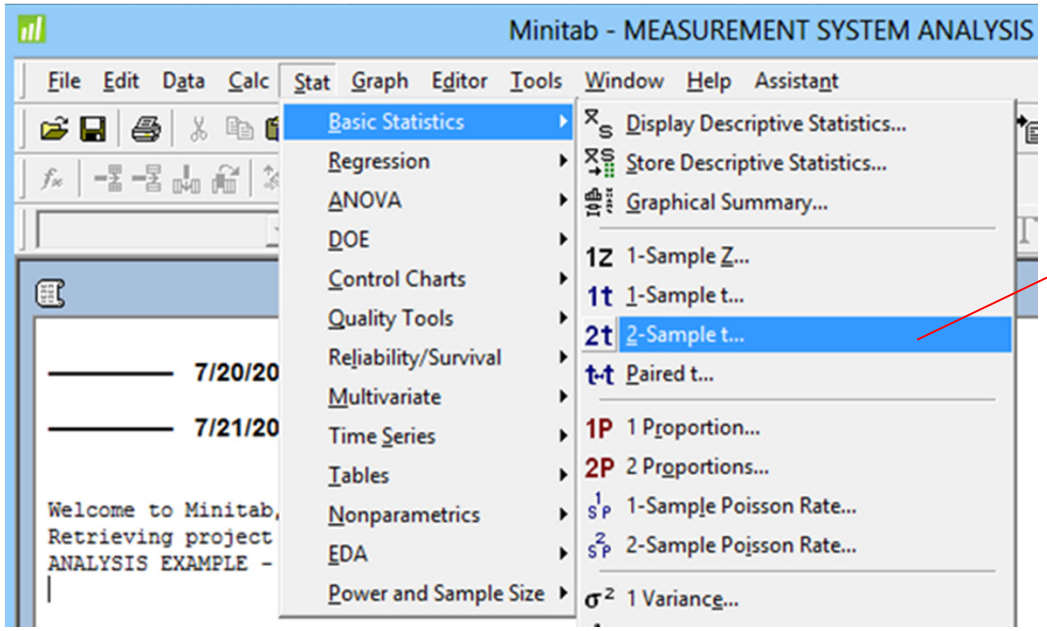
"It is 95% confident that TH measures cartridge heights lower than SG by 0.1922 on average". This helps explain why some HSA hit top cover at SG plant.

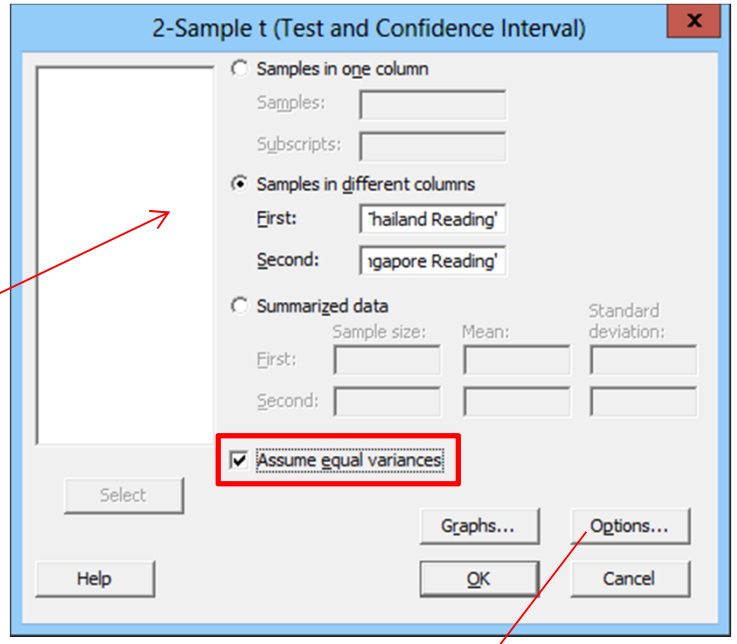
The difference must distribute normally for paired-T test.

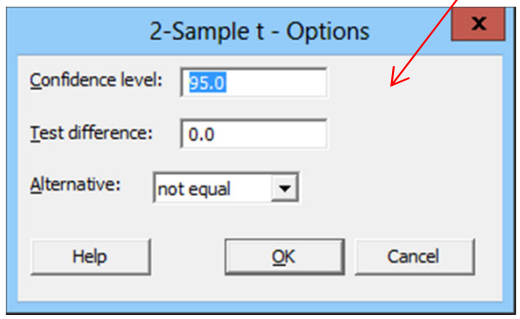


What happens if we use wrong statistical tools to analyze the data?

