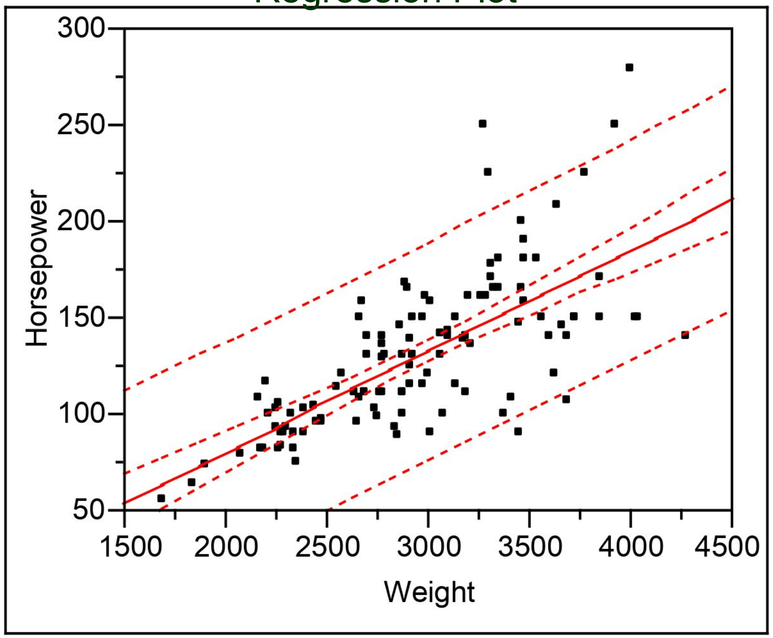
Why Do We Use These Tools?

- Gather meaningful data about a process without interruption.
- This type of study leaves the process in a natural operating state (without DOE) versus artificially inducing variation (with DOE).
- Correlation provides a graphical analysis and quantifier of the strength between independent and dependent variables.
- Regression can be used as a means of obtaining prediction equations so independent variables can be controlled.

All Possible X's

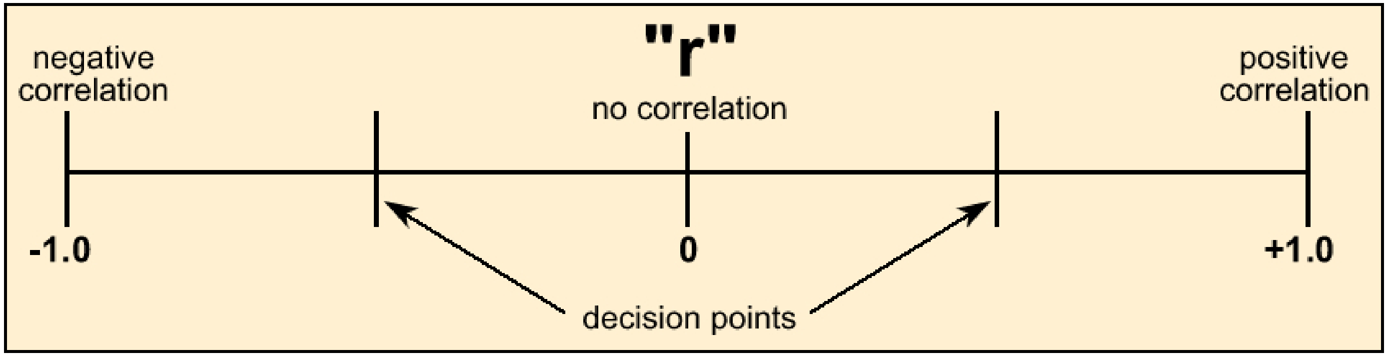
Probable X's

Regression Plot



Correlation

- Correlation is a measure of strength of association between two quantitative variables (e.g., pressure and yield) which aids in establishing Y = F (X).
- Correlation measures the strength of the relationship between two variables using the correlation coefficient, r.
- The correlation coefficient, r, will always be between -1 and +1.
- Guideline (usually based on sample size):
  - If | r | > 0.80, then relationship is significant
  - If | r | < 0.20, then relationship is not significant



*NOTE: JMP uses the Pearson's formula

Correlation

- Table for decision points in determining the correlation (positive or negative) for different sample sizes of n:

n	Decision point	n	Decision point
5	0.878	18	0.468
6	0.811	19	0.456
7	0.754	20	0.444
8	0.707	22	0.423
9	0.666	24	0.404
10	0.632	26	0.388
11	0.602	28	0.374
12	0.576	30	0.361
13	0.553	40	0.312
14	0.532	50	0.279
15	0.514	60	0.254
16	0.497	80	0.22
17	0.482	100	0.196

Data Requirements

- To conduct a correlation study, one must have:
- **Bivariate Data**: data from two variables from the same object/person
- Bivariate data is made up of ordered pairs

(Factor)	**(Response)**
X (input)	**Y (output)**
x1	y1
x2	y2
x3	y3
x4	y4
x5	y5
x_nth	y_nth

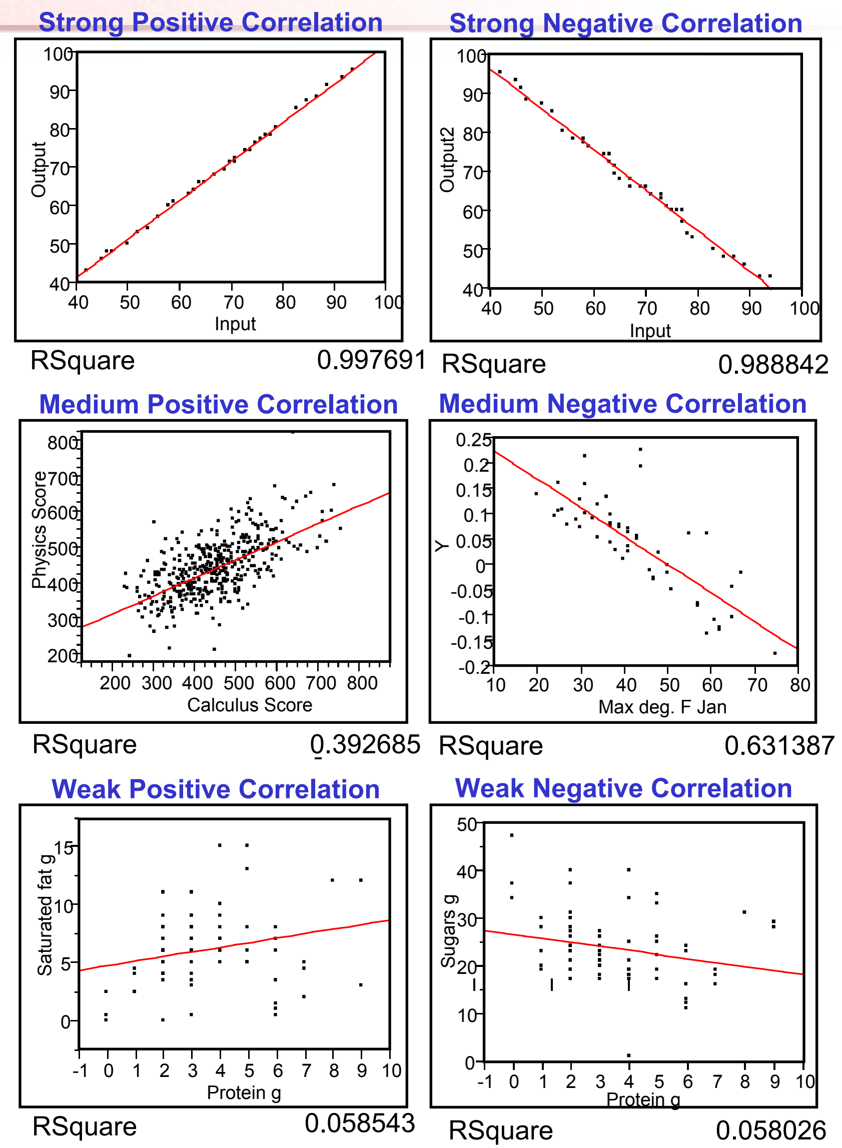
Correlation

The correlation coefficient (r):

- Always falls between -1 and +1
- Is a positive value – as the value of one variable increases, so does the other.
- Is a negative value – as the value of one variable increases, the other decreases.

