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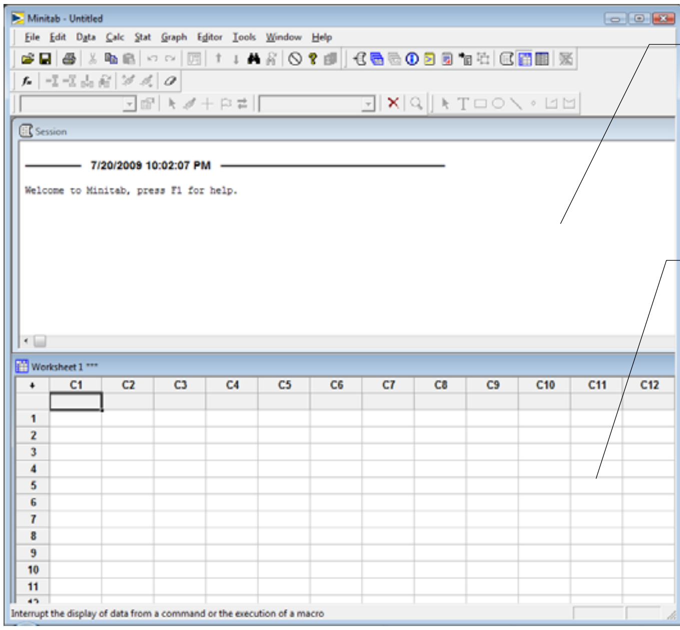
Introduction to Minitab

Minitab is a statistical analysis software package. A 30-day free trial version of Minitab 15 can be downloaded at http://www.minitab.com/en-US/products/minitab/free-trial.aspx

When you launch Minitab, you will see a split screen with two windows: session and worksheet.



The **Session** window displays statistical results of your data analysis and the commands you invoke along with any statistical analyses you may perform.

The **Worksheet** is a spreadsheet interface to input, sort, and manipulate data. How to obtain data?

- Manually enter data
  - Enter column heading above Row 1
  - Enter data
- Open an existing Minitab worksheet file (.mtw or .mpj)
- Copy and paste from an Excel spreadsheet.

Example 1 One-Way ANOVA

In many IC manufacturing, a plasma etching process is widely used. An engineer is interested in investigating the relationship between the RF power setting and the etch rate. He is interested in a particular gas (C_2F_6) and gap (0.80 cm), and wants to test four levels of RF power: 160W, 180W, 200W, and 220W. The experiment is replicated 5 times.

Step 1: Inputting Data

Open the Minitab worksheet file by clicking **File → Open Worksheet**, select the file *Example_1_Etching_Process.mtw* in your stored directory. Click **Open** button. You may see a pop-up window with message "a copy of the content of this file will be added to the current project." Click **OK**. Then you will see the data of the experiment in the worksheet.

EXAMPLE_1_ETCHING_PROCESS.MTW ***

↓	C1	C2	C3	C4
	Run No.	Power Level (W)	Etch Rate (nm/min)	
1	1	220	71.9	
2	2	180	57.9	
3	3	220	72.5	
4	4	160	54.2	
5	5	180	61.0	
6	6	200	65.1	
7	7	160	53.0	
8	8	200	62.9	
9	9	160	57.0	
10	10	160	57.5	
11	11	180	59.0	
12	12	180	59.3	
13	13	200	60.0	
14	14	220	71.5	
15	15	180	56.5	
16	16	200	63.7	
17	17	160	53.9	
18	18	200	61.0	
19	19	220	68.5	
20	20	220	70.0	
21				

Levels of the treatment / input factor

Corresponding values of the response variable

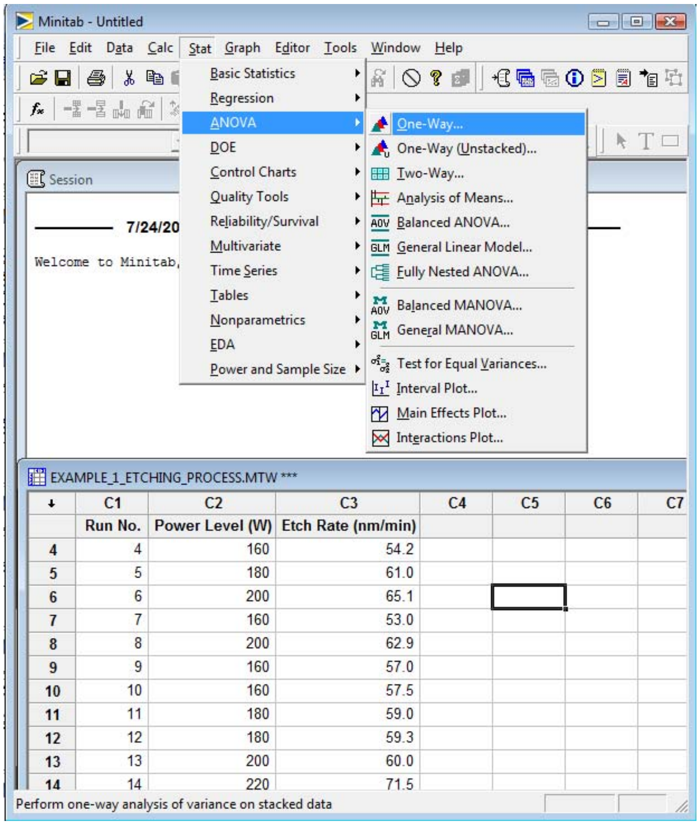
We input the levels of the treatment in one column (C2) and the corresponding values of the response variable in another column (C3). This type of data input is called the **stacked** case in Minitab. It is a preferred way because it allows arranging data with the corresponding run order (in column C1) so that the independence assumption can be checked in ANOVA analysis.

C6	C7	C8	C9	C10
Power=160	Power=180	Power=200	Power=220	
575	565	600	725	
542	593	651	700	
530	590	610	715	
539	579	637	685	
570	610	629	710	

In **unstacked** case, the response values of a given treatment are inputted in a separate column. Ex: the data for Power Level 160 to 220 are stored in columns C6 through C9 respectively. Note that the Run No. cannot be inputted in unstacked case.

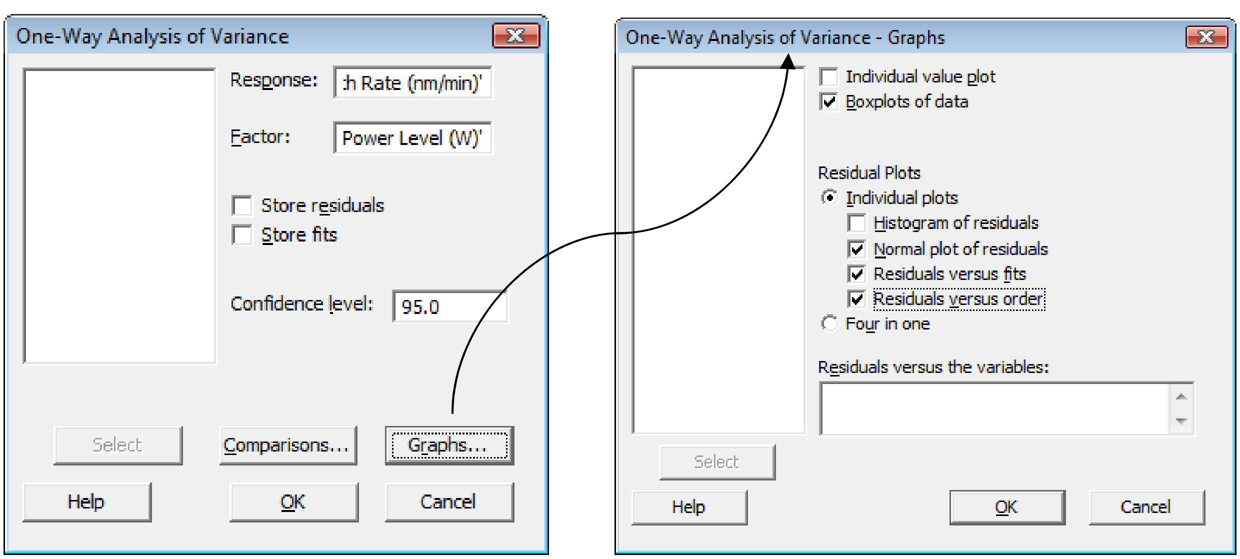
Step 2: Performing Data Analysis

Example #1 is a one-factor factorial design. To perform the One-way analysis of variance (ANOVA) for ***stacked data***, click **Stat → ANOVA → One Way**.



In the dialogue box which appears, select "C3 Etch Rate" for **Response** and "C2 Power Level" for **Factor** by double clicking the columns on the left. Then Click **Graphs** to select the output graphs of the analysis. In the dialogue box, check *"Boxplots of data", "Normal plot of residuals", "Residuals versus fits" and "Residuals versus order"*. Then Click **OK** back to previous dialogue box. Click **OK** again to generate the results of the One-way ANOVA.

The One-way ANOVA table is displayed in the session window. The boxplot, normal plot of residuals, residuals versus fits, and residuals versus order graphs are popped-up.



Step 3. ANOVA Table

ANOVA table is displayed in session window.

```
Session
———— 7/25/2009 3:45:53 PM ————————————————

Welcome to Minitab, press F1 for help.

Results for: EXAMPLE_1_ETCHING_PROCESS.MTW

One-way ANOVA: Etch Rate (nm/min) versus Power Level (W)

Source            DF      SS      MS      F      P
Power Level (W)    3  684.89  228.30  66.92  0.000
Error             16   54.58    3.41
Total             19  739.47

S = 1.847   R-Sq = 92.62%   R-Sq(adj) = 91.24%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N    Mean  StDev  ---+---------+---------+---------+------
160    5  55.120  2.002  (--*---)
180    5  58.740  1.674         (--*---)
200    5  62.540  2.053                 (--*---)
220    5  70.880  1.619                                 (---*--)
                         ---+---------+---------+---------+------
                          55.0      60.0      65.0      70.0

Pooled StDev = 1.847
```

P-value

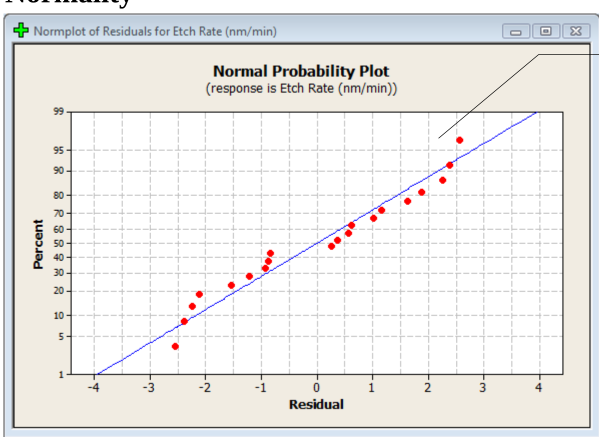
P-value is a measure of how likely the sample results are, assuming the null hypothesis is true. P-values range from 0 to 1.

A small (<0.05, a commonly used level of significance) p-value indicates that the Power Level has statistically significant effect on the Etch rate.

Step 4. Validating ANOVA Assumptions

It is necessary to check the assumptions of ANOVA before draw conclusions. There are three assumptions in ANOVA analysis: normality, constant variance, and independence.

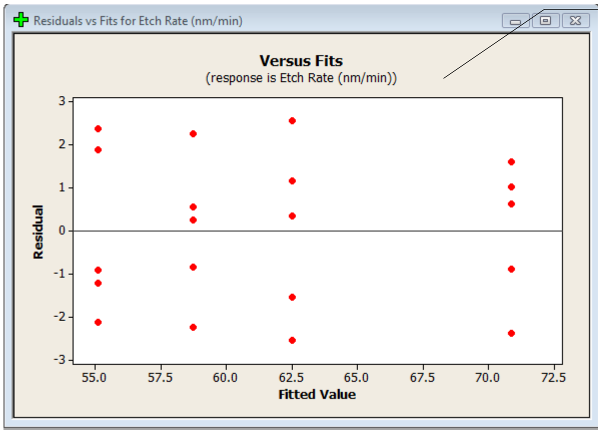
Normality



Normality – ANOVA requires the population in each treatment from which you draw your sample ***be normally distributed.***

The population normality can be checked with a *normal probability plot of residuals*. If the distribution of residuals is normal, the plot will resemble a straight line.

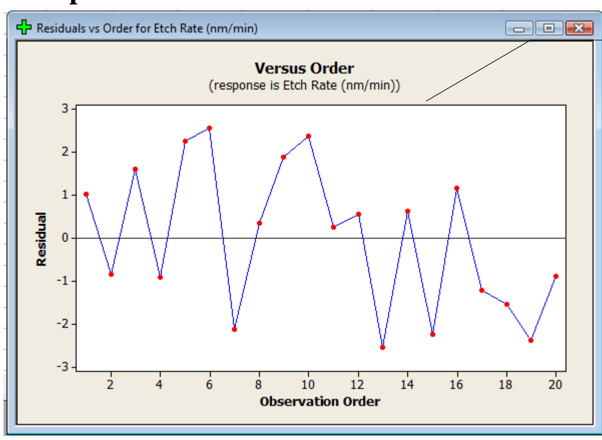
Constant Variance



Constant Variance -- ***The variance of the observations in each treatment should be equal.***
The constant variance assumption can be checked with *Residuals versus Fits* plot. This plot should show a random pattern of residuals on both sides of 0, and should not show any recognizable patterns.

A common pattern is that the residuals increase as the fitted values increase.

Independence

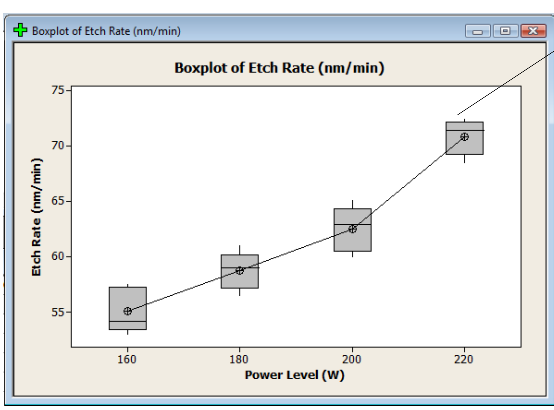


Independence – ANOVA requires that ***the observations should be randomly selected from the treatment population.***
The independence, especially of time-related effects, can be checked with the *Residuals versus Order* (time order of data collection) plot. A positive correlation or a negative correlation means the assumption is violated. If the plot does not reveal any pattern, the independence assumption is satisfied.

The normality plot of the residuals above shows that the residuals follow a normal distribution. Both plot of residuals versus fitted values and plot of residuals versus run order do not show any pattern. Thus, both constant variance and independence assumptions are satisfied.