If someone uses T-test to analyze the data, the results will look like this.







What happens if we use wrong statistical tools to analyze the data?

Two-Sample T-Test and CI: Thailand Reading, Singapore Reading

```
Two-sample T for Thailand Reading vs Singapore Reading

                     N   Mean  StDev  SE Mean
Thailand Reading    90  15.10   1.21     0.13
Singapore Reading   90  15.29   1.18     0.12


Difference = mu (Thailand Reading) - mu (Singapore Reading)
Estimate for difference:  -0.192
95% CI for difference:  (-0.544, 0.160)
T-Test of difference = 0 (vs not =): T-Value = -1.08  P-Value = 0.283  DF = 178
Both use Pooled StDev = 1.1974
```

As mentioned before that the t-test and z-test are quite sensitive to part-to-part variation, which, in this case, is very large (σ = 1.2) compared to the difference (0.192) that we can observe, it is not surprised then that the results from this 2-sample t-test cannot confirm the difference between cartridge height readings between TH and SG plants.

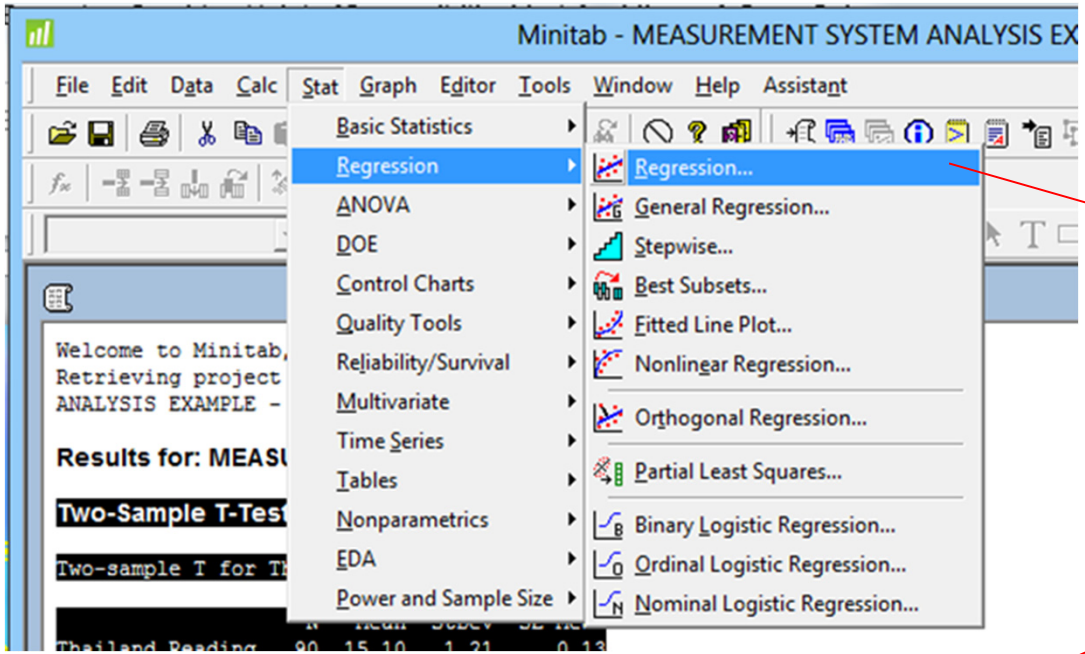
Action 3: Finding SG-TH Reading Correlation

Conclusion from previous analysis was:

"It is 95% confident that TH measures cartridge heights lower than SG by 0.1922 on average". This helps explain why some HSA hit top cover at SG plant.

The question immediately followed is : how the readings are correlated? If correlations exist, we can then find new criteria for cartridge height spec to screen parts for SG plants.

We then begin the next step with simple linear regression.