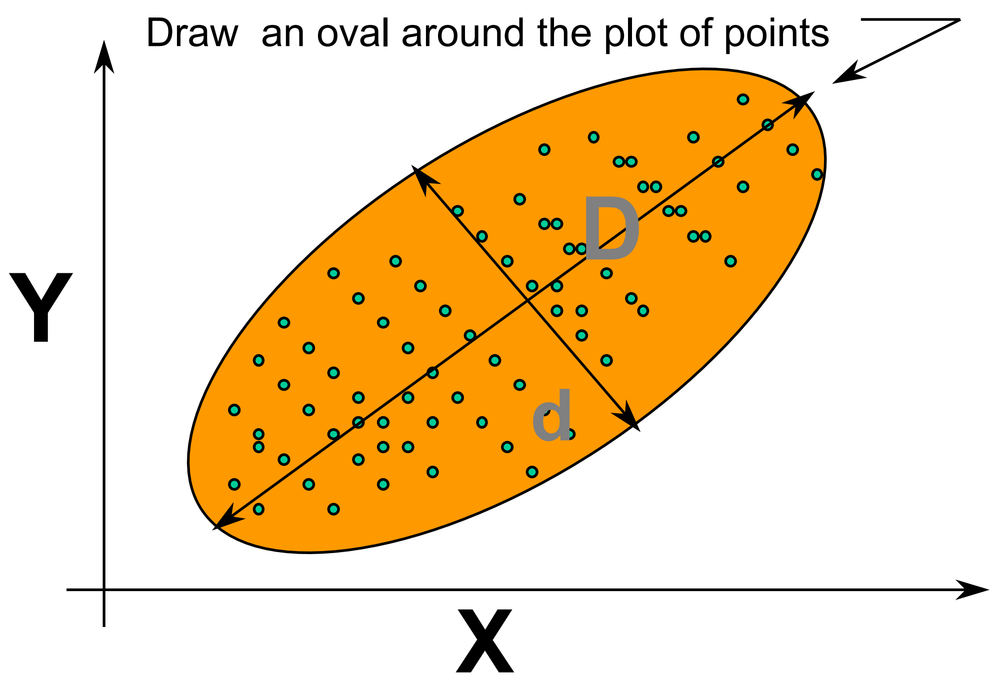
The Correlation Formula:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$



Estimating the Correlation Coefficient

1. Measure the length of the MAX diameter (D) of the oval with a scale
2. Measure the length of the MIN diameter (d) of the oval with a scale
3. Estimate the value of " r " by calculating: ± (1- [d/D])
4. Attach the sign in the direction of the slope of D



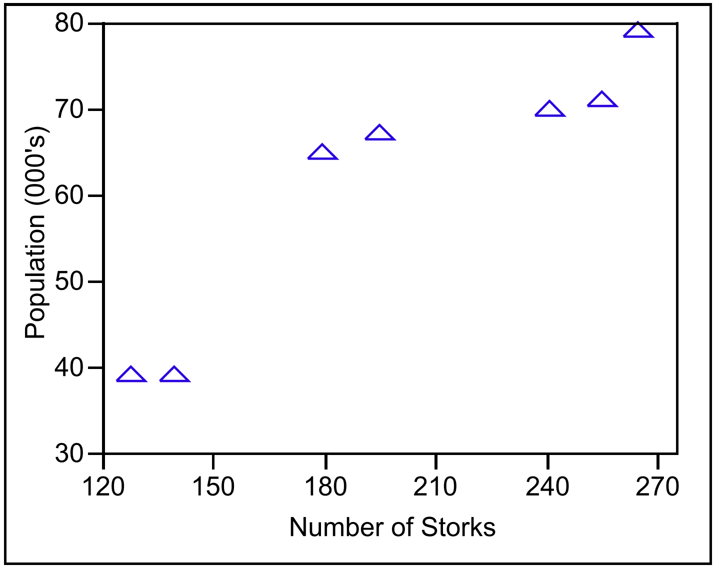
Abuse and Misuse of Correlation

- If we establish a correlation between y and x1, that does NOT necessarily mean variation in x1 caused variation in y.
- A third variable may be ‘lurking’ that causes both x1 and y to vary.
- In conclusion, an association between two variables does NOT mean there is a cause-and-effect relationship.

Correlation does NOT determine causation!

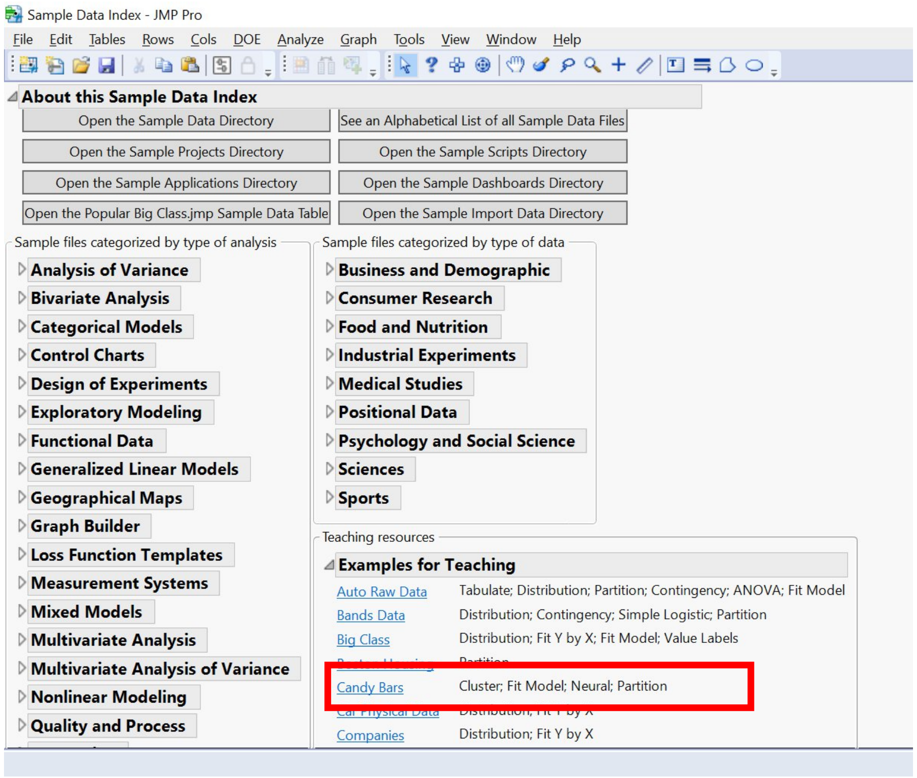
Stork Example

- **Correlation does not imply causation.**
- Look at the graph of population and storks below.
- Question: Would killing storks be an adequate method of birth control?
- We may identify a relationship by observing a process; two variables tend to increase together and decrease together. However, this does not necessarily mean that we can adjust one variable by manipulating the other variable.



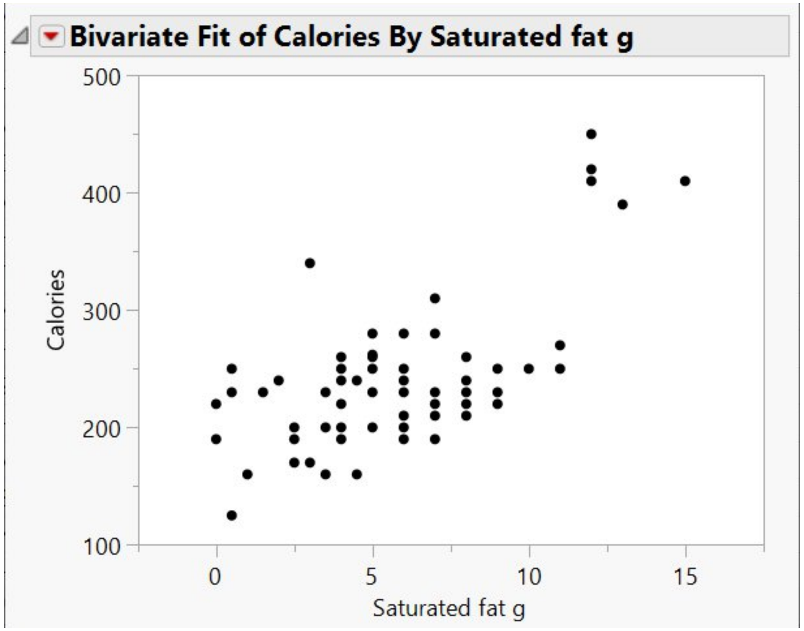
Correlation Example 1

- Open the data table **JMP>Help>Sample Index> Examples for Teaching> Candy Bars.jmp**



Correlation Example 1

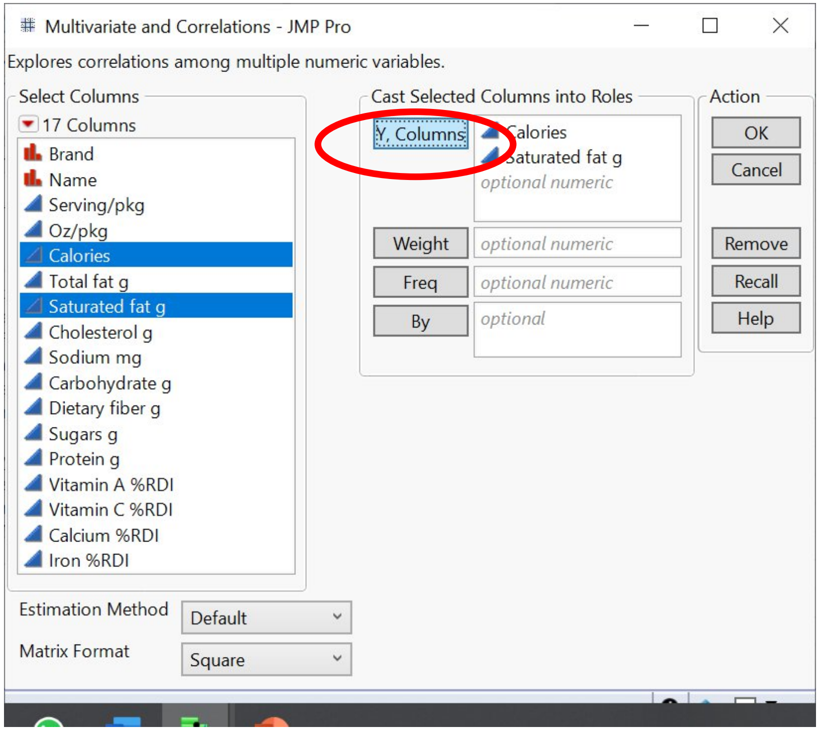
- Plot the data first
  - **JMP>Analyze>Fit Y By X**
  - For **Y, Response** select *Calories*
  - For **X, Factor** select *Saturated fat g*
  - Click **OK**