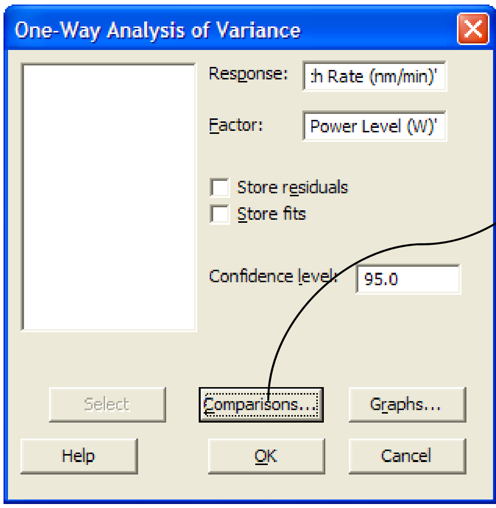
Step 5. Interpreting ANOVA Results and Multiple Comparisons

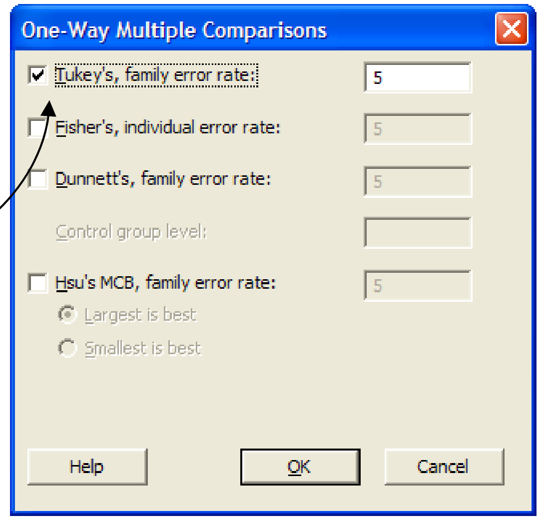
The ANOVA table shows that the power level has statistically significant effect on the etch rate. **The Effect of the factor** (power level) can be displayed using a boxplot as shown below. The boxplot shows that the etch rate increases as the power level increases.

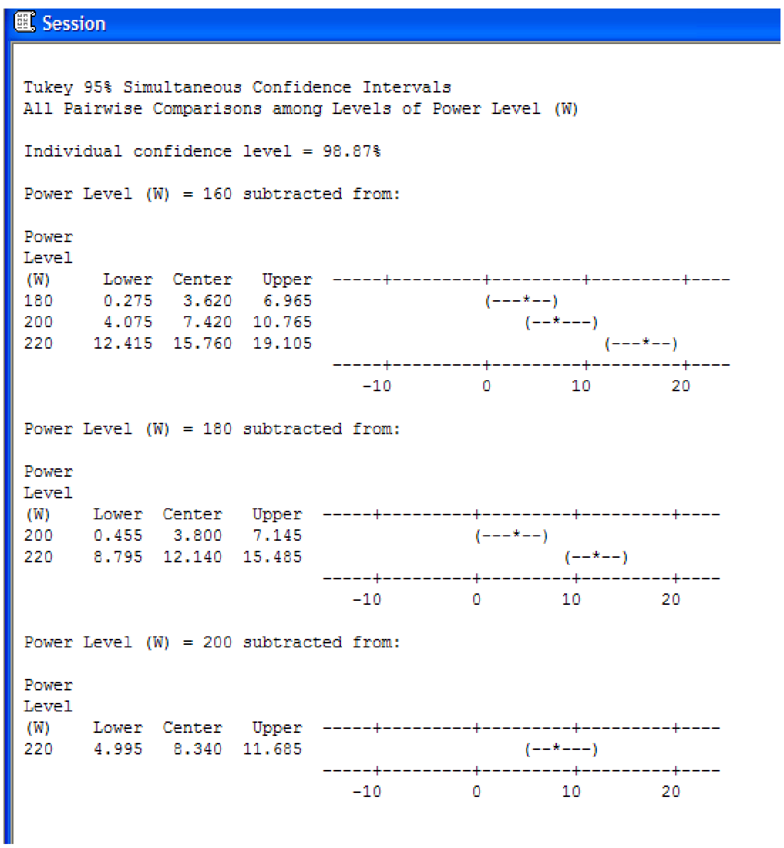


Boxplot
Boxplot here is a graphical summary of the distribution of Etch Rate at each Power Level.

After we conclude that there is significant different in etch rate between different power levels, the next question to ask is that which ones are different from the rest. In this case, a common method is to use Tukey's multiple comparisons to construct confidence intervals for the differences between each pair of means. The Tukey's multiple comparison results are displayed in the session window.






Session

```
Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Power Level (W)

Individual confidence level = 98.87%

Power Level (W) = 160 subtracted from:

Power
Level
(W)     Lower   Center   Upper   -----+---------+---------+---------+----
180     0.275    3.620   6.965              (---*--)
200     4.075    7.420  10.765                  (--*---)
220    12.415   15.760  19.105                          (---*--)
                                 -----+---------+---------+---------+----
                                    -10         0        10        20

Power Level (W) = 180 subtracted from:

Power
Level
(W)    Lower   Center   Upper   -----+---------+---------+---------+----
200    0.455    3.800   7.145              (---*--)
220    8.795   12.140  15.485                       (--*--)
                                -----+---------+---------+---------+----
                                   -10         0        10        20

Power Level (W) = 200 subtracted from:

Power
Level
(W)    Lower   Center   Upper   -----+---------+---------+---------+----
220    4.995    8.340  11.685                  (--*---)
                                -----+---------+---------+---------+----
                                   -10         0        10        20
```

Step 6. Save the analysis results

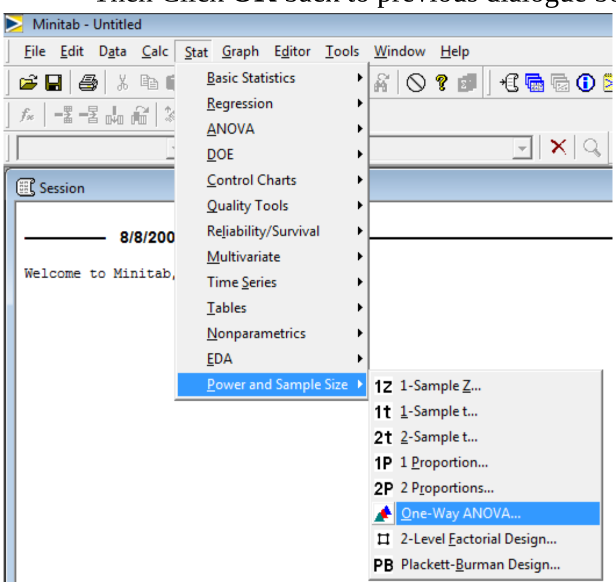
You can save all the analysis work you have done by choosing **File → Save Project as**.

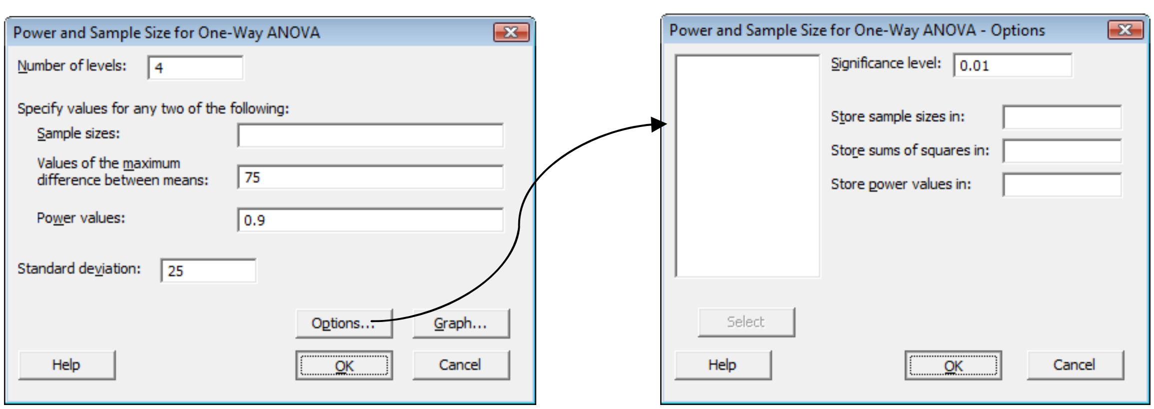
Determining Sample Size in One-way ANOVA

It is important to choose a proper sample size in planning an experiment. To determine one-way ANOVA sample size in Minitab, Click **Stat → Power and Sample Size → One-Way ANOVA.**

Assume we want to determine sample size in Example #1 before the experiment was conducted.

- In the dialogue box, input "4" in "**Number of levels**" since the number of factor levels in Example #1 is 4.
- Input the estimated value, "75", in "**Value of the maximum difference between means**" provided that we will conclude the factor has statistically significance effect on the response variable if the mean difference in the response variable resulted from two different treatment levels exceeds a specified value, "75" in this example.
- Input "0.9" in "**Power values**".
- Input the estimated value, "25", in "**Standard deviation**". The standard deviation is an estimate of the population standard deviation. One can estimate the standard deviation through prior experience or by conducting a pilot study.
- Click **Option** and set "**Significance level**" to "0.01" if the confidence level is set at 99%, or set "**Significance level**" to "0.05" if the confidence level is set at 95%.
- Then Click **OK** back to previous dialogue box. Click **OK** again to calculate the sample size.





The results is displayed below. The required sample size for each level is 6 if the maximum difference in treatment mean is 75, power level at 90%, confidence level at 99% (alpha = 0.01), and standard deviation is 25. Thus, the total run should be 24 (6 x 4 levels).

Session

Power and Sample Size

```
One-way ANOVA

Alpha = 0.01  Assumed standard deviation = 25  Number of Levels = 4


          Sample  Target                    Maximum
SS Means    Size   Power  Actual Power  Difference
  2812.5       6     0.9      0.915384          75

The sample size is for each level.
```

Power Curve for One-way ANOVA

Example 2 Two-factor Factorial Design

The purpose of this experiment is to investigate the effect of reflow peak temperature and time above liquidus (TAL) on lead-free solder joint shear strength. The data are in *Example_2_Solder_Reflow_0402.mtw*.

Step 1. Open the Minitab worksheet file by clicking **File → Open Worksheet**, select the file *Example_2_Solder_Reflow_0402.mtw* in your stored directory. Click **Open** button. You may see a pop-up window with message "a copy of the content of this file will be added to the current project." Click **OK**. Then you will see the data of the experiment in the worksheet.

Example_2_Solder_Reflow_0402.MTW ***

↓	C1	C2	C3	C4
	Run No.	Peak Temp	TAL	Shear Force
1	1	240	60	1262.85
2	1	240	60	1322.84
3	1	240	60	1531.11
4	1	240	60	1291.66
5	1	240	60	1423.03
6	1	240	60	1241.52
7	2	250	60	1418.00
8	2	250	60	1352.41
9	2	250	60	902.43
10	2	250	60	1070.17
11	2	250	60	1293.82
12	2	250	60	823.28
13	3	230	60	1659.77

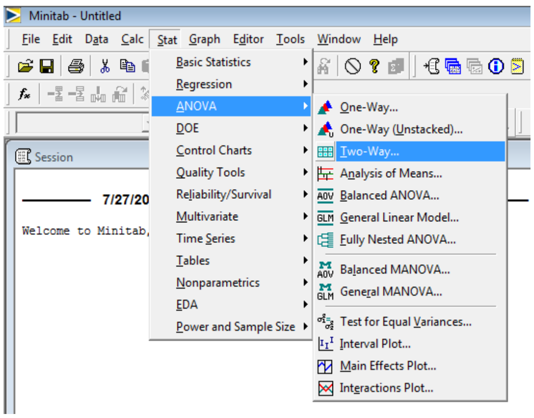
Response variable: Shear Force
Input factors: Peak Temperature and TAL (Time Above Liquidus)

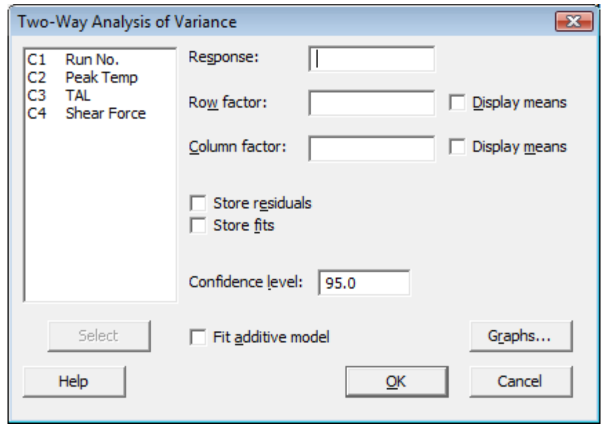
Two methods in Minitab can be used for this analysis: ***Two-Way ANOVA*** and ***General Linear Model***

Note that one-way ANOVA, as used in Example #1, tests the equality of population means when there is only one factor. If there are two or more input variables or factors, two-way ANOVA or general linear models should be used. Two-way ANOVA performs an analysis of variance for two-factor factorial design. In two-way ANOVA, the data must be balanced (all cells must have the same number of observations), and factors must be fixed. If the data are not balanced and/or the factors are not fixed, general linear models should be used for analyzing two-factor factorial designs. General linear model can be used for analyzing block designs, more than three-factor factorial designs, and others. General linear models can be used for multiple comparisons as well.

Method #1: Two-Way ANOVA

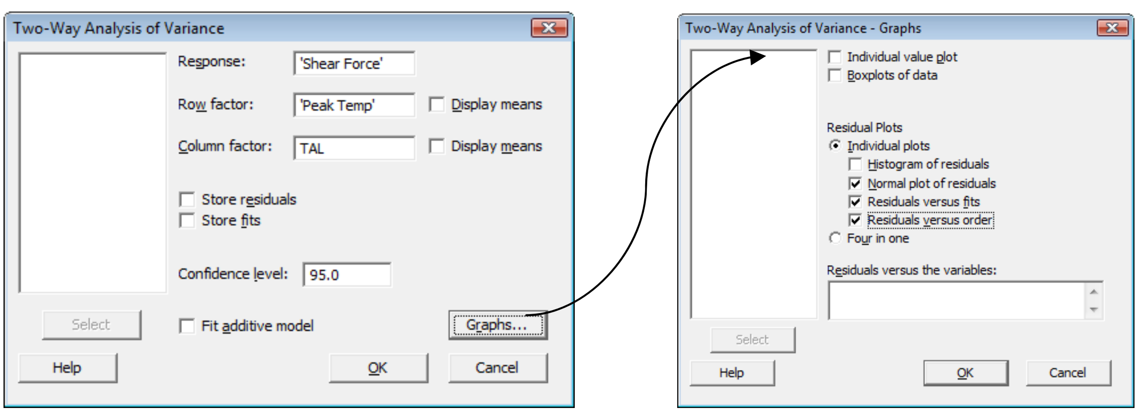
Step 2: To perform the Two-way ANOVA for stacked data, click **Stat → ANOVA → Two-Way**.





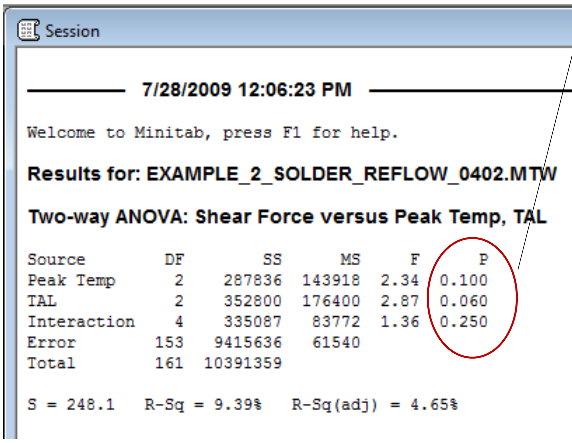
You will see the above dialogue box. Select “C4 Shear Force” for **Response** and “C2 Peak Temp” for **Row factor** and “C3 TAL” for **Column factor** by double clicking the columns on the left. Row factor and Column factor are interchangeable.