Minitab - MEASUREMENT SYSTEM ANALYSIS EX
File Edit Data Calc Stat Graph Editor Tools Window Help Assistant
Basic Statistics
Regression
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DOE
Control Charts
Quality Tools
Reliability/Survival
Multivariate
Time Series
Tables
Nonparametrics
EDA
Power and Sample Size
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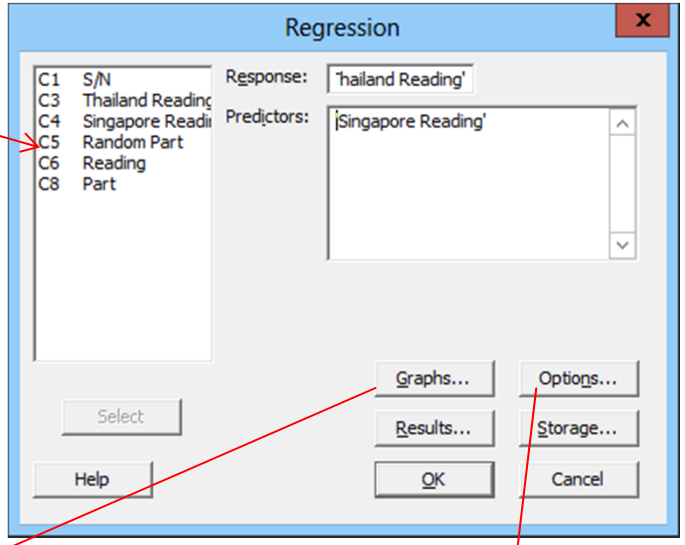
General Regression...
Stepwise...
Best Subsets...
Fitted Line Plot...
Nonlinear Regression...
Orthogonal Regression...
Partial Least Squares...
Binary Logistic Regression...
Ordinal Logistic Regression...
Nominal Logistic Regression...
Welcome to Minitab,
Retrieving project
ANALYSIS EXAMPLE -
Results for: MEASU
Two-Sample T-Tes
Two-sample T for T


Regression
C1 S/N
C3 Thailand Reading
C4 Singapore Readi
C5 Random Part
C6 Reading
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Response: 'hailand Reading'
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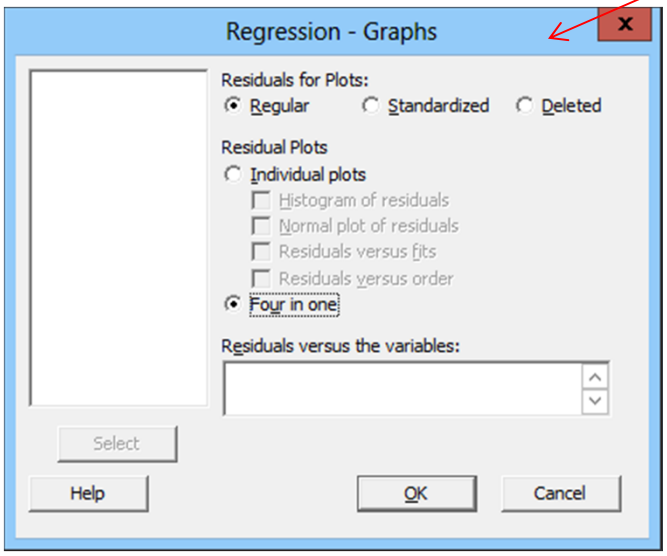
Regression - Graphs
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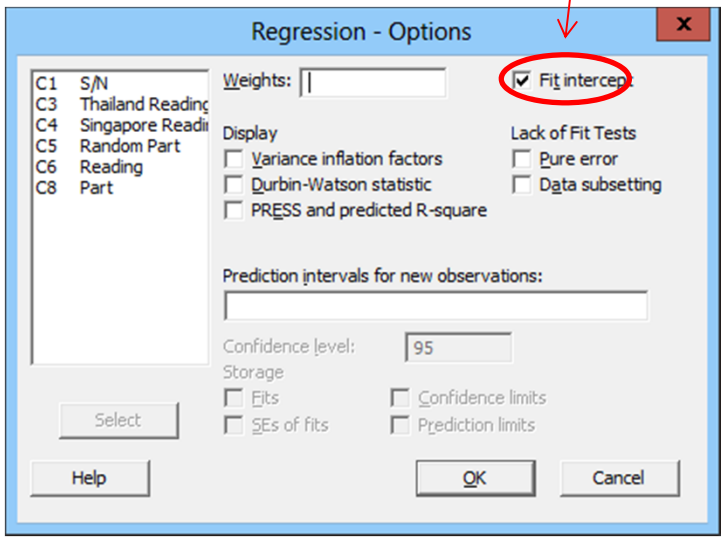

Regression - Options
C1 S/N
C3 Thailand Reading
C4 Singapore Readi
C5 Random Part
C6 Reading
C8 Part
Weights:
Fit intercept
Display
Variance inflation factors
Durbin-Watson statistic
PRESS and predicted R-square
Lack of Fit Tests
Pure error
Data subsetting
Prediction intervals for new observations:
Confidence level: 95
Storage
Fits
SEs of fits
Confidence limits
Prediction limits
Select
Help
OK
Cancel

Regression Analysis: Thailand Reading versus Singapore Reading

The regression equation is
Thailand Reading = - 0.432 + 1.02 Singapore Reading

(y = a + b*x)

Predictor	Coef	SE Coef	T	P
Constant	-0.4317	0.1730	-2.50	0.014
Singapore Reading	1.01566	0.01128	90.03	0.000

Both a and b are significant.