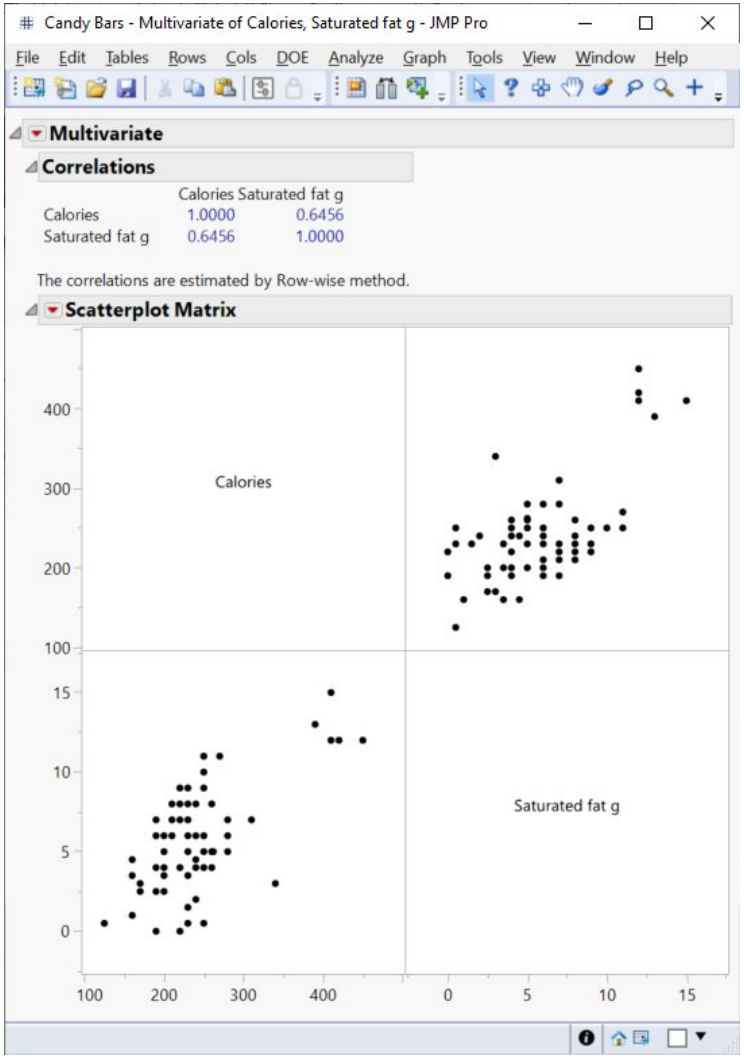
Correlation Example 1

Run the Correlation Analysis

- **Analyze>Multivariate Methods>Multivariate**
- For **Y, Columns**, choose *Calories* and then *Saturated fat g*
- Click **OK**

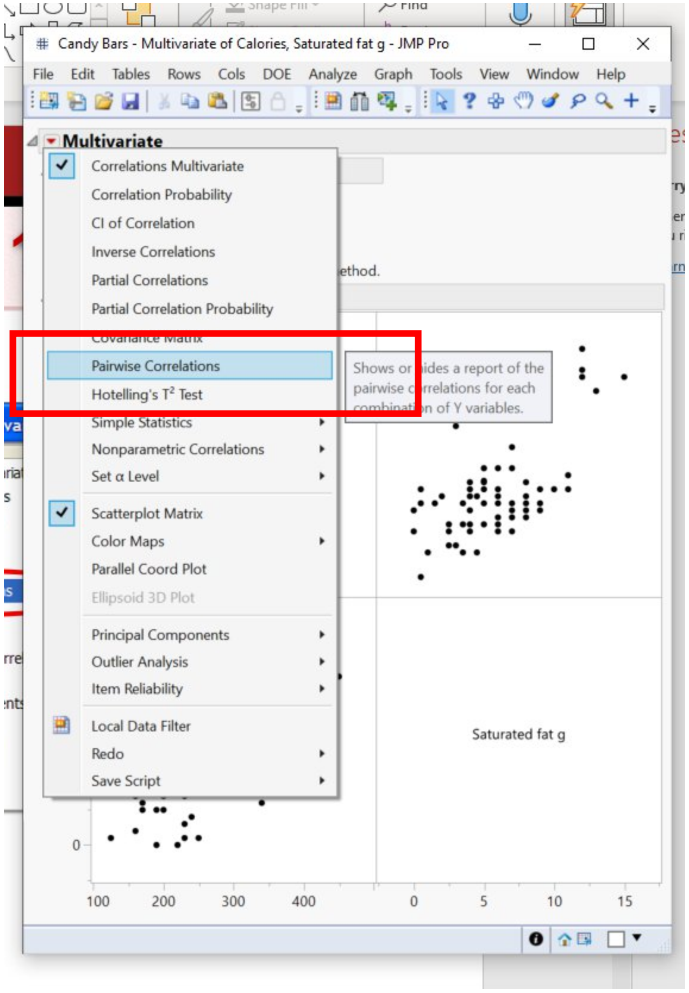


Correlation Example 1



Correlation Example 1

- Click-on the **Multivariate Red Triangle** and select **Pairwise Correlations** to see the p-values.



Correlation Example 1

Pairwise Correlations

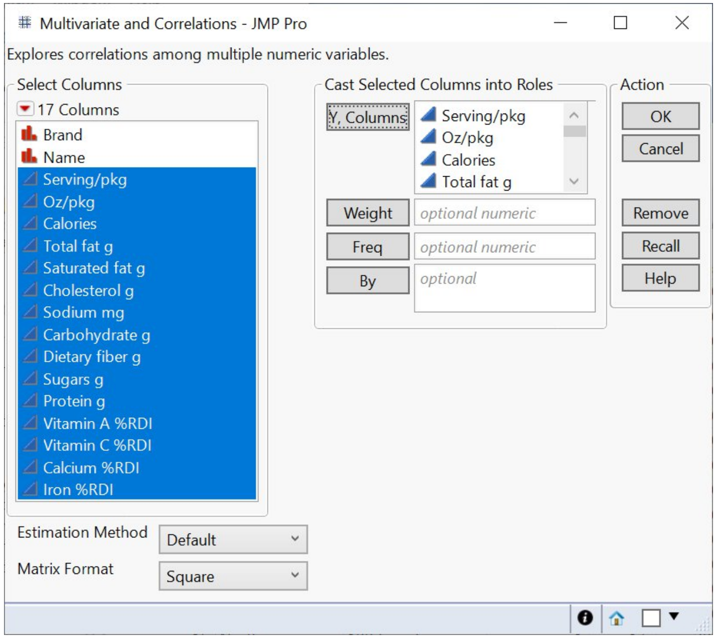
Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
Saturated fat g	Calories	0.6456	75	0.4906	0.7611	<.0001*	

Graphical picture of Correlation (r = 0.6456)

- Are the two variables related? What is r?
- What are your conclusions?

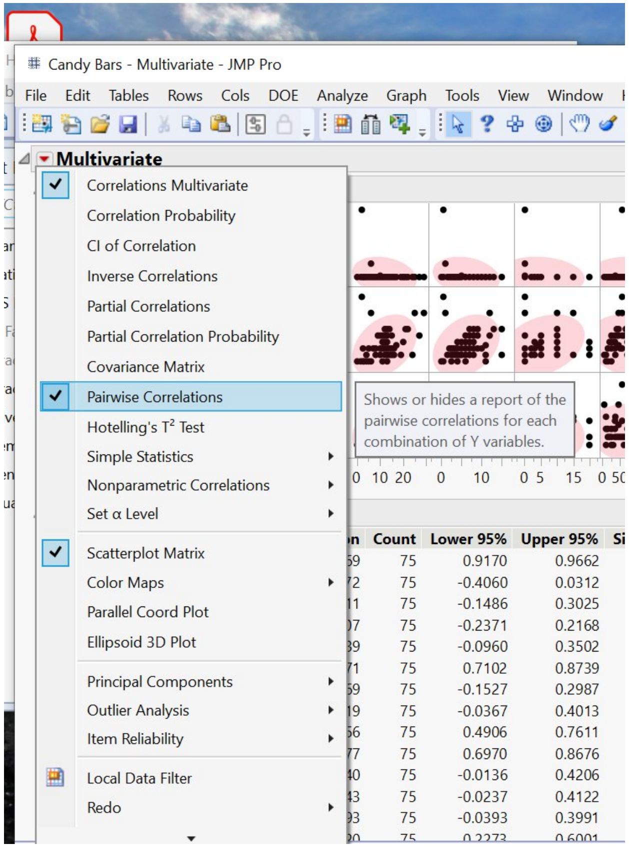
Correlation Example 1

- **Analyze>Multivariate Methods>Multivariate**
- For **Y,Columns**, Choose *Servings/pkg* through *Iron %RDI*
- Click **OK**
- All the different combinations of the correlation graphs for the selected variables are generated in the output window.