Then Click **Graphs** to select the output graphs of the analysis. In the dialogue box, check *“Normal plot of residuals”, “Residuals versus fits” and “Residuals versus order”*. Then Click **OK** back to previous dialogue box. Click **OK** again to generate the results of the Two-way ANOVA.



Step 3. ANOVA Table

The ANOVA table is displayed in the Session Window.


Session

7/28/2009 12:06:23 PM

Welcome to Minitab, press F1 for help.

Results for: EXAMPLE_2_SOLDER_REFLOW_0402.MTW

Two-way ANOVA: Shear Force versus Peak Temp, TAL

Source	DF	SS	MS	F	P
Peak Temp	2	287836	143918	2.34	0.100
TAL	2	352800	176400	2.87	0.060
Interaction	4	335087	83772	1.36	0.250
Error	153	9415636	61540		
Total	161	10391359			

S = 248.1 R-Sq = 9.39% R-Sq(adj) = 4.65%

P value

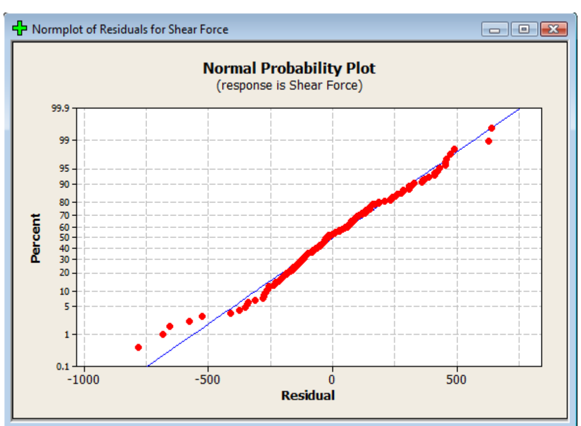
None of the P values was below 0.05. Thus, we cannot reject the null hypothesis, which is the lead-free solder joint shear strength of 0402 is same at different reflow profile.

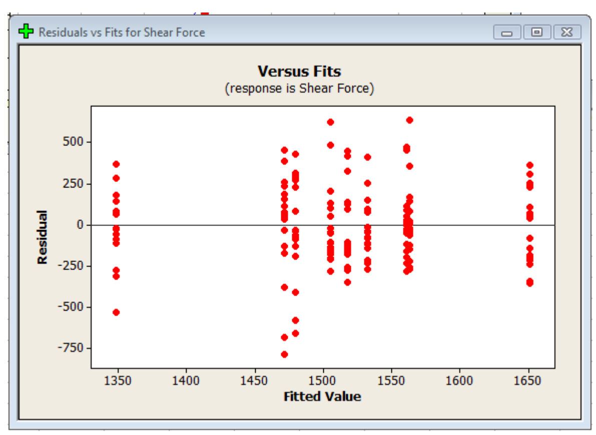
Since none of the p-values was below 0.05, we cannot reject the null hypothesis, or we cannot conclude that the reflow profile has significant effect on the lead-free solder joint shear strength of 0402 component at 95% confidence level. The analysis can stop here.

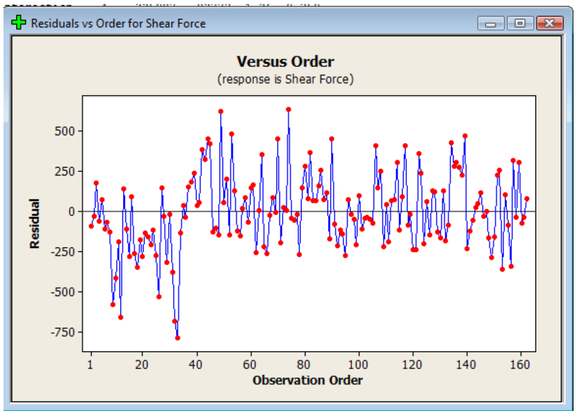
If at least one of the p-values is below 0.05, continue Step 4 validating ANOVA assumptions and Step 5 interpreting ANOVA results.

Step 4. Validating ANOVA Assumptions

As stated in Example #1, there are three assumptions in ANOVA analysis: normality, constant variance, and independence. The normality plot of the residuals is used to check the normality of the treatment data. If the distribution of residuals is normal, the plot will resemble a straight line. The constant variance assumption is checked by the plot of residuals versus fitted values. If the plot of residual vs. fitted values (treatment) does not show any pattern, the constant variance assumption is satisfied. If the plot of residual vs. run order (time order of data collection) does not reveal any pattern, the independence assumption is satisfied. It seems that there is nothing unusual about the residuals in Example #2.

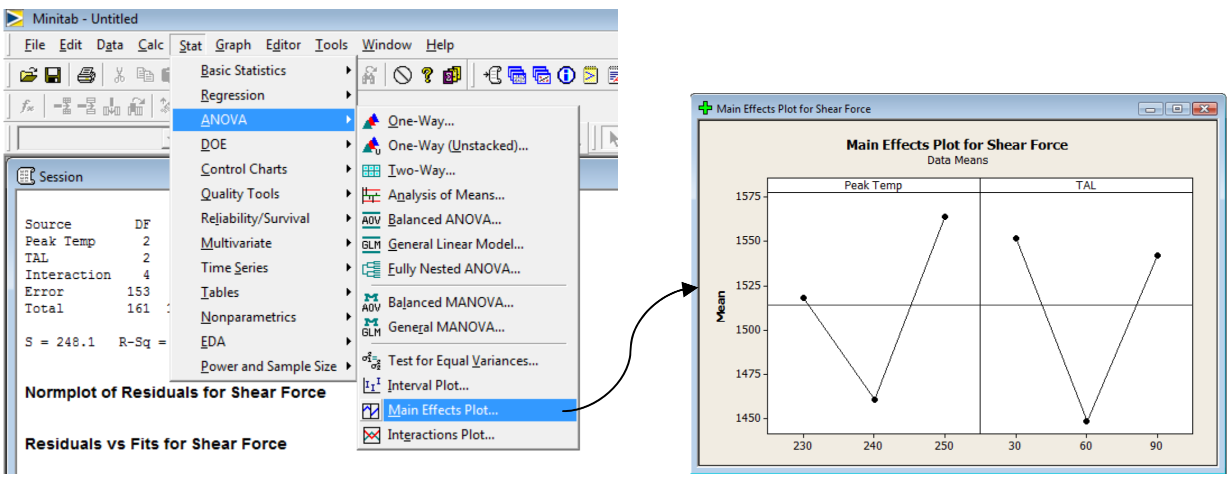






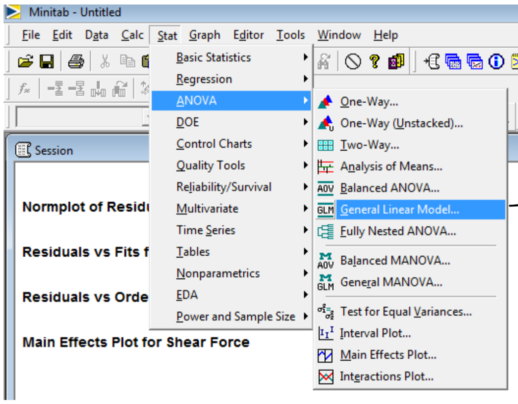
Step 5. Interpreting ANOVA Results

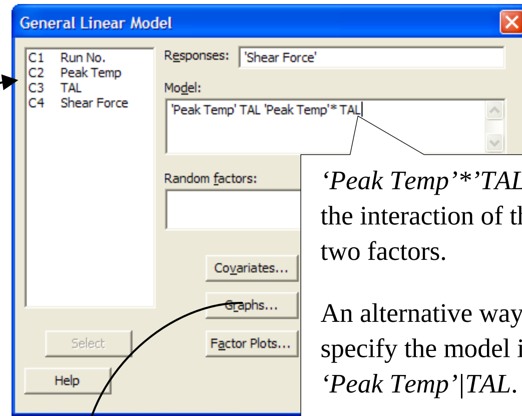
Assume there were significant factors; the **Main Factor Plot** can be obtained by clicking **Stat → ANOVA → Main Effects Plot,** and the **Interaction Plot** can be obtained by clicking **Stat → ANOVA → Interactions Plot**



Method #2: General Linear Model

General Linear Model is a more general approach to perform ANOVA. To perform the two-factor ANOVA using General Linear Model, click **Stat → ANOVA → General Linear Model.** In the General Linear Model dialogue box, double click "C4 Shear Force" for **Response.** In **Model**, type *Peak Temp*, *TAL*, and *Peak Temp*TAL*. Then select output graphs by click **Graph** option.



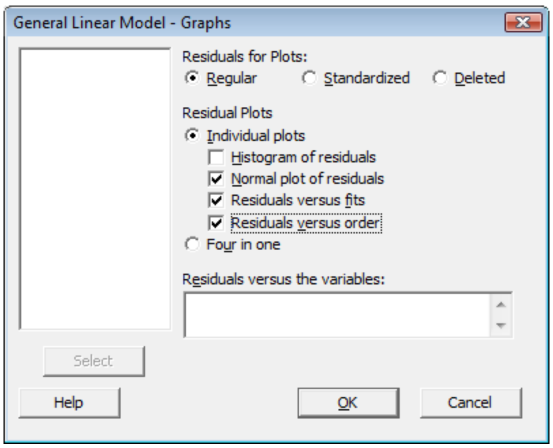


'Peak Temp''TAL'* is the interaction of the two factors.

An alternative way to specify the model is *'Peak Temp'|TAL*.

If no interaction term is specified, the model terms will be

'Peak Temp' TAL



The ANOVA table of the analysis is displayed below. The results are same as the Two-way ANOVA.

```
Session

General Linear Model: Shear Force versus Peak Temp, TAL

Factor     Type   Levels  Values
Peak Temp  fixed       3  230, 240, 250
TAL        fixed       3  30, 60, 90


Analysis of Variance for Shear Force, using Adjusted SS for Tests

Source          DF    Seq SS   Adj SS  Adj MS     F      P
Peak Temp        2    287836   287836  143918  2.34  0.100
TAL              2    352800   352800  176400  2.87  0.060
Peak Temp*TAL    4    335087   335087   83772  1.36  0.250
Error          153   9415636  9415636   61540
Total          161  10391359


S = 248.073   R-Sq = 9.39%   R-Sq(adj) = 4.65%
```

ANOVA assumptions check and ANOVA table interpretation are similar to two-way ANOVA. Please refer to Example #3 regarding to details of checking ANOVA assumptions and interpreting ANOVA results in General Linear Model.

Example 3: Randomized Complete Block Design

A study is planned to investigate whether the quality of senior projects differs between three student groups. Eight senior projects were randomly selected from the each of these three groups. Industrial advisory board (IAB) members were asked to evaluate the quality of senior projects using rubric-based instruments. A randomized complete block design (RCBD) was chosen with reviewer (IAB evaluator) as a block.

Step 1: Inputting Data

Open the Minitab worksheet file by clicking **File → Open Worksheet**, select the file *Example_3_Senior_Project.mtw* in your stored directory. Click **Open** button. You may see a pop-up window with message "a copy of the content of this file will be added to the current project." Click **OK**. Then you will see the data of the experiment in the worksheet.

EXAMPLE_3_SENIOR_PROJECTS.MTW ***

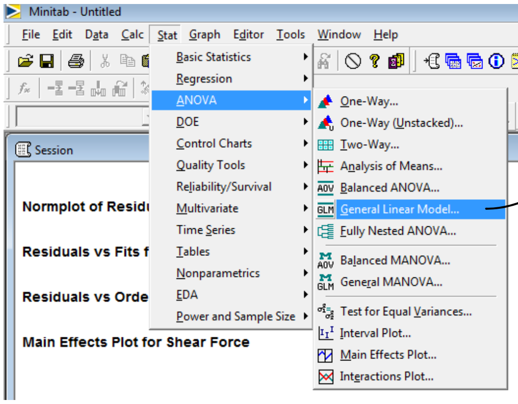
↓	C1	C2	C3
	Reviewer No.	Group	Evaluation_Scores
1	1	3	76
2	1	2	92
3	1	1	70
4	2	2	75
5	2	3	88
6	2	1	85
7	3	3	77
8	3	2	83
9	3	1	65
10	4	2	92
11	4	3	75

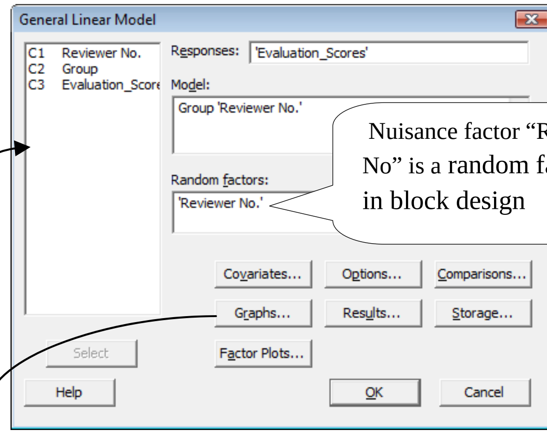
Response variable: Evaluation_Scores
Input factors: Group
Nuisance factor: Reviewer
General Linear Model in Minitab can be used for this analysis.
Blocking is used to remove the effects of Reviewers

Step 2: Performing Data Analysis

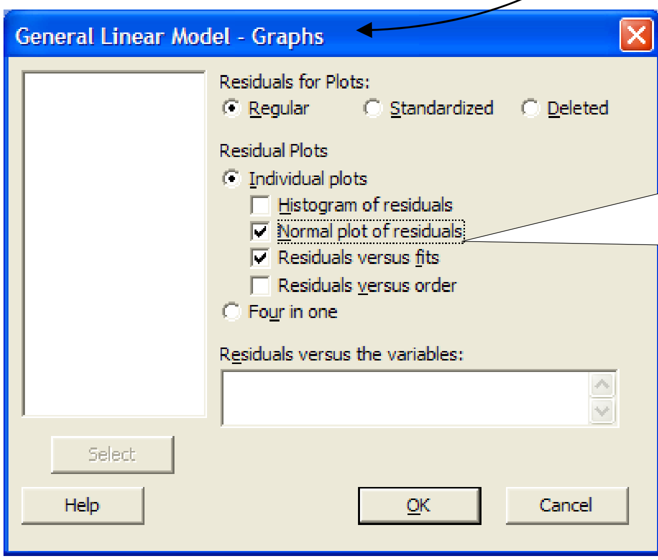
In analyzing a RCBD, no interaction between the factor (group) and the block (reviewer) is assumed. Thus, the two-way ANOVA cannot be used. In this case, general linear model should be used.