S = 0.126091 R-Sq = 98.9% R-Sq(adj) = 98.9%

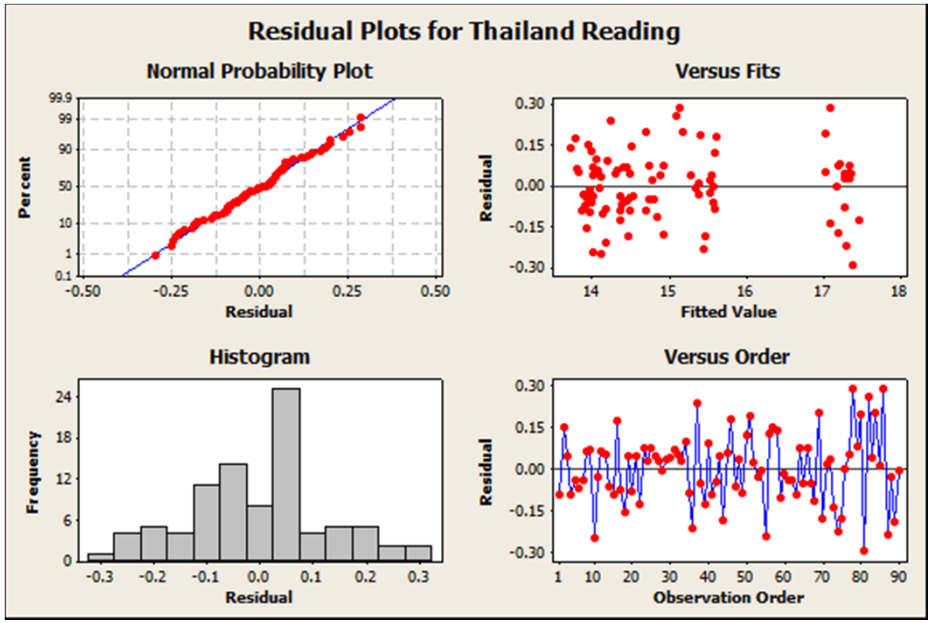
Regression model can explain 98.9% of the total spread (SS) in data.

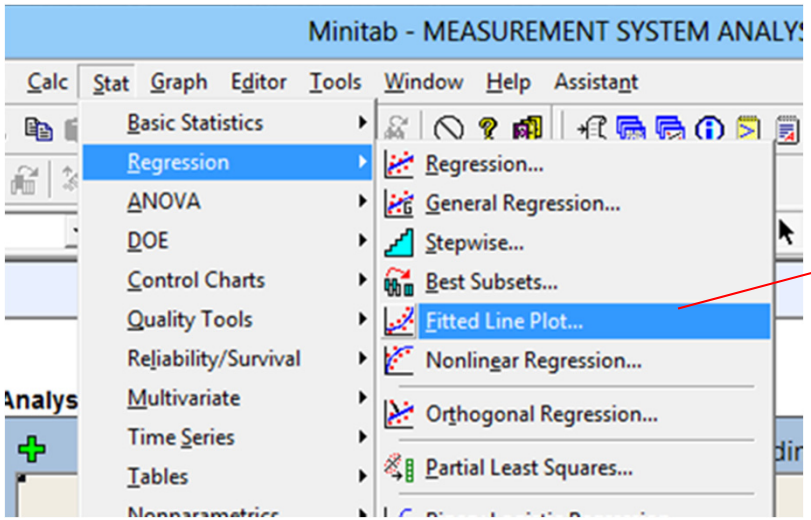
Analysis of Variance

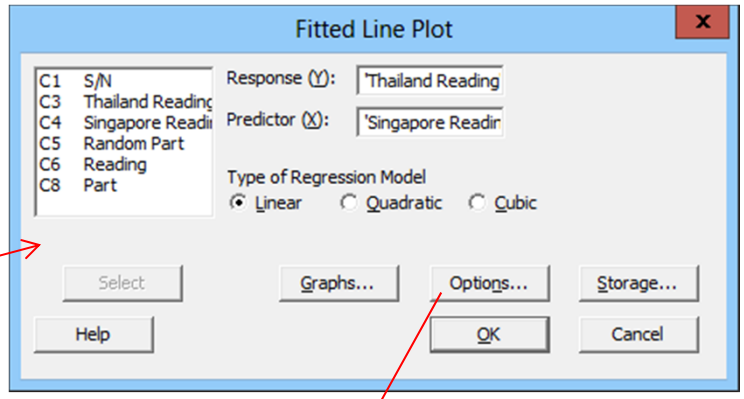
Source	DF	SS	MS	F	P
Regression	1	128.88	128.88	8106.28	0.000
Residual Error	88	1.40	0.02		
Total	89	130.28			