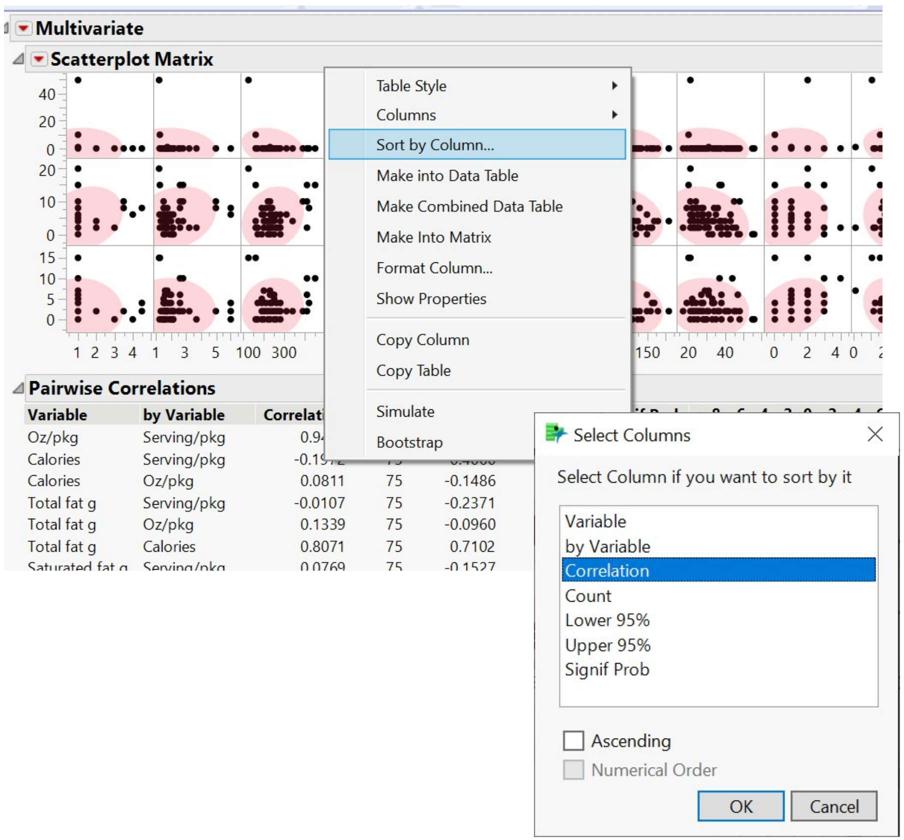
Correlation Example 1

- **Click on red diamond in Multivariate, chose**
- **Multivariate> Pairwise Correlations**
- Analyze all combinations of Scatterplots and the Correlation Coefficients



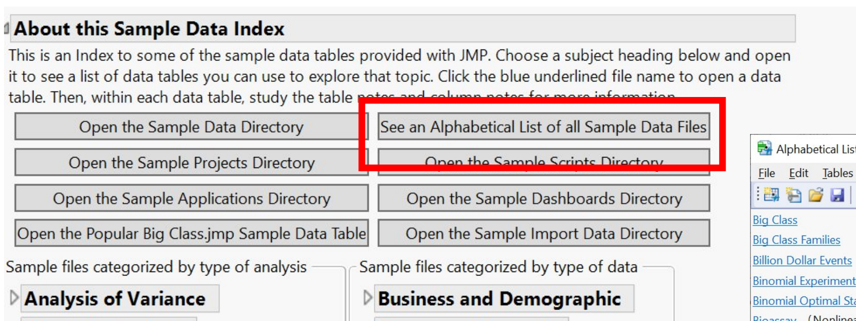
Correlation Example 1

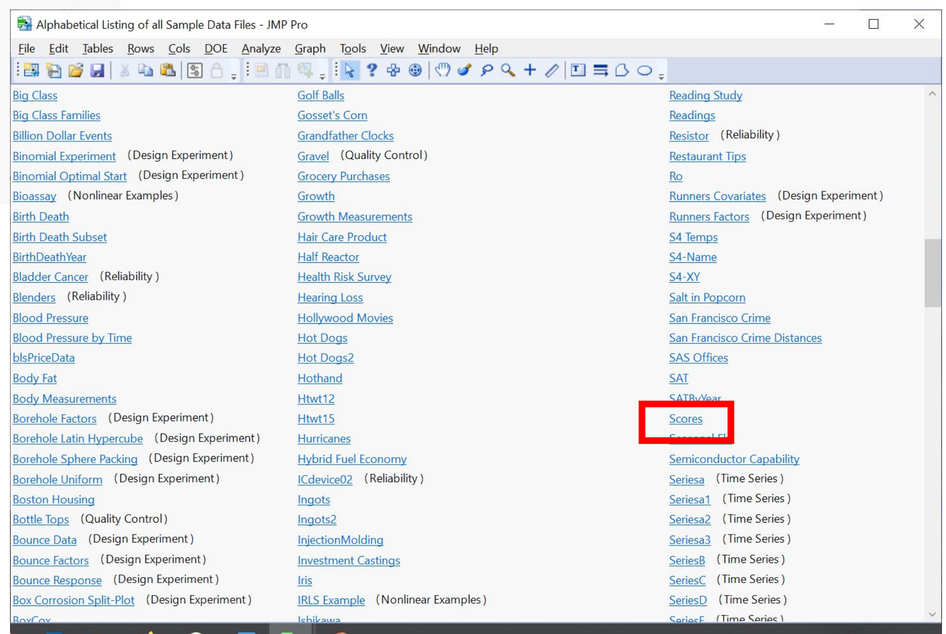
- TIP: You can order the correlation values by right-clicking on the Pairwise Correlations table and selecting **Sort by Column**. Then select the “Correlation” column
- The table is rank ordered by correlation coefficient from +1 to -1.



Correlation Example 2

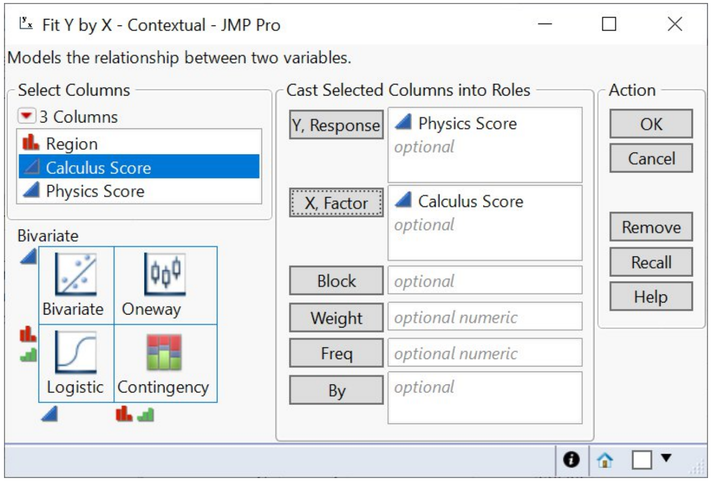
- Open the menu **JMP>Help>Sample Index**
- Click on See an **Alphabetical List of all Sample Data Files**
- Scroll & Select **Scores.jmp**

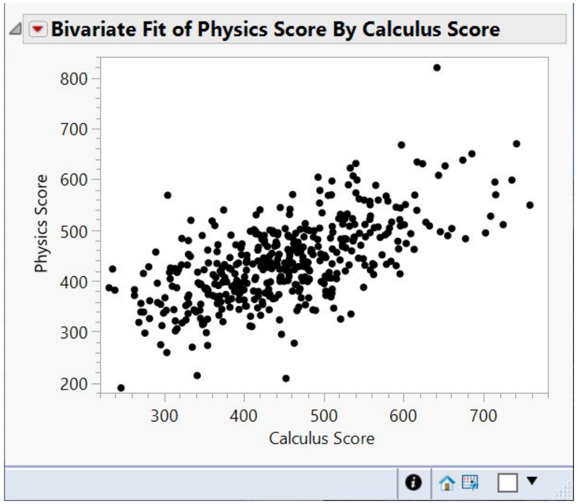




Correlation Example 2

- Always plot the data first
  - **JMP>Analyze>Fit Y by X**
  - For **Y, Response** select *Physics Score*
  - For **X, Factor** select *Calculus Score*
  - Click **OK**