To perform the ANOVA via General Linear Model, click **Stat → ANOVA → General Linear Model.** In the General Linear Model dialogue box, double click "C3 Evaluation_Score" for **Responses** and "C2 Group" and "C1 Review No." for **Model.** Double click "C1 Reviewer No." for **Random factors.**





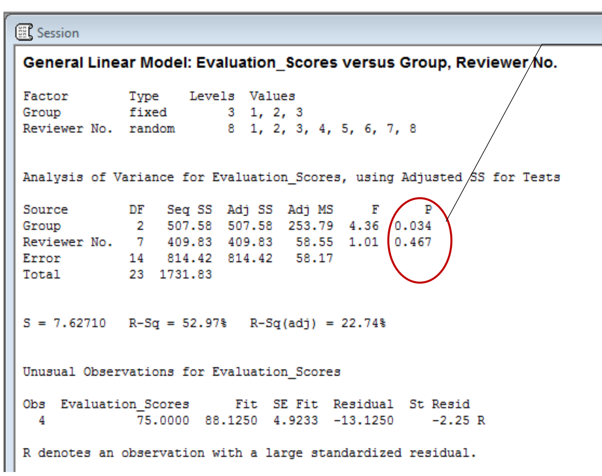
Nuisance factor "Review No" is a random factor in block design



Two charts are selected to validate **normality** and **constant variance** assumptions. Note that no run order was reported in this study. Thus, the independence assumption will not be checked.

Step 3. ANOVA Table

The ANOVA table is displayed in session window.

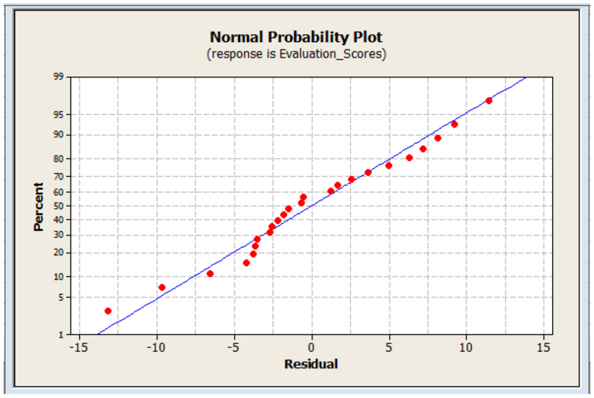


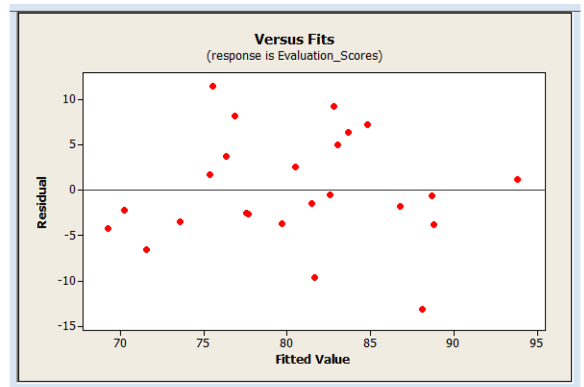
```
Session
General Linear Model: Evaluation_Scores versus Group, Reviewer No.

Factor        Type    Levels  Values
Group         fixed        3  1, 2, 3
Reviewer No.  random       8  1, 2, 3, 4, 5, 6, 7, 8


Analysis of Variance for Evaluation_Scores, using Adjusted SS for Tests

Source        DF   Seq SS  Adj SS  Adj MS     F      P
Group          2   507.58  507.58  253.79  4.36  0.034
Reviewer No.   7   409.83  409.83   58.55  1.01  0.467
Error         14   814.42  814.42   58.17
Total         23  1731.83


S = 7.62710   R-Sq = 52.97%   R-Sq(adj) = 22.74%


Unusual Observations for Evaluation_Scores

Obs  Evaluation_Scores      Fit  SE Fit  Residual  St Resid
  4            75.0000  88.1250  4.9233  -13.1250    -2.25 R

R denotes an observation with a large standardized residual.
```

P-value
P values for Group was below 0.05. This indicates that there is statistically difference in average senior project quality between different student groups.

Step 4. Validating ANOVA Assumptions

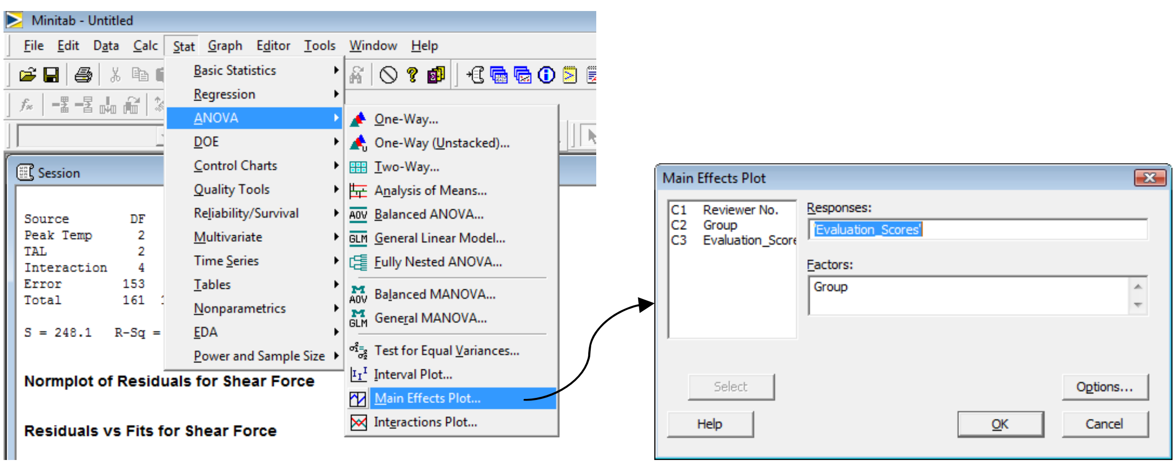
The normality plot of residuals and the residuals versus fits plot are shown below. It seems that there are no unusual residuals here.

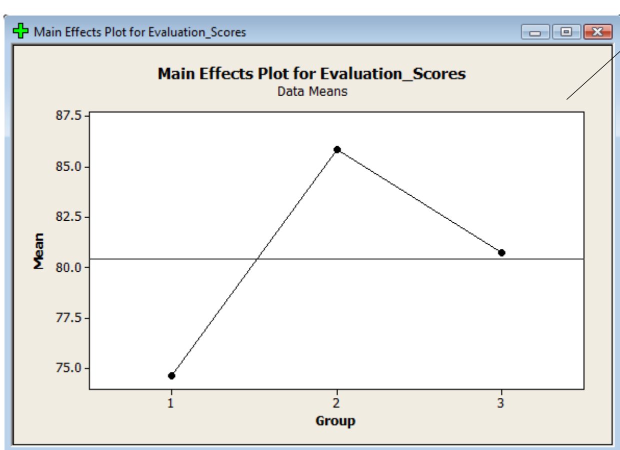




Step 5. Interpreting ANOVA Results

Since there is significant factor, we would like to see the **Main Factor Plot.** It can be obtained by clicking **Stat → ANOVA → Main Effects Plot**. In the dialogue box, select "C3 Evaluation_Scores" for the **Responses** and select "C2 Group" for **Factors**.





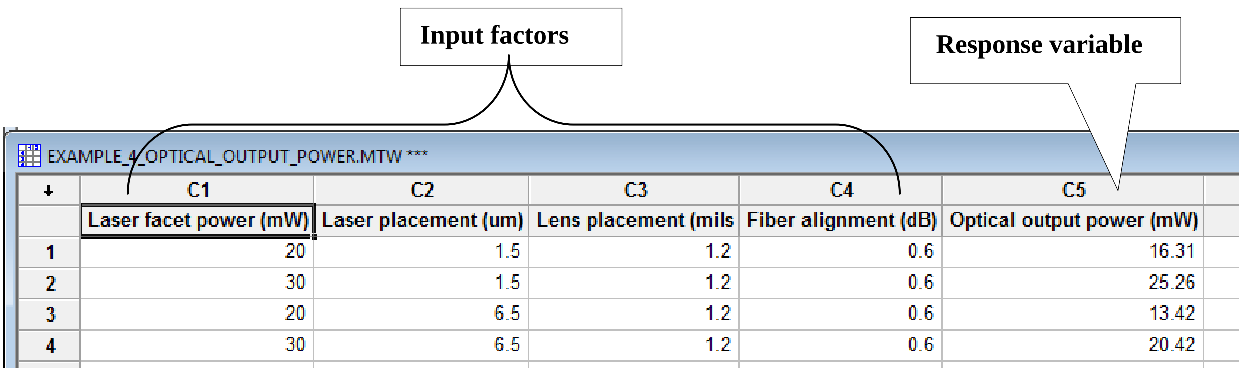
There is statistically significant difference among groups. Group #2 is the best.

Example 4: Factorial design with Replications

Find out the critical process variables that affect the optical output power and develop a regression model.

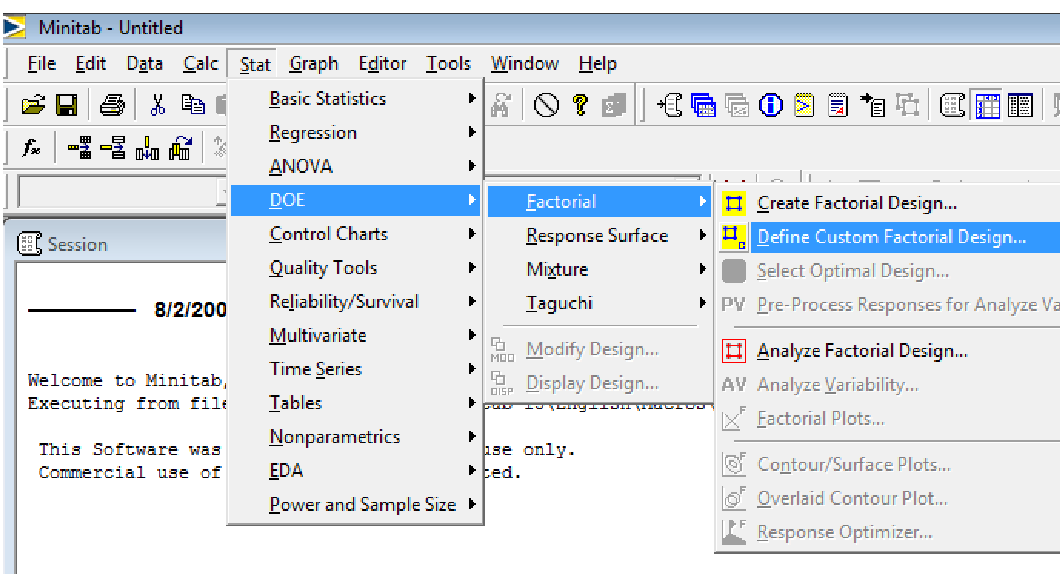
Step 1: Inputting Data

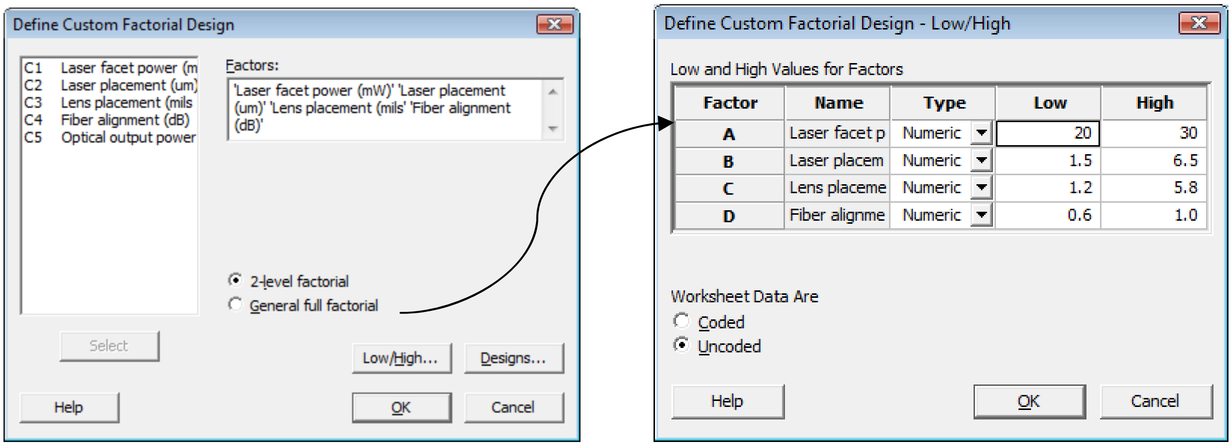
Open the Minitab worksheet file by clicking **File → Open Worksheet**, select the file *Example_4_Optical_Output_Power.mtw* in your stored directory. Click **Open** button. You may see a pop-up window with message “a copy of the content of this file will be added to the current project.” Click **OK**. Then you will see the data of the experiment in the worksheet.



Step 2: Defining the Factorial Design.

Please click **Stat → DOE → Factorial → Define Custom Factorial Design.** In the pop-up dialogue box, select four input factors by double clicking all four factors for **Factors** as shown below. Then click **Low/High** button, the low and high values for each factor are shown in the pop-up window. Then Click **OK** back to previous dialogue box. Click **OK** again to finish defining custom factorial design.