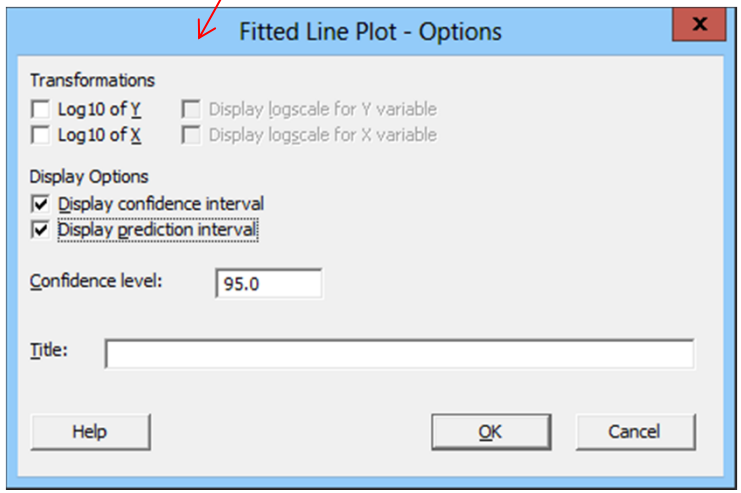
Regression is significant compared to error.

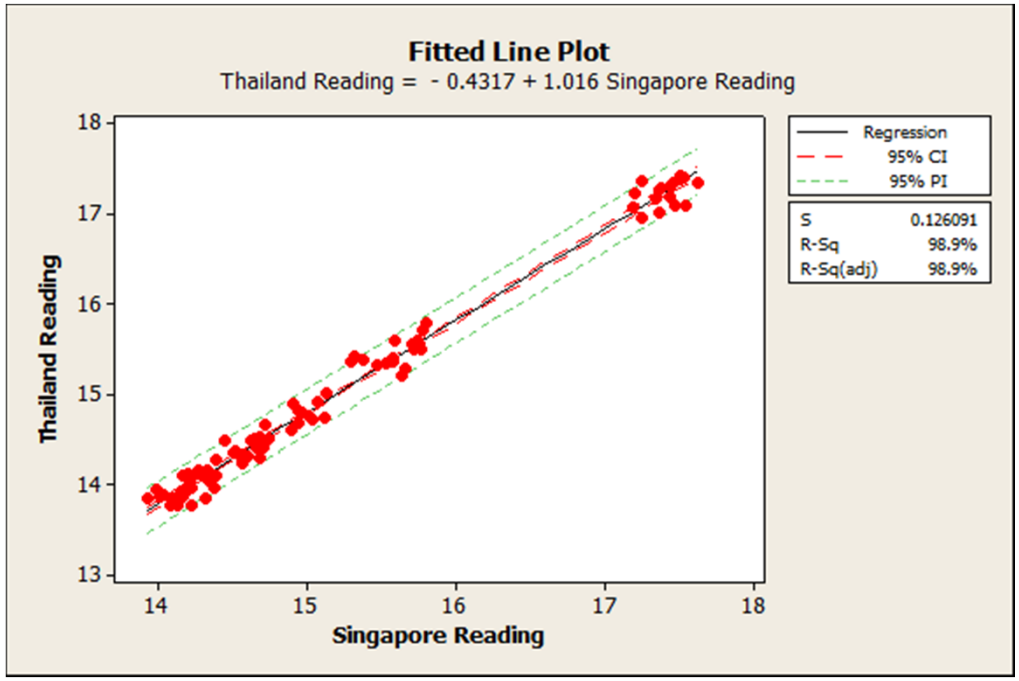
Model checking:
Is error NID(0, σ^2) ?
Ans: Yes











Regression Plot

The regression equation is
Thailand Reading = - 0.432 + 1.02 Singapore Reading

If maximum cartridge height (before HSA hitting top cover) at SG plant is 17.5, what should be the cartridge height spec for TH plant screening before sending parts to SG?

Overall Corrective Actions:

TH: - Cut-in new spec for cartridge height screening.
- Use the regression model above to predict readings at SG.
- Set up tester SPC, Product SPC for yield and performance monitoring.

SG: - Tight control of cartridge installation process.
- Continuous monitoring and feedback.