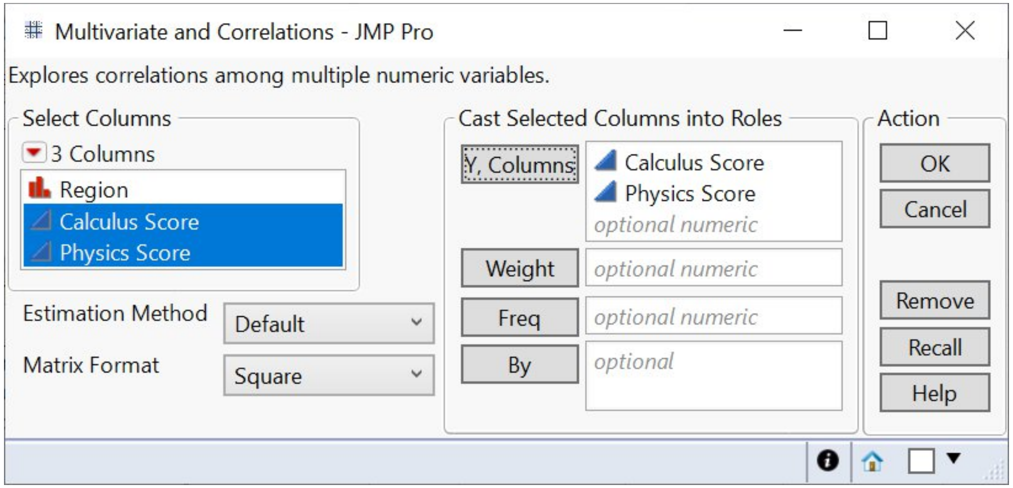




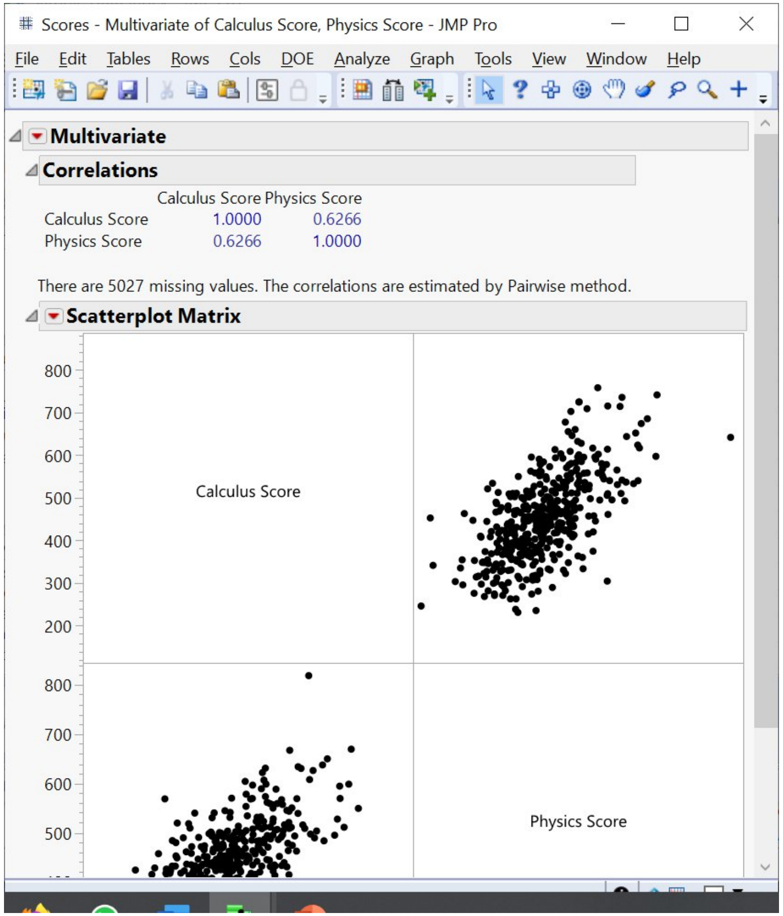
Correlation Example 2

Run the Correlation Analysis

- **Analyze>Multivariate Methods>Multivariate**
- For **Y, Columns**, choose *Calculus Score* and then *Physics Score*
- Click **OK**

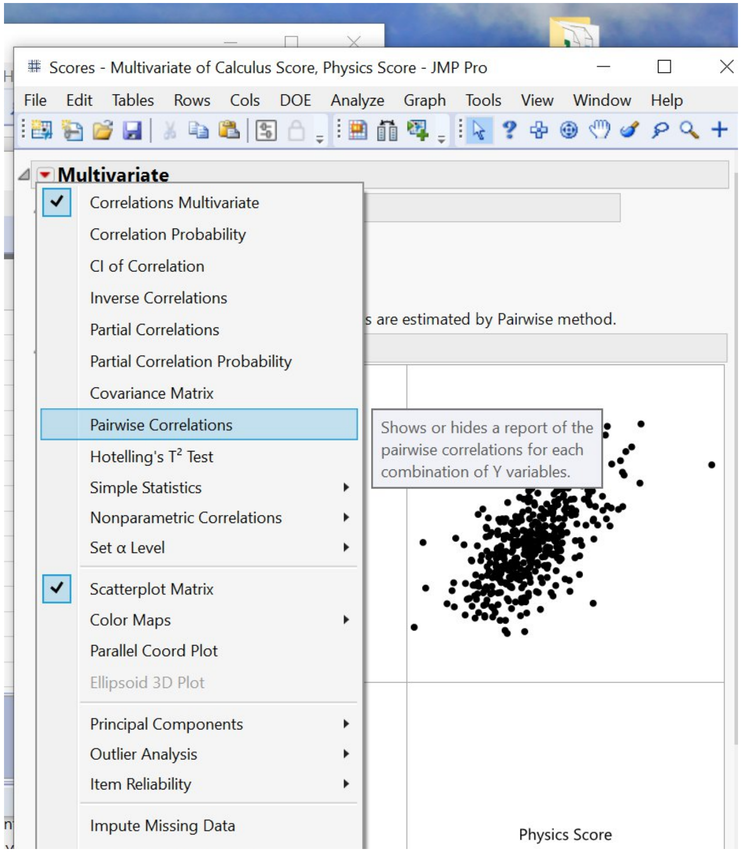


Correlation Example 2



Correlation Example 2

- Click-on the **Multivariate Red Triangle** and select **Pairwise Correlations** to see the p-values.



Correlation Example 2

Pairwise Correlations

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
Physics Score	Calculus Score	0.6266	436	0.5660	0.6805	<.0001*	

- Are the two variables related? What is r?
- What are your conclusions?

Regression Analysis

- Correlation tells us the strength of a relationship, not the exact numerical relationship.
- The next step for analyzing continuous data is the determination of the regression equation.
- Regression analysis calculates a “prediction equation” which can mathematically predict Y for any given X.
- The primary objective of regression analysis is to make **PREDICTIONS**.
- The regression equation is simply the one that **BEST FITS** the plotted data.
- Examples of prediction equations:

$Y = a + b\,x$	(linear model)
$Y = a + b\,x + c\,x^2$	(with quadratic term)
$Y = a + b\,x + c\,x^2 + d\,x^3$	(with cubic term)
$Y = a\,(b^{x})$	(exponential model)

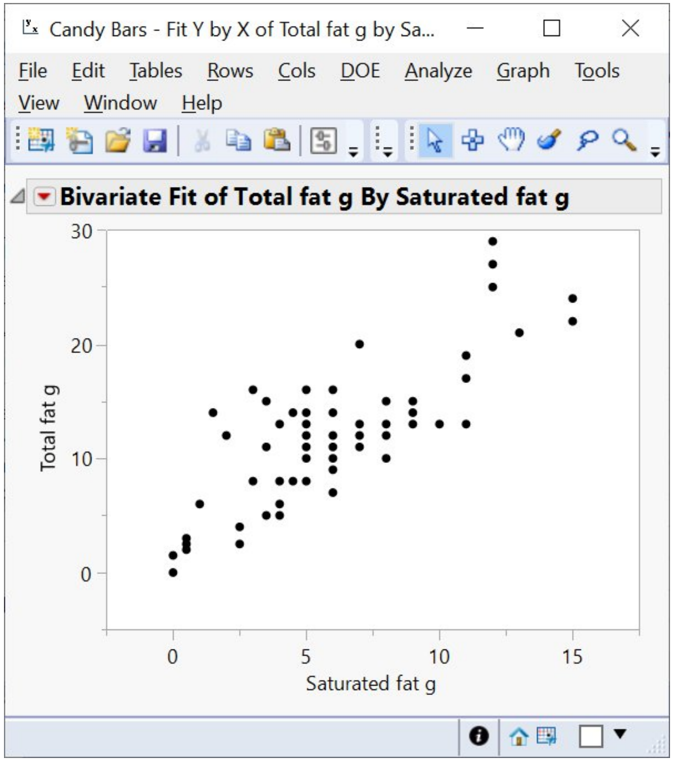
Coefficient of Determination, R-Squared

- The output from the fitted line plot contains an equation which relates the predictor (input variable) to the response (output variable).
- The **R-sq.** value is the square of the correlation coefficient. It is also the **fraction of the variation in the output (response) variable that is explained by the equation**.
- What is a good value? It depends on the process and the industry. For example, a chemist may require an R-sq of 0.99. However, the fact that one input variable may account for 65% of the variation in your final product may be phenomenal too!

Regression Example (Fitted Line Plot)

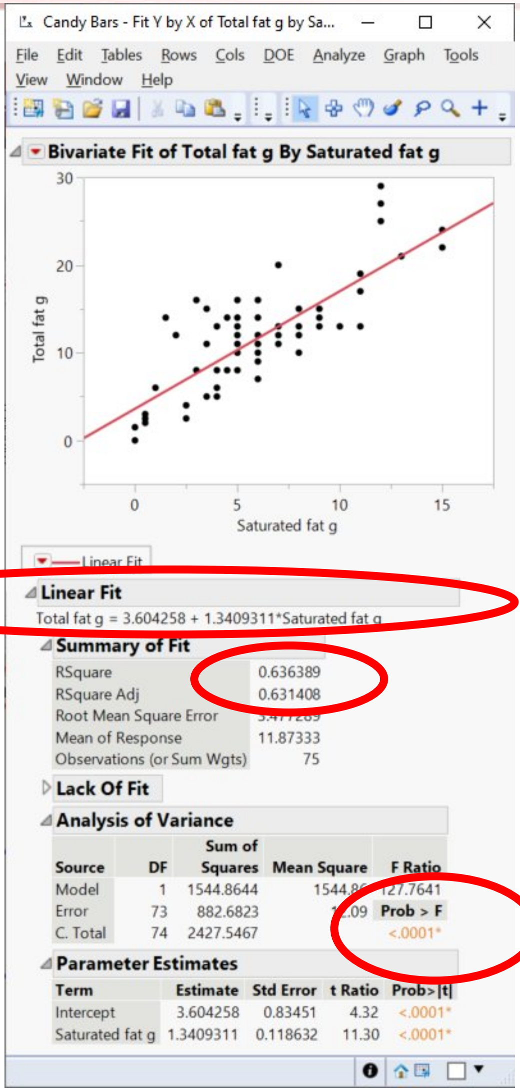
- Open the data table **JMP>Help>Sample Index>Examples for Teaching>Candy Bars.jmp**

- Plot the data first
  - **JMP>Analyze>Fit Y by X**
  - For **Y, Response** select *Total Fat g*
  - For **X, Factor** select *Saturated Fat g*
  - Click **OK**