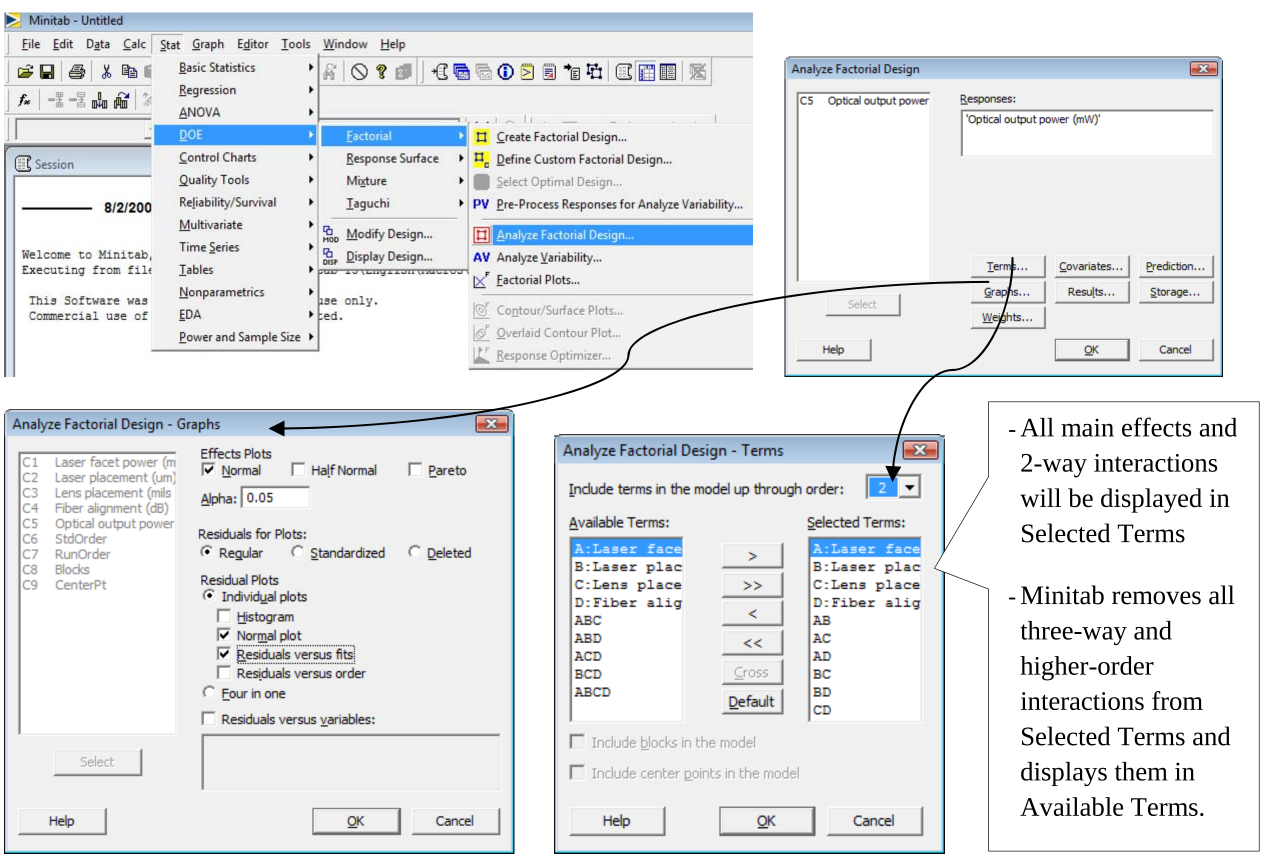




Step 3: Analyzing the factorial design

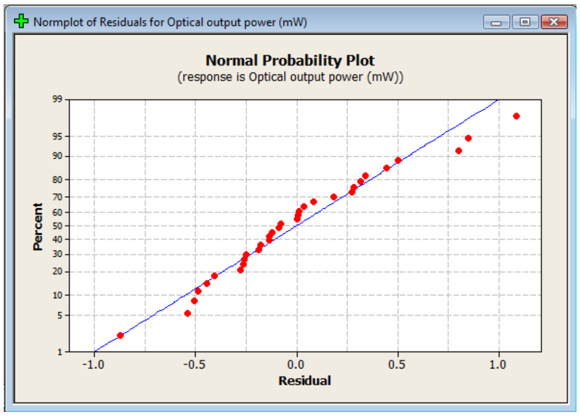
After define the factorial design, perform the analysis by click **Stat → DOE → Factorial → Analyze Factorial Design.** In the pop-up window, double click "C5 Optical output power" for **Responses.** In the pop-up window, click the button "**Terms**" and set the maximum order for terms in the model as "**2**".

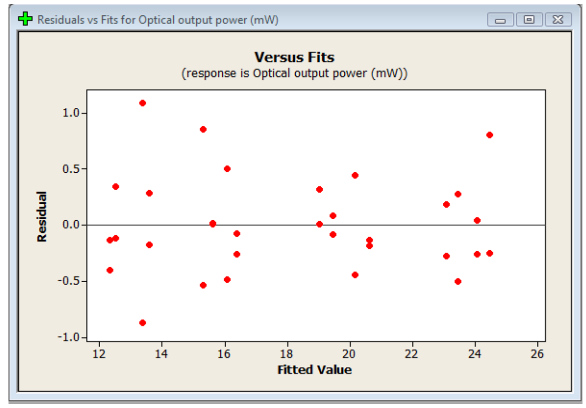
In the dialogue box for **Graph**, Check **Normal** under **Effect Plots** to display a normal probability plot of the effects; check to plot the **Regular Residuals**; check to plot **Normal plot** and **Residuals versus fits** of the **Residual plots**.



Step 4: Validating the assumptions

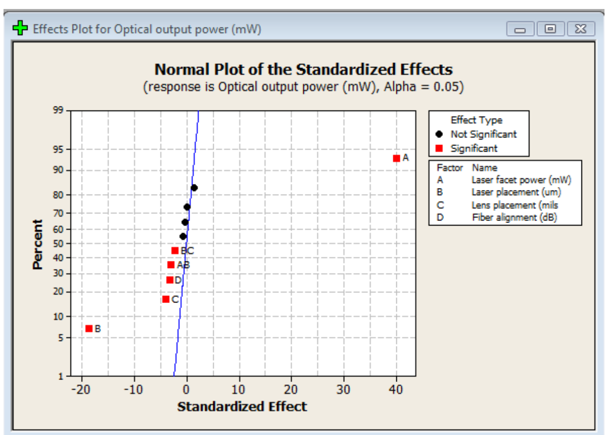
The results show that both **normality** and **constant variance** assumptions were met.

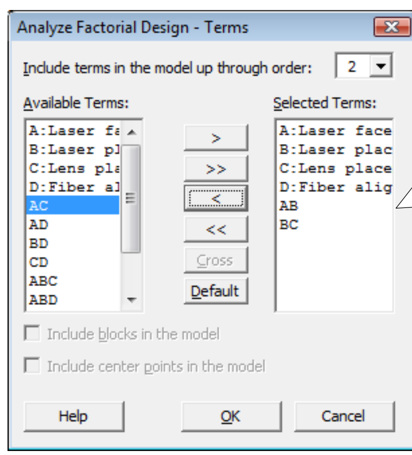




Step 5: Finding significant factors and re-analyzing the design

According to the following Normal plot of the standardized effects, factors A, B, C, D, AB and BC have significant effect on the response. Since AC, AD, BD, and CD terms are in-significant, we can drop these terms in the model. The design can be re-analyzed following Step 1 and 2. The only difference is to **choose only the significant factors** into the **Selected Terms** in the model.

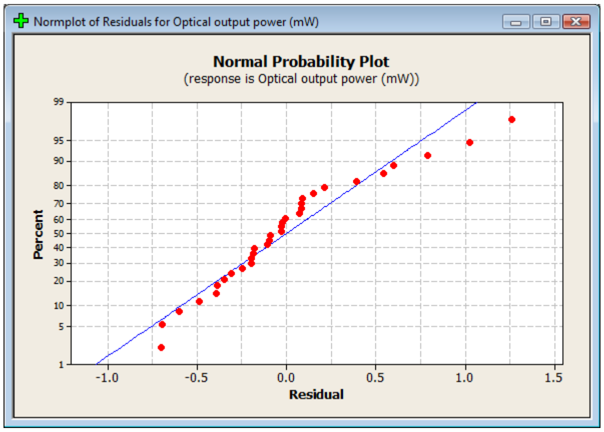


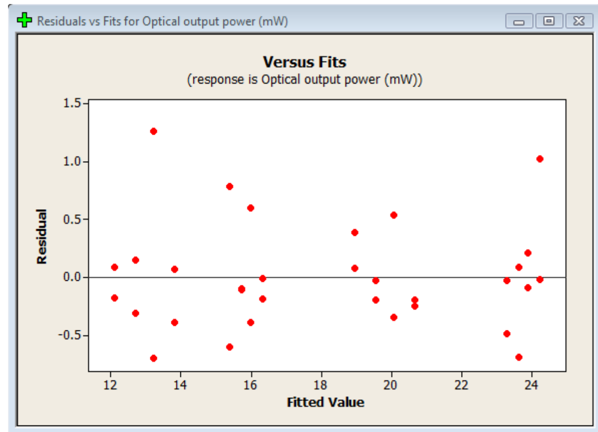


Only factors A, B, C, D, AB and BC are selected.

Step 6: Validating the assumptions again

The results for the re-analysis show that the **normality** and **constant variance** assumptions were met.





Step 7: Interpreting the ANOVA Results

ANOVA table is shown in the session window as below.

Session

Factorial Fit: Optical outp versus Laser facet , Laser placem, ...

```
Estimated Effects and Coefficients for Optical output power (mW) (coded units)

Term                      Effect    Coef  SE Coef       T      P
Constant                          18.090  0.09010  200.77  0.000
Laser facet power (mW)     7.388   3.694  0.09010   41.00  0.000
Laser placement (um)      -3.424  -1.712  0.09010  -19.00  0.000
Lens placement (mils      -0.732  -0.366  0.09010   -4.06  0.000
Fiber alignment (dB)      -0.599  -0.300  0.09010   -3.33  0.003
Laser facet power (mW)*   -0.529  -0.265  0.09010   -2.94  0.007
  Laser placement (um)
Laser placement (um)*     -0.387  -0.193  0.09010   -2.15  0.042
  Lens placement (mils


S = 0.509698    PRESS = 10.6411
R-Sq = 98.81%   R-Sq(pred) = 98.06%   R-Sq(adj) = 98.53%


Analysis of Variance for Optical output power (mW) (coded units)

Source              DF   Seq SS   Adj SS   Adj MS       F      P
Main Effects         4  537.645  537.645  134.411  517.38  0.000
2-Way Interactions   2    3.439    3.439    1.720    6.62  0.005
Residual Error      25    6.495    6.495    0.260
  Lack of Fit        9    1.388    1.388    0.154    0.48  0.865
  Pure Error        16    5.107    5.107    0.319
Total               31  547.579


Unusual Observations for Optical output power (mW)

                  Optical
                   output
Obs  StdOrder  power (mW)      Fit  SE Fit  Residual  St Resid
  2         2     25.2600  24.2334  0.2384    1.0266     2.28R
 27        27     14.4700  13.2084  0.2384    1.2616     2.80R

R denotes an observation with a large standardized residual.
```

P-value
A small (<0.05, a level of significance) p-value indicates that the four main factors and 2 interactions have statistically significant effect on the response.

Step 8. Plots for the main effects and interaction effects

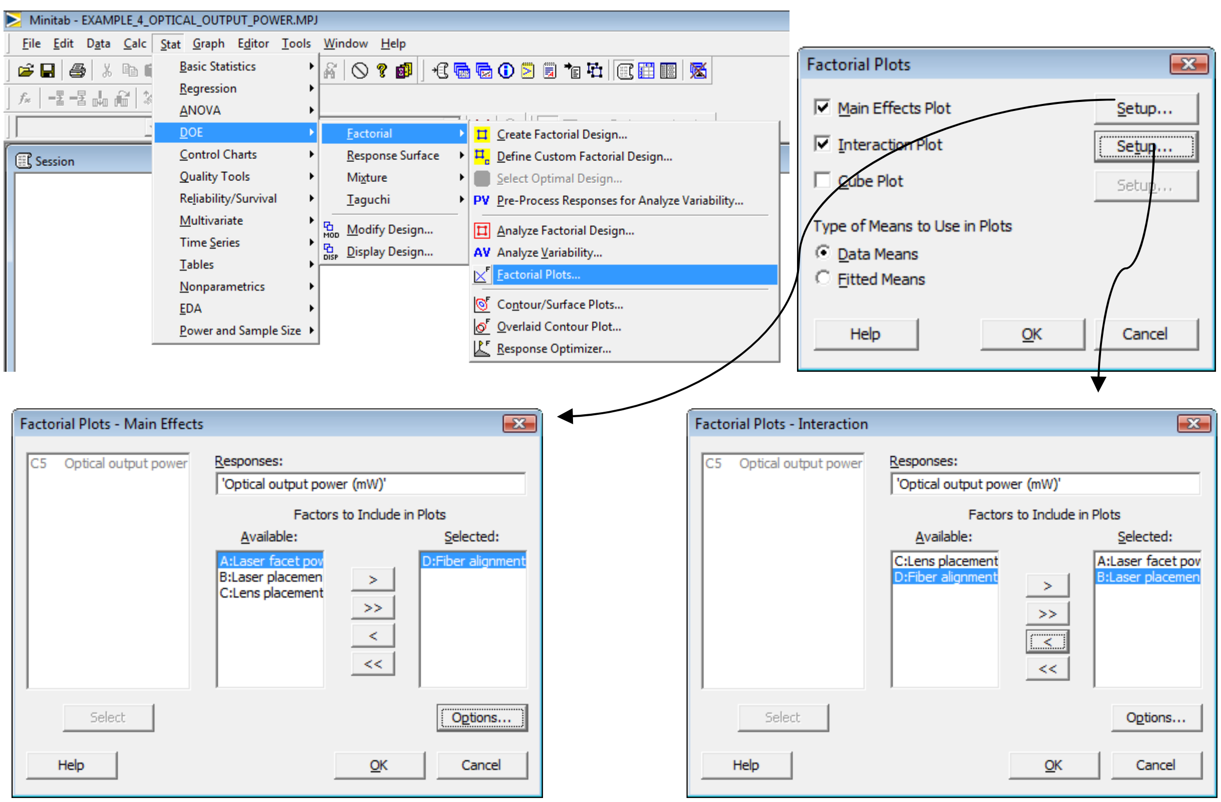
The ANOVA table shows that all four factors are significant and there are significant interactions between “Lens placement” and “Laser placement”, and between “Laser placement” and “Laser facet power”.

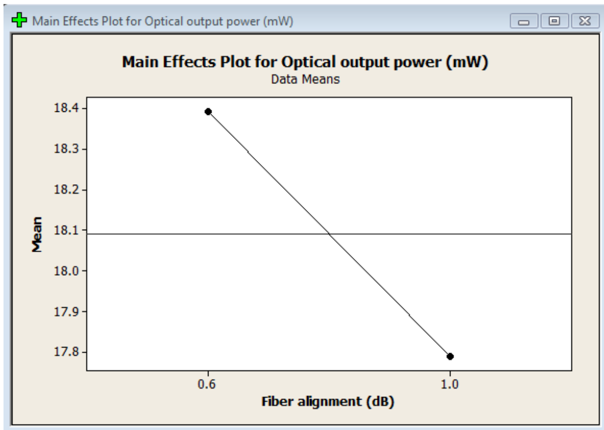
As stated before, if the interaction is significant, ignore the main effect of these factors and only present the interaction plot. Since the factor “Fiber alignment” has no interaction with other factors, the main effect plot of “Fiber alignment” is meaningful. Thus, the interaction plot of “Lens placement” and “Laser placement”, interaction plot of “Laser placement” and “Laser facet power”, and main effect plot of “Fiber alignment” should be displayed.

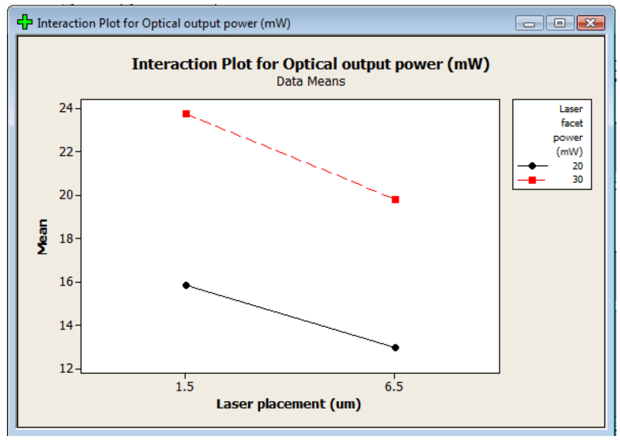
Plots for the main effects and the interaction effects can be obtained by clicking **Stat → DOE → Factorial → Factorial Plots**. In the dialogue box, check **Main Effect Plots** and **Interaction Plots**.

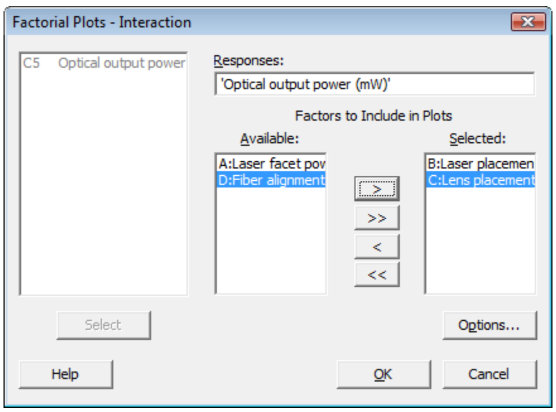
- Click **Setup** button for **Main Effect Plot**. In the dialogue box appears, select “Optical output power” for **Responses** and “Fiber alignment” for **Selected** factor. Then Click **OK.** Note that multiple main factors’ effect plot can be setup in the dialogue box although in this example only one factor is displayed.
- Click **Setup** button for **Interaction Plot**. In the dialogue box appears, select “Laser facet power” and “Laser placement” for **Selected** factors**.** Then Click **OK.**
- Click OK again to obtain the plots.

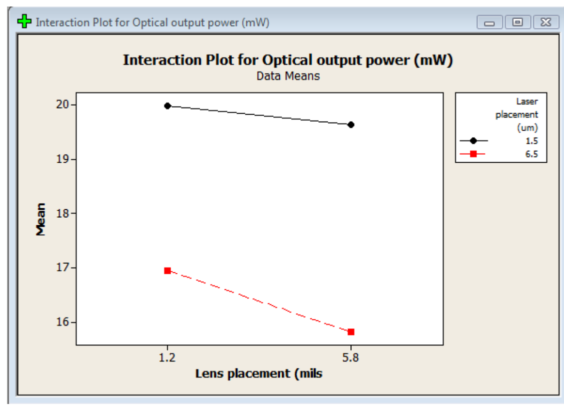
- Following same procedure, another interaction plot, “Lens placement” vs. “Laser placement” can be obtained.











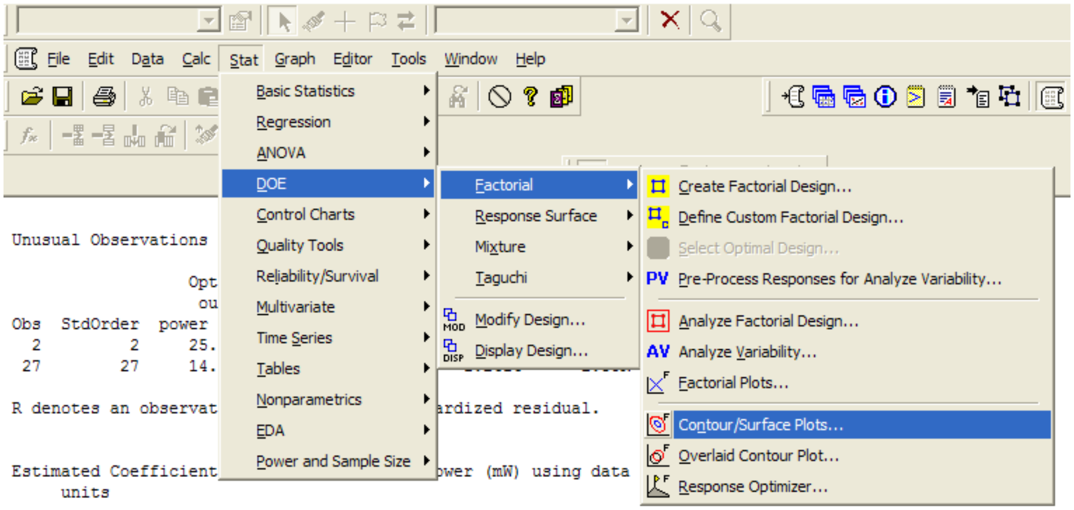
Regression Model

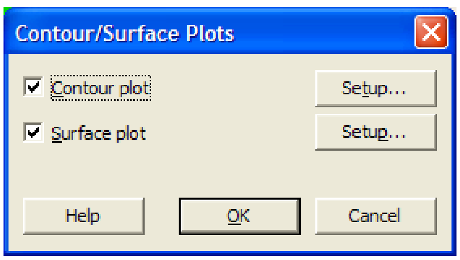
From the session window, we can get the estimated coefficients for the **regression model** as follows:

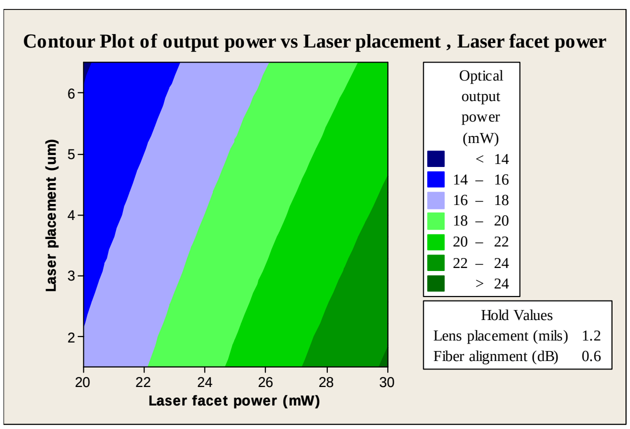
Optical output power = 1.527 + 0.824* (Laser facet power) - 0.0378* (Laser placement) - 0.025* (Lens placement) - 1.498* Fiber alignment - 0.021* (Laser facet power*Laser placement) - 0.034* (Laser placement*Lens placement)

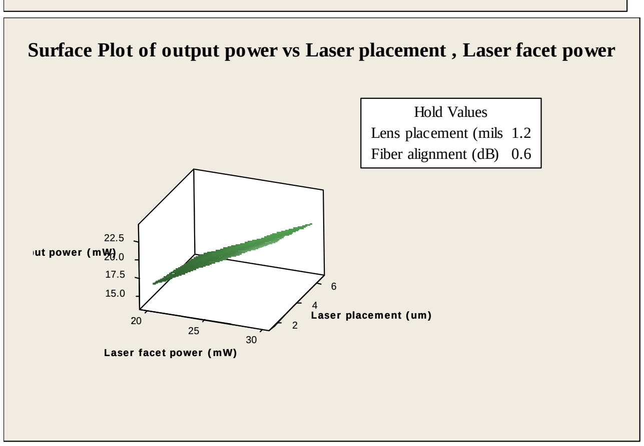
Contour Plot and Surface Plot

Click **Stat → DOE → Factorial → Contour/Surface Plots…** In the pop-up window, check both **Contour plot** and **Surface plot**. You may click **Setup** button and change the setup in the pop-up window. Then click **OK** button. The contour plot and surface plot of Example #4 are shown below.


File Edit Data Calc Stat Graph Editor Tools Window Help
Basic Statistics
Regression
ANOVA
DOE
Control Charts
Quality Tools
Reliability/Survival
Multivariate
Time Series
Tables
Nonparametrics
EDA
Power and Sample Size
Factorial
Response Surface
Mixture
Taguchi
Modify Design...
Display Design...
Create Factorial Design...
Define Custom Factorial Design...
Select Optimal Design...
Pre-Process Responses for Analyze Variability...
Analyze Factorial Design...
Analyze Variability...
Factorial Plots...
Contour/Surface Plots...
Overlaid Contour Plot...
Response Optimizer...
Unusual Observations


Contour/Surface Plots
Contour plot
Setup...
Surface plot
Setup...
Help
OK
Cancel


Contour Plot of output power vs Laser placement , Laser facet power
Laser placement (um)
Laser facet power (mW)
Optical output power (mW)
< 14
14 – 16
16 – 18
18 – 20
20 – 22
22 – 24
> 24
Hold Values
Lens placement (mils) 1.2
Fiber alignment (dB) 0.6

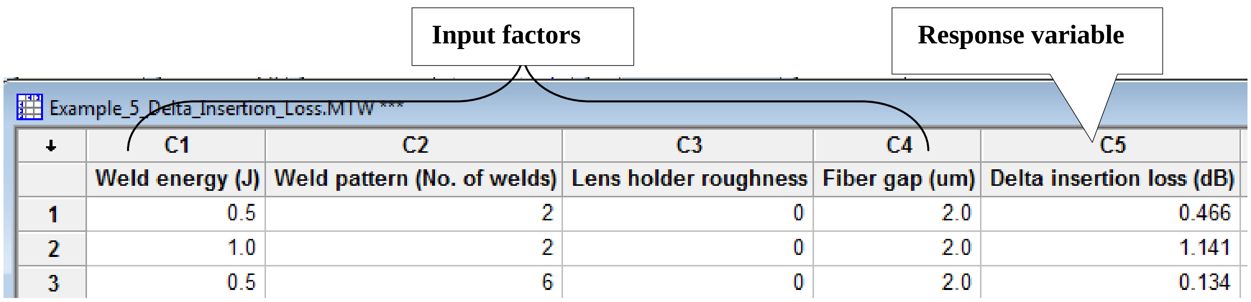

Surface Plot of output power vs Laser placement , Laser facet power
Hold Values
Lens placement (mils 1.2
Fiber alignment (dB) 0.6
Laser placement (um)
Laser facet power (mW)

Example 5: Factorial Design without Replication

Example #5 is a unreplicated 2^4 factorial design. Find out the critical process variables that affect the delta insertion loss and setting levels to meet design objective of delta insertion loss less than 1 dB.

Step 1: Inputting Data

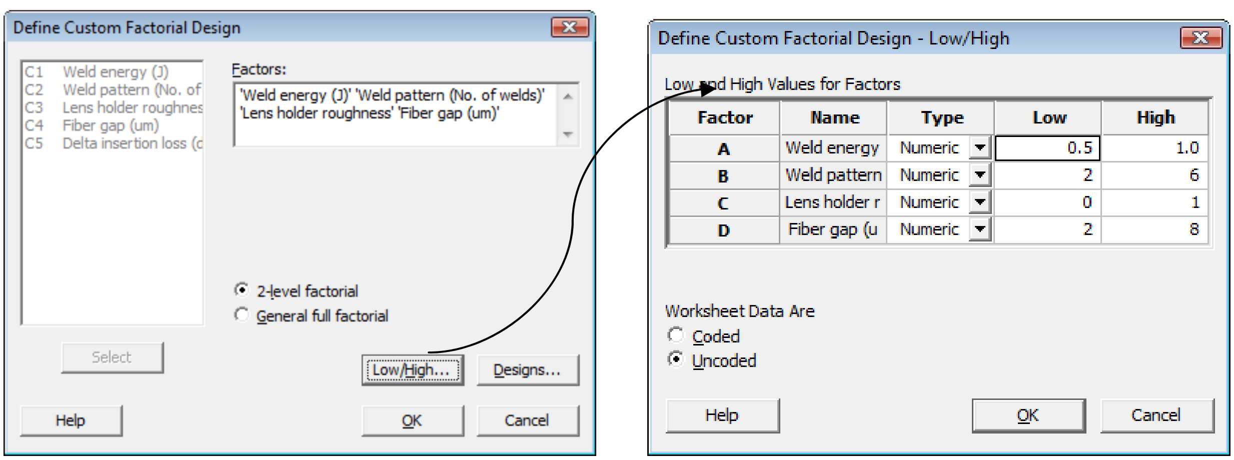
Open the Minitab worksheet file by clicking **File → Open Worksheet**, select the file *Example_5_Delta_Insertion_Loss.mtw* in your stored directory. Click **Open** button. You may see a pop-up window with message "a copy of the content of this file will be added to the current project." Click **OK**. Then you will see the data of the experiment in the worksheet.



↓	C1	C2	C3	C4	C5
	Weld energy (J)	Weld pattern (No. of welds)	Lens holder roughness	Fiber gap (um)	Delta insertion loss (dB)
1	0.5	2	0	2.0	0.466
2	1.0	2	0	2.0	1.141
3	0.5	6	0	2.0	0.134

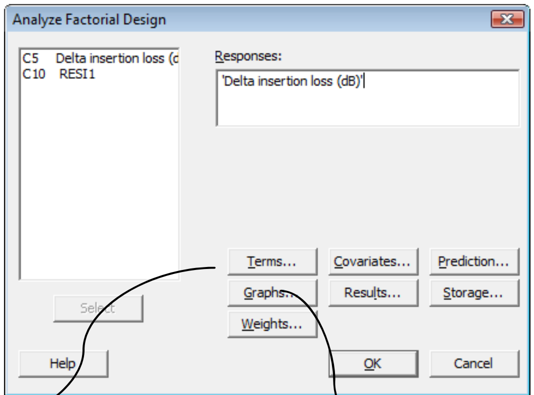
Step 2: Defining the Factorial Design.

Click **Stat → DOE → Factorial → Define Custom Factorial Design.** In the pop-up dialogue box, select four input factors by double clicking all four factors for **Factors** as shown below. Then click **Low/High** button, the low and high values for each factor are shown in the pop-up window. Then Click **OK** back to previous dialogue box. Click **OK** again to finish defining custom factorial design.

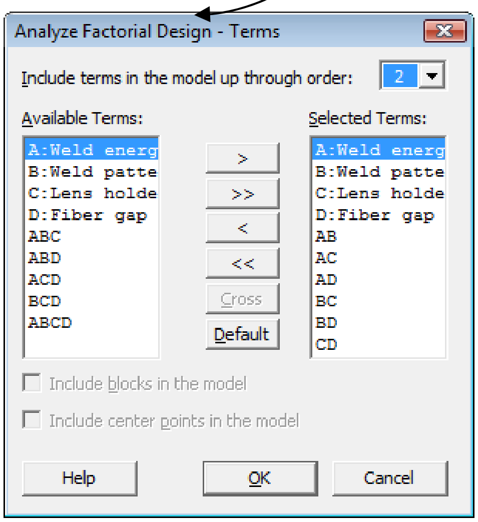


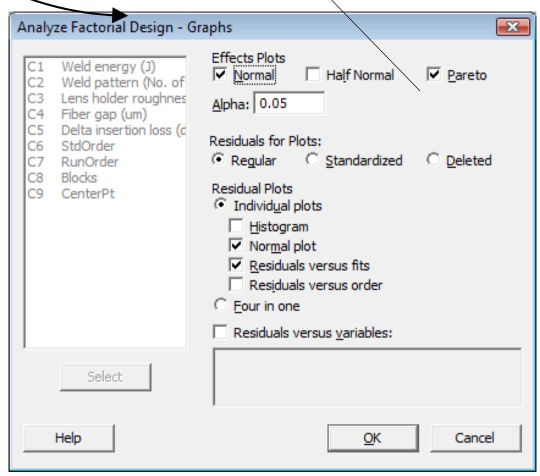
Step 3: Analyzing the factorial design

After define the factorial design, perform the analysis by click **Stat → DOE → Factorial → Analyze Factorial Design.** In the pop-up window, double click "C5 Delta insertion loss (dB)" for **Responses.** In the pop-up window, click the button "**Terms**" and set the maximum order for terms in the model as "**2**".