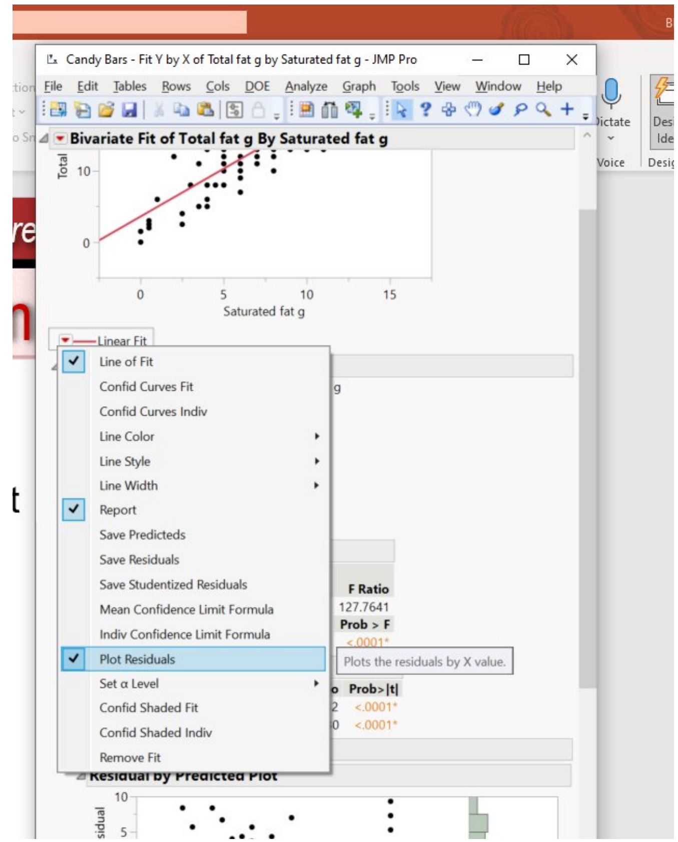
Regression Example (Fitted Line Plot)

- Click-on the **Bivariate Fit of Total Fat by Saturated Fat** and select **Fit Line**.
- Note the Prediction Equation and the RSquare value.
- 63.6% of the variation in the data can be explained by the model.



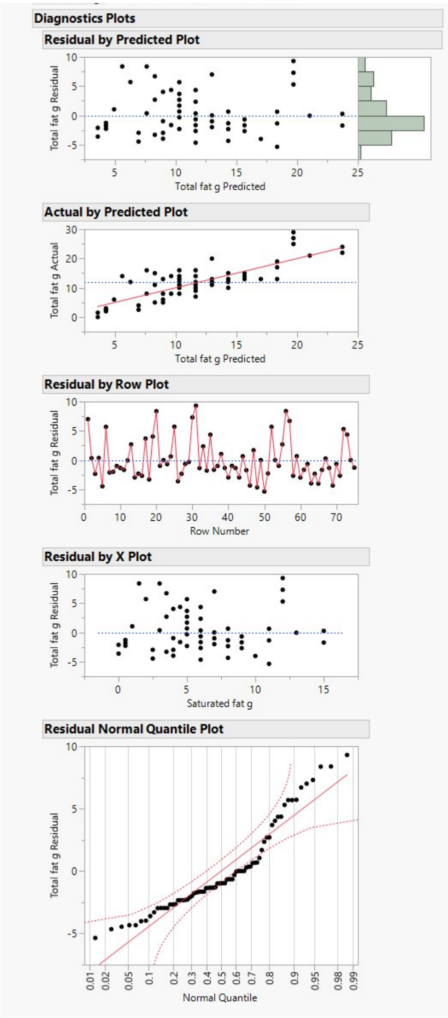
Regression Example (Fitted Line Plot)

- Examine the Residuals
- Click-on the **Linear Fit Red Triangle** and select **Plot Residuals**

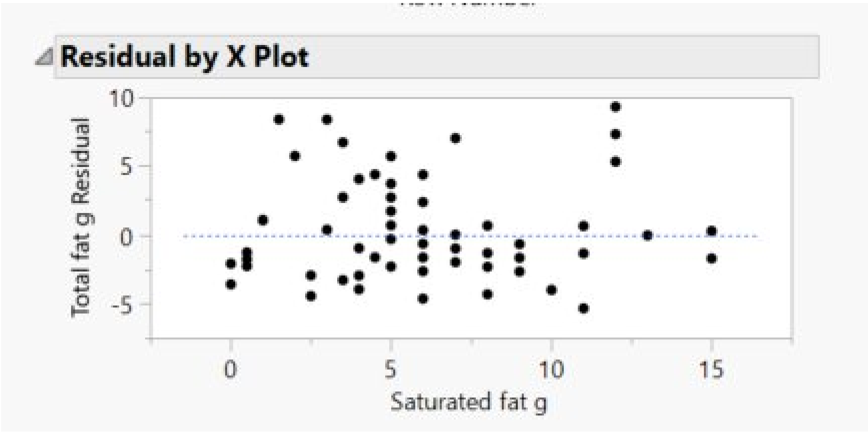


Regression Example (Residuals)

- What do residuals show you?
- What does residual by predicted plot mean?
- What does the Normal Quantile Plot tell you?



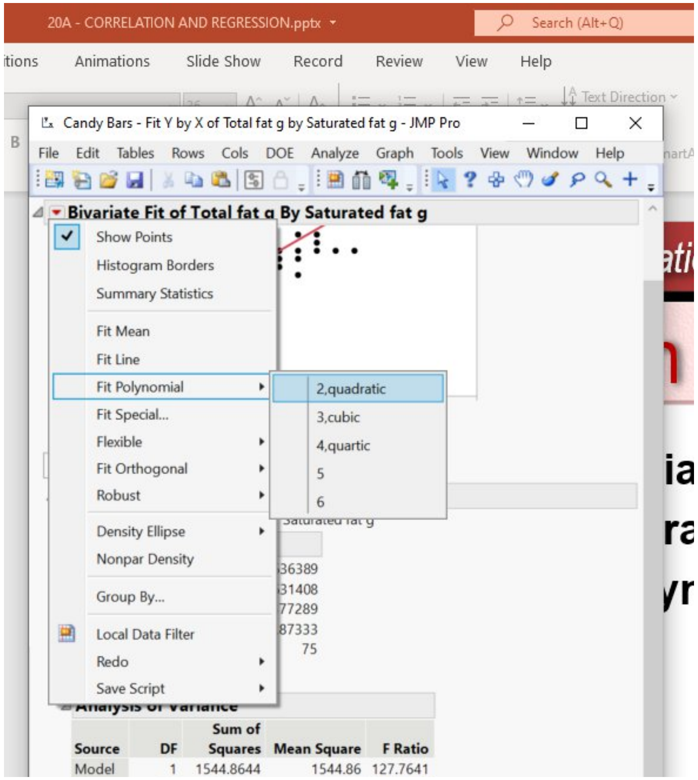
Regression Example (Fitted Line Plot)



- Obtain a prediction equation:
  - Do you need a higher order model?
  - Investigate the residuals plot.

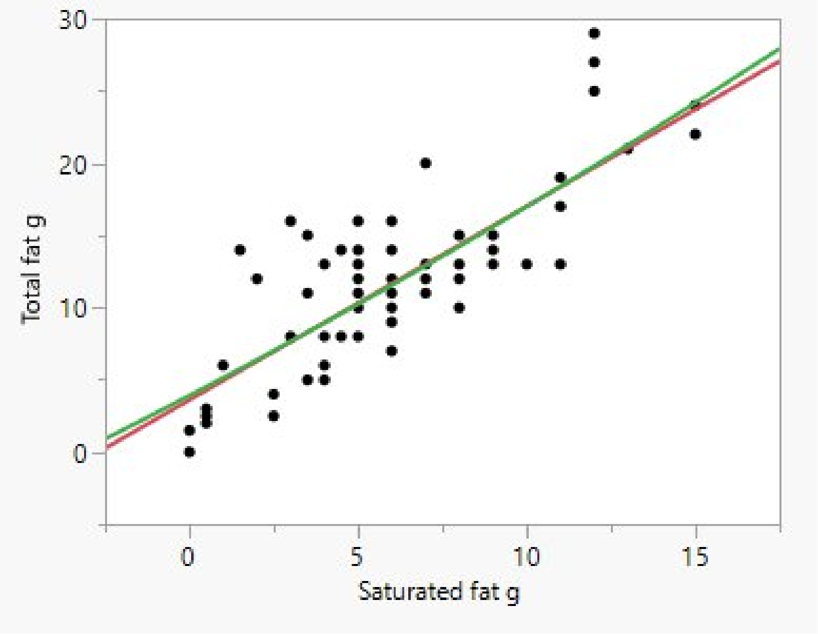
Regression Example (Fitted Line Plot)

- Click-on the **Bivariate Fit of Total Fat by Saturated Fat** and select **Fit Polynomial> 2,quadratic**.



Regression Example (Fitted Line Plot)

- Note that the Quadratic Model is not an improvement over the linear model.



Regression Example (Fitted Line Plot)

- The RSquare value for the quadratic model is 0.636941.
- The squared term in the model does not improve the model, and it is not significant as shown by the p>value of .7417

Polynomial Fit Degree=2

Total fat g = 3.5810782 + 1.3285343*Saturated fat g + 0.0086968*(Saturated fat g-6.16667)^2

Summary of Fit

RSquare	0.636941
RSquare Adj	0.626856
Root Mean Square Error	3.498695
Mean of Response	11.87333
Observations (or Sum Wgts)	75

Lack Of Fit

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	1546.2044	773.102	63.1575
Error	72	881.3422	12.241	Prob > F
C. Total	74	2427.5467		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.5810782	0.842565	4.25	<.0001*
Saturated fat g	1.3285343	0.125105	10.62	<.0001*
(Saturated fat g-6.16667)^2	0.0086968	0.026285	0.33	0.7417

Class Examples

Use correlation/regression to analyze the Candy Bars.jmp file. Does the Total Fat, X, predict the Calories, Y, in the candy bars?