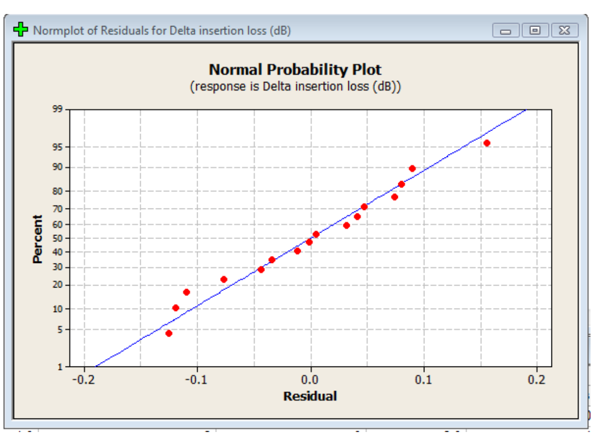
In the **Analyze Factorial Design – Graphs** pop-up window, Check **Normal** and **Pareto** under **Effect Plots** to display a normal probability plot and Pareto chart of the effects; check to plot the **Regular Residuals**; check to plot **Normal plot** and **Residuals versus fits** of the **Residual plots**.

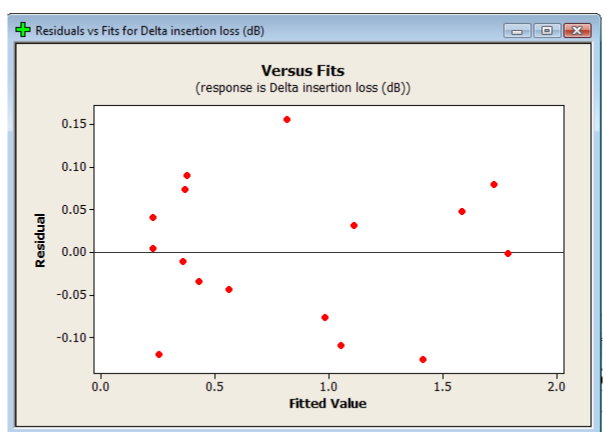




Step 4: Validating the assumptions

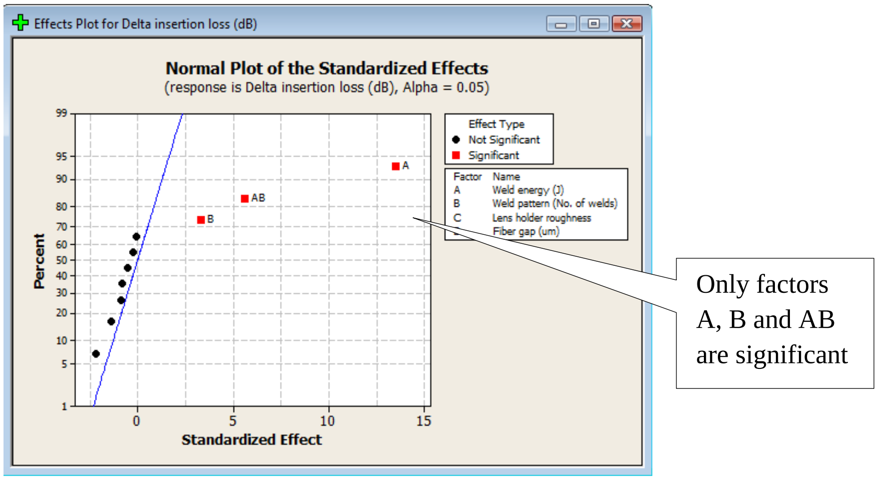
The results show that both **normality** and **constant variance** assumptions were met.

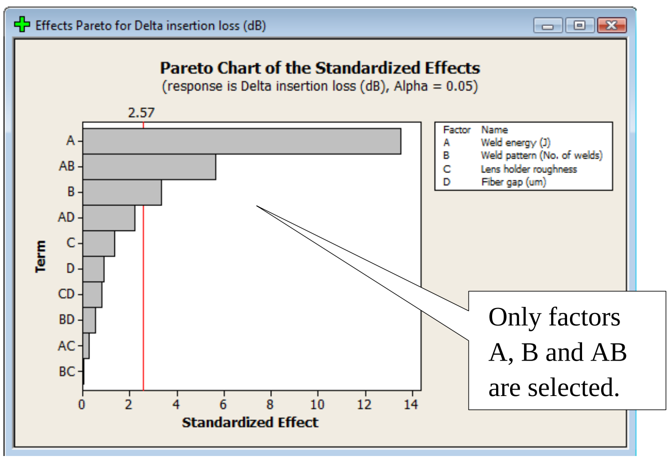


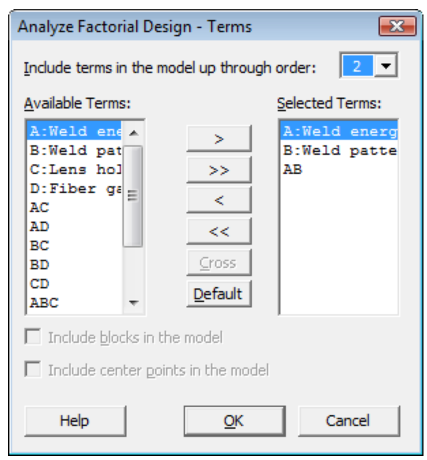


Step 5: Finding significant factors and re-analyzing the design

According to the following Normal plot of the standardized effects, factors A, B and AB have significant effect on the response. Pareto chart shows the same results. Since other terms are insignificant, we can drop these terms in the model. The design can be re-analyzed following Step 1 and 2. The only difference is to **choose only the significant factors** into the **Selected Terms** in the model.

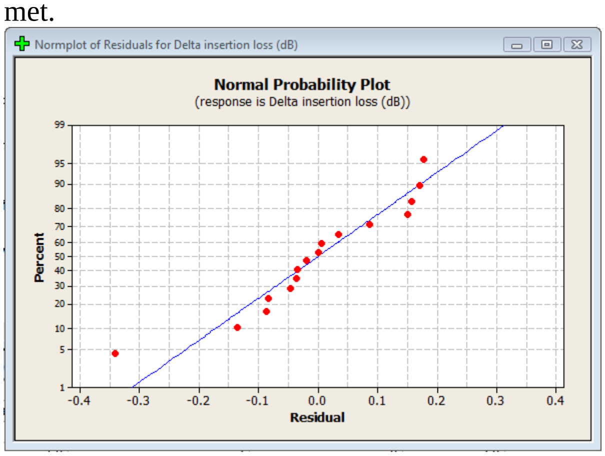


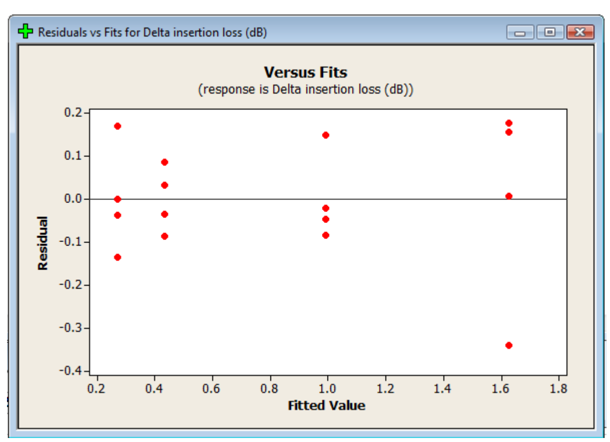




Step 6: Validate the assumptions again

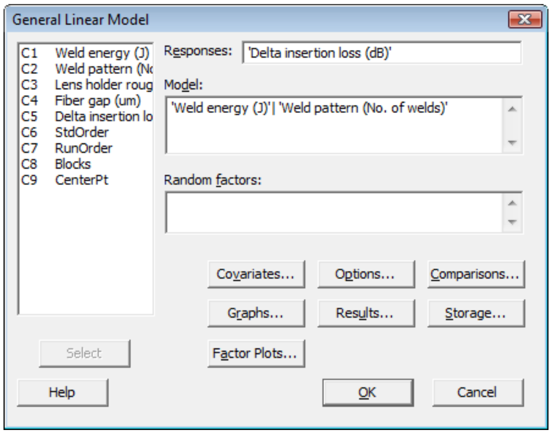
The results for the re-analysis show that the **normality** and **constant variance** assumptions were met.

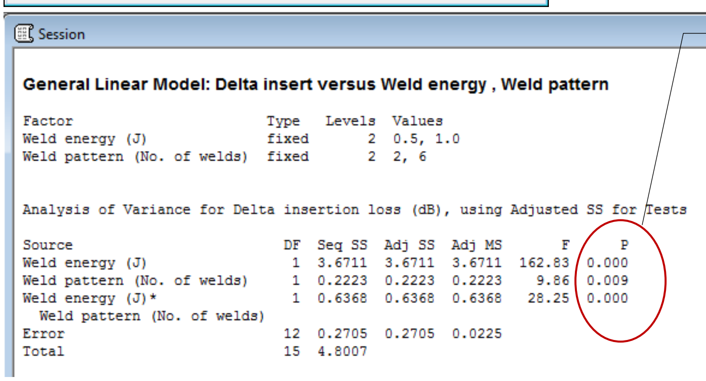




Step 7: Interpreting the ANOVA Results

Perform General Linear Model to generate ANOVA table. Click **Stat → ANOVA → General Linear Model.** In the General Linear Model dialogue box, double click "C5 Delta insertion loss (dB)" for **Responses** and "C1 Weld energy (J)" | "C2 Weld pattern (No. of welds)" for **Model.**





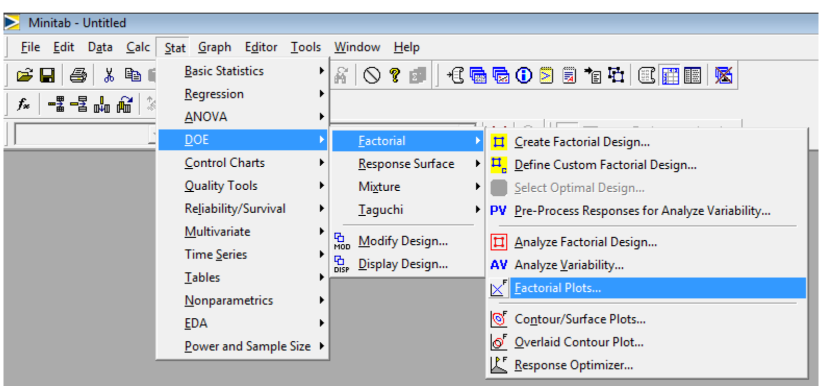
Factor	Type	Levels	Values
Weld energy (J)	fixed	2	0.5, 1.0
Weld pattern (No. of welds)	fixed	2	2, 6

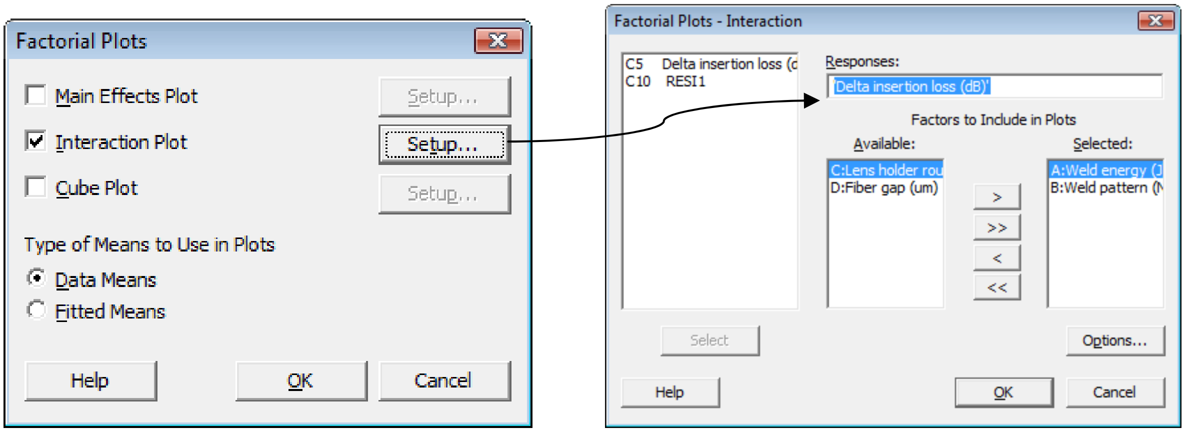
Analysis of Variance for Delta insertion loss (dB), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Weld energy (J)	1	3.6711	3.6711	3.6711	162.83	0.000
Weld pattern (No. of welds)	1	0.2223	0.2223	0.2223	9.86	0.009
Weld energy (J)* Weld pattern (No. of welds)	1	0.6368	0.6368	0.6368	28.25	0.000
Error	12	0.2705	0.2705	0.0225		
Total	15	4.8007				

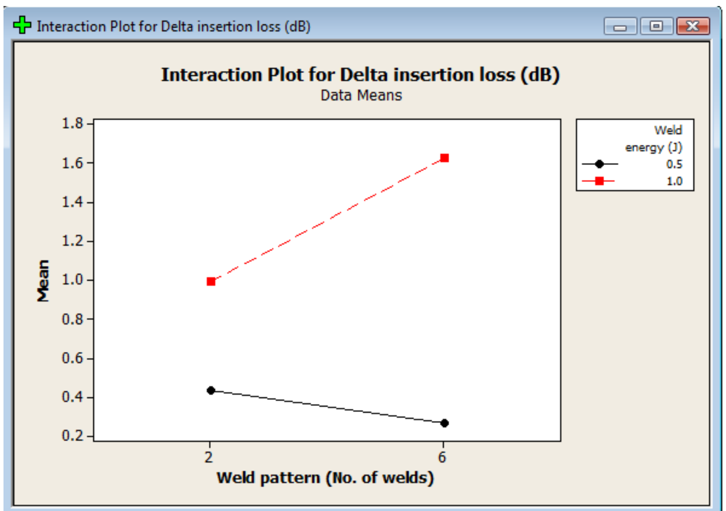
P-value
A small (<0.05, a level of significance) p-value indicates that the two main factors and their interactions have statistically significant effect on the response.

Since an interaction exists between "Weld energy" and "Weld pattern", only an interaction plot is needed and no main factor plots are necessary. Interaction plot can be obtained by clicking **Stat → DOE → Factorial → Factorial Plots**. In the dialogue box, choose **Interaction Plot** and click **Setup**. In the Setup dialogue box, select factor A and B to include into the plots.





The interaction plot is displayed below.

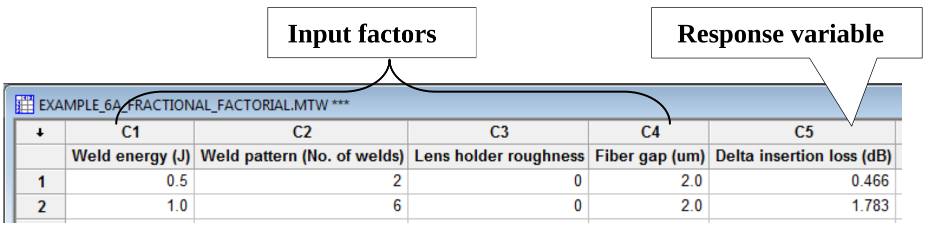


Example 6A Fractional Factorial Design

Example 6A is a ½ fractional factorial design of Example #5 with I = ABCD. Thus, example 6A has only 8 runs.

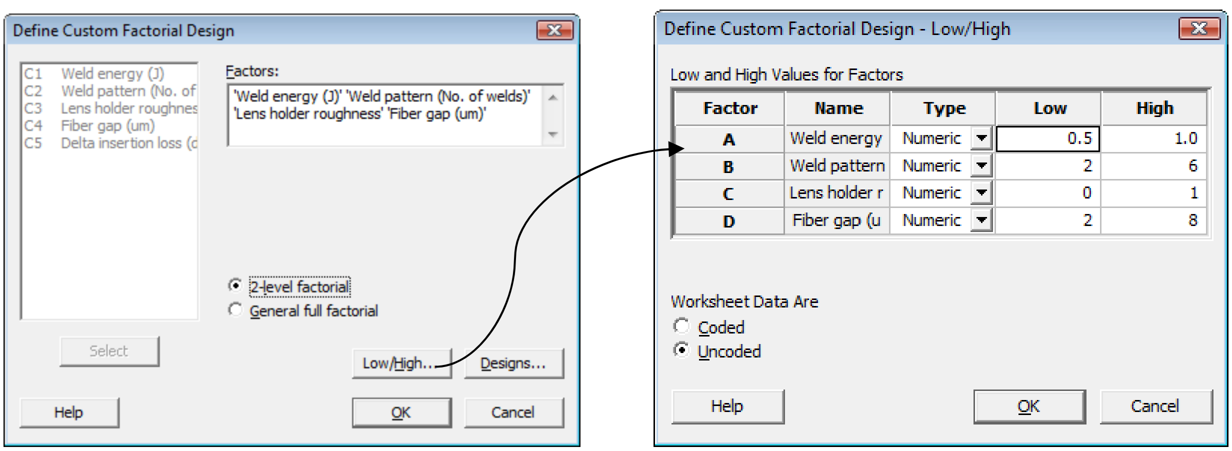
Step 1: Inputting Data

Open the Minitab worksheet file by clicking **File → Open Worksheet**, select the file *Example_6A_Fractional_Factorial.mtw* in your stored directory. Click **Open** button. You may see a pop-up window with message "a copy of the content of this file will be added to the current project." Click **OK**. Then you will see the data of the experiment in the worksheet.



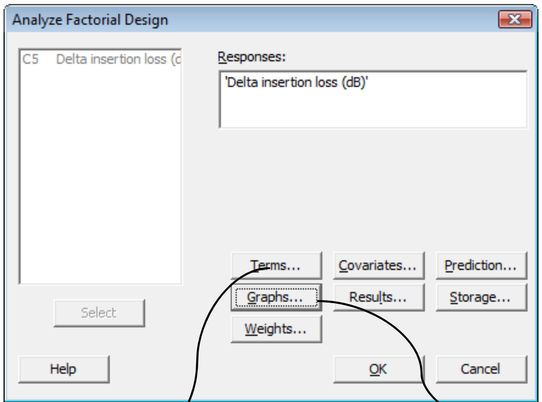
Step 2: Defining the Factorial Design.

Click **Stat → DOE → Factorial → Define Custom Factorial Design.** In the pop-up dialogue box, select all four factors by double clicking these four factors for **Factors** as shown below. Then click **Low/High** button, the low and high values for each factor are shown in the pop-up window. Then click **OK** back to previous dialogue box. Click **OK** again to finish defining custom factorial design.

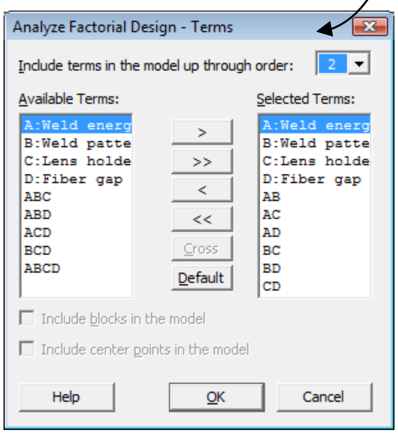


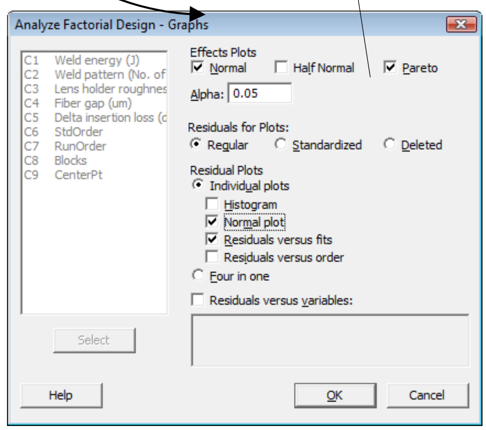
Step 3: Analyzing the factorial design

After define the factorial design, perform the analysis by click **Stat → DOE → Factorial →Analyze Factorial Design.** In the pop-up window, double click "C5 Delta insertion loss (dB)" for **Responses.** In the pop-up window, click the button "**Terms**" and set the maximum order for terms in the model as "**2**".



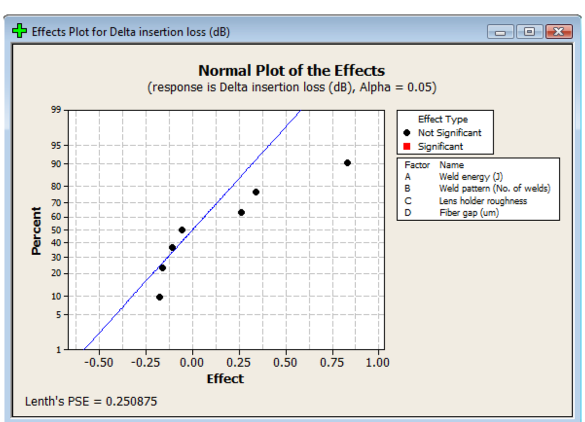
In the **Analyze Factorial Design – Graphs** pop-up window, Check **Normal** and **Pareto** under **Effect Plots** to display a normal probability plot and Pareto chart of the effects; check to plot the **Regular Residuals**; check to plot **Normal plot** and **Residuals versus fits** of the **Residual plots**.

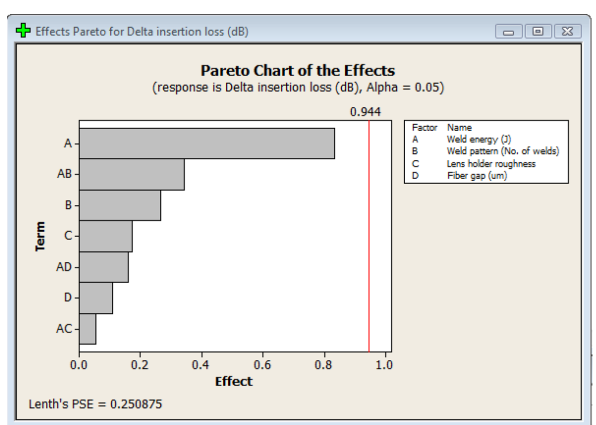




Step 4: Finding significant factors

According to the following **Normal plot of the standardized effects** and **Pareto chart of the standard effects**, none of the factors seems to have significant effect on the response variable. But factors A and B and interaction AB were shown significant in Example 5. The reason that fractional factorial design shown in Example 6A failed to uncover some significant effects is that sample size is too small. This comparison shows that the right conclusion from the Example 6A should be "we cannot conclude that any of factors has statistically significant effect on the delta insertion loss." It is inappropriate to conclude that any of factors does not have statistically significant effect on the delta insertion loss."





Example 6B Fractional Factorial Design

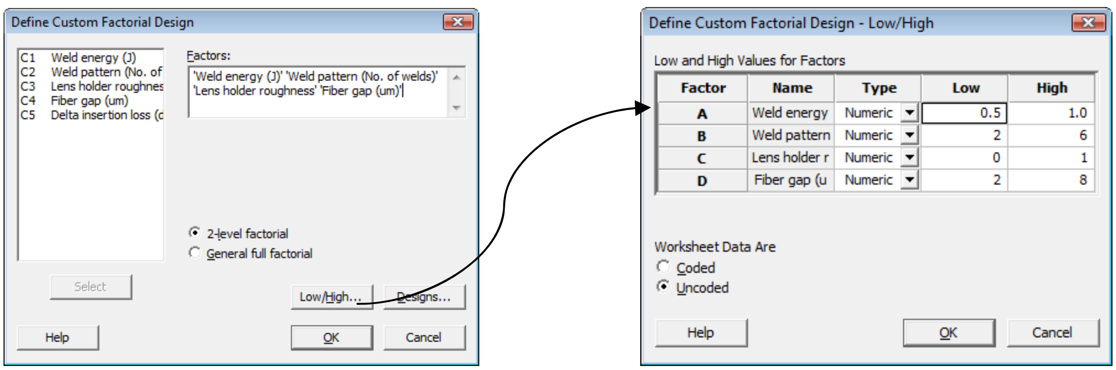
Example 6B is a ½ fractional factorial design of Example #5 with I = -ABCD. Thus, Example 6B is very similar to Example 6A. The only difference is that Example 6B run the other half of the 8 treatments. Though the data in Example 6B is different from Example 6A, the analysis procedures are the same in Minitab.

Step 1: Inputting Data

Open the Minitab worksheet file by clicking **File → Open Worksheet**, select the file *Example_6B_Fractional_Factorial.mtw* in your stored directory. Click **Open** button. You may see a pop-up window with message "a copy of the content of this file will be added to the current project." Click **OK**. Then you will see the data of the experiment in the worksheet.

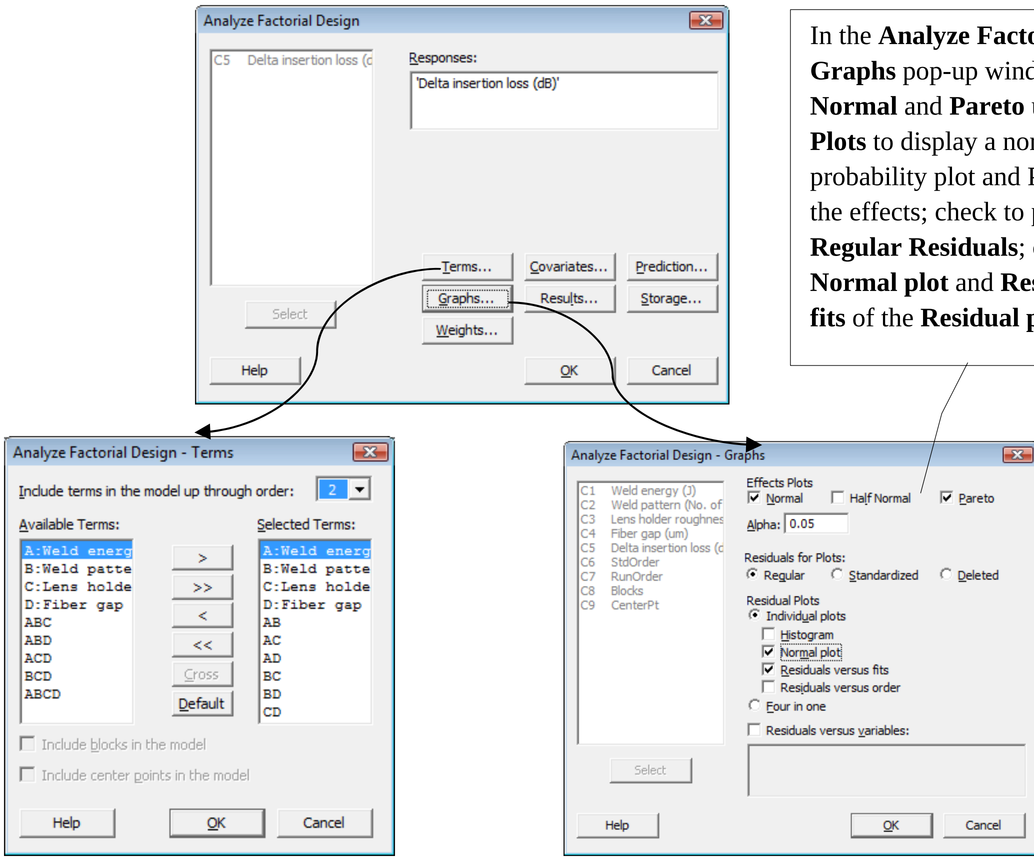
Step 2: Defining the Factorial Design.

Click **Stat → DOE → Factorial → Define Custom Factorial Design.** In the pop-up dialogue box, select all four factors by double clicking these four factors for **Factors** as shown below. Then click **Low/High** button, the low and high values for each factor are shown in the pop-up window. Then click **OK** back to previous dialogue box. Click **OK** again to finish defining custom factorial design.



Step 3: Analyzing the factorial design

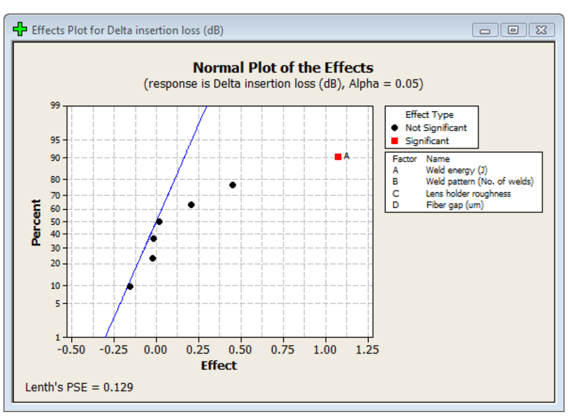
After define the factorial design, perform the analysis by click **Stat → DOE → Factorial → Analyze Factorial Design.** In the pop-up window, double click "C5 Delta insertion loss (dB)" for **Responses.** In the pop-up window, click the button "**Terms**" and set the maximum order for terms in the model as "**2**".

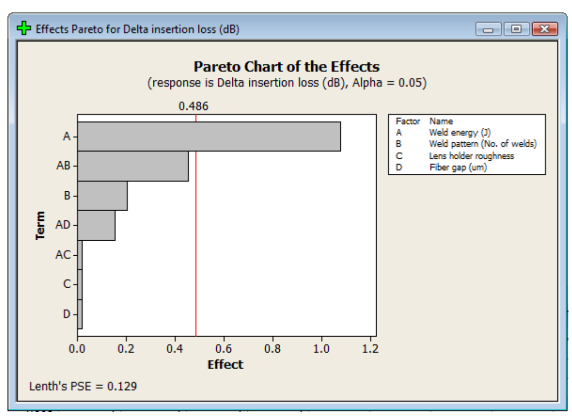


In the **Analyze Factorial Design – Graphs** pop-up window, Check **Normal** and **Pareto** under **Effect Plots** to display a normal probability plot and Pareto chart of the effects; check to plot the **Regular Residuals**; check to plot **Normal plot** and **Residuals versus fits** of the **Residual plots**.

Step 4: Finding significant factors

According to the following **Normal plot of the standardized effects** and **Pareto chart of the standard effects**, only factor A, Weld energy, has significant effect on the response variable. Analysis of Example #5 shows that factors A and B and interaction AB were shown significant. Analysis of Example #6A shows none of factors is significant. The reason that fractional factorial design shown in Example 6B failed to uncover some significant effects is same as described in Example 6A, which is because sample size is too small.





Please refer to Example #5 for checking ANOVA assumptions, interpreting ANOVA results, and generating regression model.