- Are the two variables related?
- What is “r”? What is R-Sq?
- What are your conclusions for each analysis?
- Try a polynomial of degree = 2.
- Try a polynomial of degree = 3.
- Do either improve the R-Sq?

Summary

- Correlation is a very useful tool in the process industry.
- Correlation is the measure of the **relationship** between two quantitative variables.
- Correlation does NOT determine causation!
- Regression analysis seeks to find a relationship between the variables in the form of a prediction equation which may or may not be linear.
- In regression, the equation may be the desired answer, or it may be the means to the desired prediction.

TRUE or FALSE Question:

When the calculated value of r is between the table value of r and 1 (positive or negative), have we established a cause- and-effect relationship between the two variables?

INTRODUCTION TO IMPROVE

Objectives

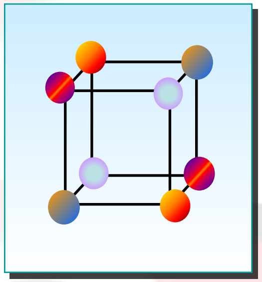
- Discuss the typical flow through the Improve phase of a project
- Overview of the types of improvement strategies
- Use a Pick Chart to evaluate solutions

Improve Flow

Based on root cause analysis, brainstorm potential solutions, risks, costs and benefits.

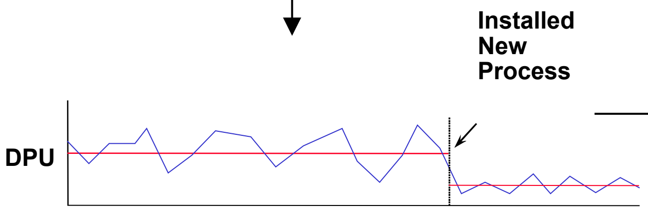
Prioritize Solutions

DOE Where Appropriate



Review / Approve solutions with management

Pilot solutions and measure effectiveness



Solution Implementation Plan

Reach Goals

No

Yes

Update financials & Project Plan Improve Tollgate

Root Causes

- Identified in Analyze.
- Rank in relative importance.
- Brainstorm potential solutions for each root cause.
- Prioritize root causes with solutions.

Prioritizing Root Causes

Root Cause	Solutions	Cost	Benefits
1.	1.		
	2.		
	3.		
2.			
3.			

Pick Chart

Implementation	Benefits: Big	Benefits: Small
Easy	Implement	Possible
Hard	Change	Kill

Types of Solutions

- Lean Strategies
- DOE
- Pilot Study
- Error Proofing

LEAN IMPROVEMENT TOOLS

Objectives

- Review the eight types of wastes found in processes
- Understand how to apply the 5 S + 1 principles to improving a process

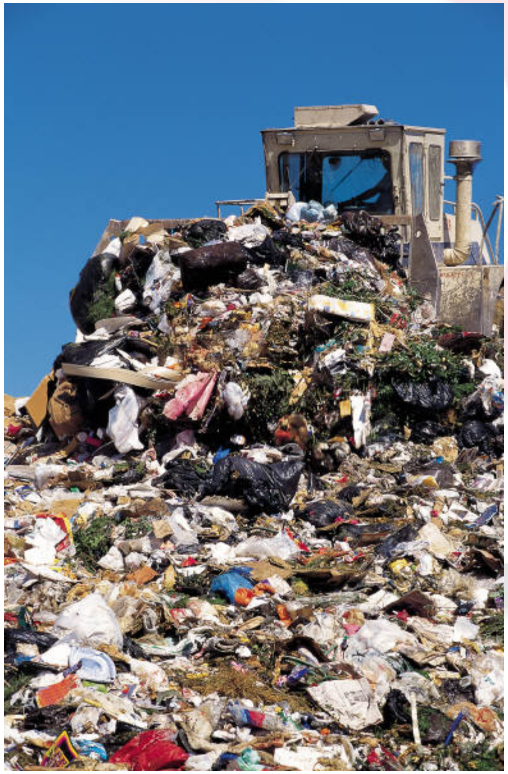
Lean Six Sigma

- Reduce complexity in processes
- Create efficient, continuous flow processes
- Identify and eliminate waste

Waste

Non – Value Added activities are considered to be WASTE in a process.

- **D**efects
- **O**verproduction
- **T**ransportation
- **W**aiting
- **I**nventory
- **M**otion
- **P**rocessing
- **I**ntellect



5 S + 1

Sort

- Keep only what is needed in your area

Set in Order

- A place for everything and everything in its place

Shine

- Clean the work space

Standardize

- Develop systems to maintain the improvements

Sustain

- Self discipline to maintain established procedures

Safety

- Removing hazards and dangers

5 S + 1

Before

5 S + 1

After

5 S + 1

KAIZEN WORKSHOPS

Objectives

- Define Kaizen.
- Understand how Kaizen events may be used for improvement within the DMAIC framework.
- Discuss the steps included in a Kaizen workshop.

Kaizen

A core lean concept, Kaizen is the philosophy of continuous improvement through the removal of wastes in a process.

Kaizen Workshops

- Implement rapid process improvements
- Short, focused projects (3 – 5 days)
- Cross-functional teams
- Solutions implemented immediately

Kaizen Workshops

Kaizen Workshops may be used effectively to address:

- Customer complaints
- Processes that are not clearly defined
- Processes that generate a large number of defects
- Processes that have not been standardized
- Processes that are not error proofed
- Processes that have very lengthy cycle times

Roles and Responsibilities

- Management
- Kaizen lead or facilitator
- Team members
- Subject matter experts

Management

- Executives, managers and process owners
- Assist in identifying projects
- Provide resources and remove barriers to success
- Attend kickoff meeting
- Celebrate success

Kaizen Lead or Facilitator

- Responsible for completing pre-event planning
  - Objective setting
  - Selecting and notifying participants
  - Preparing training materials
  - Assemble background information
  - Logistics
  - Coordinate with participants' departments and management to make resources available for the workshop
- Facilitates the workshop
- Manages implementation of solutions

Team Members

- Participate in the workshop
- Process expertise
- Carry out project tasks as assigned
- Provide updates on the status of solution implementations or action plan

Subject Matter Experts

- Participate in events as needed
- Provide expertise
- Assist in managing the implementation of solutions

Tools

- Brainstorming
- Cause & Effect Diagrams
- 5 S + 1
- Error Proofing
- Value Matrix or Value Stream Maps

Typical Schedule

- Pre-event Activities
  - Objectives
  - Resources
  - Logistics
  - Background
  - Collect data
  - Validate value stream

Typical Schedule

- Day 1
  - Management kickoff
  - Brief team on project objectives and pre-work
  - Training
  - Review and validate value matrix/value stream
- Days 2 – 3
  - Complete any data collection
  - Identify and verify root causes
  - Identify sources of waste
  - Brainstorm improvements to remove wastes and reduce variability

Typical Schedule

- Day 4
  - Create a solution action list
  - Implement improvements
  - Train employees
  - Test and refine solution
- Day 5
  - Document new procedures
  - Present results to management team
  - Create a control plan

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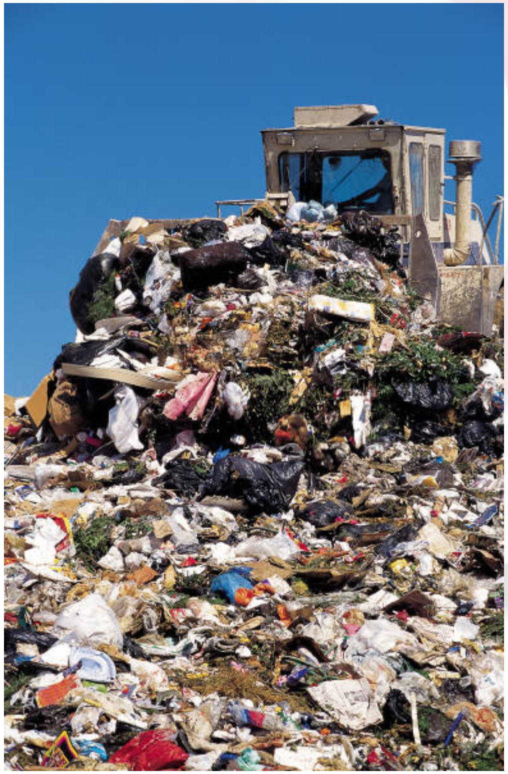

5 S + 1

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5 S + 1

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5 S + 1

After

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Kaizen Lead or Facilitator

- Responsible for completing pre-event planning
  - Objective setting
  - Selecting and notifying participants
  - Preparing training materials
  - Assemble background information
  - Logistics
  - Coordinate with participants' departments and management to make resources available for the workshop
- Facilitates the workshop
- Manages implementation of solutions

Team Members

- Participate in the workshop
- Process expertise
- Carry out project tasks as assigned
- Provide updates on the status of solution implementations or action plan

Subject Matter Experts

- Participate in events as needed
- Provide expertise
- Assist in managing the implementation of solutions

Tools

- Brainstorming
- Cause & Effect Diagrams
- 5 S + 1
- Error Proofing
- Value Matrix or Value Stream Maps

Typical Schedule

- Pre-event Activities
  - Objectives
  - Resources
  - Logistics
  - Background
  - Collect data
  - Validate value stream

Typical Schedule

- Day 1
  - Management kickoff
  - Brief team on project objectives and pre-work
  - Training
  - Review and validate value matrix/value stream
- Days 2 – 3
  - Complete any data collection
  - Identify and verify root causes
  - Identify sources of waste
  - Brainstorm improvements to remove wastes and reduce variability

Typical Schedule

- Day 4
  - Create a solution action list
  - Implement improvements
  - Train employees
  - Test and refine solution
- Day 5
  - Document new procedures
  - Present results to management team
  - Create a control plan

Lean Six Sigma

2^K Factorial Experiments

2^K Factorial Experiments

Objective: To develop a mathematical relationship between the significant factors and the response variable.

Deliverables: Y=f(x), Mathematical Model, DOE Report, Updated FMEA

2^K Factorial Experiments

Objective	Project Deliverables
DOE Planning	Experiment Planning Experiments
Screening Experiments (What are the significant factors?)	Fractional Factorial Experiments Reduced List of Input Variables
Y=f(x) (What is the mathematical relationship between the significant factors and the response variable?)	Mathematical Model 2^K Factorial Experiments Full Factorial Experiments Established Input Levels
Process Documentation	Updated Process FMEA DOE Report(s)

2^K Factorial Experiments Agenda

- Why do we need 2^K factorial experimentation?
- 2^K Standard Order Designs
  - Exercise:
    - Calculating main effects
    - Calculating interactions
  - 2^K Example (using JMP)
  - 2^K Exercises (using JMP)

2^K Factorial Experiments Agenda

- Adding Center Points
  - 2^K Example with center points (using JMP)
- Adding Blocking
  - 2^K Example with Blocking
- 2^K Vocabulary
- Steps for DOE Analysis

Juran 47.38

Why Use 2^K Factorial Experiments?

- The **GOAL** is to obtain a mathematical relationship which characterizes:
  - Y = f(x1, x2, x3, …)
- The mathematical relationship allows us to identify not only the *critical factors* but also the *best levels* for those factors.
- 2^K Factorial Experiments investigate multiple factors where each factor is studied at only two levels.

Why Use 2^K Factorial Experiments?

- 2^K Factorial Experiments allow us to investigate a large number of factors simultaneously in relatively few runs compared to full factorial designs.
- Finally, 2^K designs are used most frequently in industrial DOE applications because they are very easy to analyze and lend themselves well to sequential studies.

Types of 2^K Factorials

- **One observation per treatment combination**
  - **Usually low statistical power**
  - **Use Normal Quantile Plots or Pareto charts instead of F-tests**
  - **Can create full factorials by leaving unimportant factors out**

Types of 2^K Factorials

- **More than one observation per treatment combination (known as repeats or replicates)**
  - **Better estimates of error**
  - **Better statistical power**
  - **Can still run reduced models**
  - **F-tests, normal plots and pareto charts can be used**

Standard Order Of 2^K Designs

- **2^K factorials refer to k factors, each with 2 levels. A 2^2 factorial is a 2x2 factorial. This design has two factors with two levels and can be executed in only 2x2 or 4 runs. Likewise a 2^3 factorial has 3 factors, each with two levels. This experiment can be done 2x2x2 or 8 runs.**

Standard Order Of 2^K Designs *(Cont.)*

- **The design matrix for 2^K factorials is usually shown in standard order. The low level of a factor is designated with "-" or –1 and the high level is designated with "+" or 1. An example of a design matrix follows.**

2^2 Factorial

Temp	Conc
-1	-1
1	-1
-1	1
1	1

↔

2^3 Factorial

Temp	Conc	Catalyst
-1	-1	-1
1	-1	-1
-1	1	-1
1	1	-1
-1	-1	1
1	-1	1
-1	1	1
1	1	1

Standard Order Of 2^K Designs Exercise

- **Create a 2^4 Factorial Design Matrix**
- **What are the minimum number of runs needed?**
- **Verify your results using JMP: JMP>DOE>Classical>Full Factorial Design**
- **Add two 2-level continuous factors and two 2-level categorical factors**

Standard Order Of 2^K Designs Exercise

Open JMP – new data table

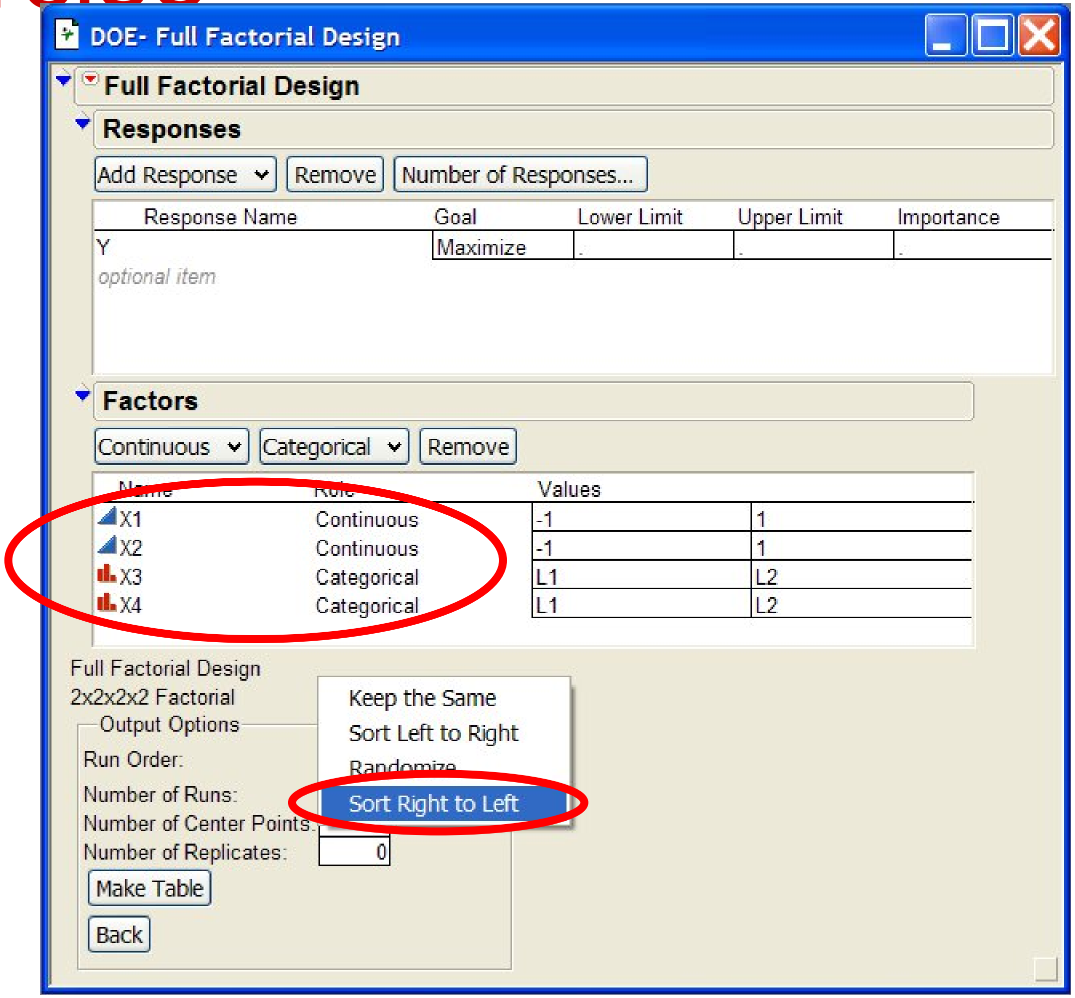
Click on DOE

Select Classical > Full Factorial Design

Y is response, Maximize

Select 2 continuous, 2 categorical variables, 2 levels each, click continue

Standard Order Of 2^K Designs Exercise



Standard Order Of 2^K Designs Exercise

2x2x2x2 Factorial

2x2x2x2 Factorial
Design 2x2x2x2 Factorial
Screening
Model

Columns (6/0)
Pattern
X1 ✱
X2 ✱
X3 ✱
X4 ✱
Y ✱

Rows
All rows 16
Selected 0
Excluded 0
Hidden 0
Labelled 0

	Pattern	X1	X2	X3	X4	Y
1	−−11	-1	-1	L1	L1	•
2	+−11	1	-1	L1	L1	•
3	−+11	-1	1	L1	L1	•
4	++11	1	1	L1	L1	•
5	−−21	-1	-1	L2	L1	•
6	+−21	1	-1	L2	L1	•
7	−+21	-1	1	L2	L1	•
8	++21	1	1	L2	L1	•
9	−−12	-1	-1	L1	L2	•
10	+−12	1	-1	L1	L2	•
11	−+12	-1	1	L1	L2	•
12	++12	1	1	L1	L2	•
13	−−22	-1	-1	L2	L2	•
14	+−22	1	-1	L2	L2	•
15	−+22	-1	1	L2	L2	•
16	++22	1	1	L2	L2	•

Exercise: Calculating Main Effects

Step 1: Problem Statement: A process engineer would like to determine the effect of Quench Temperature, Quench Time, and Quench Oil types on the hardness of a steel shaft. Goal: Maximize Hardness.

Step 2: The factors and levels:

- Quench Temp: 160º C (-1), 180º C (1)
- Quench Time (sec): 5 (-1), 15 (1)
- Quench Oil Type: Brand A (-1), Brand B (1)

Exercise: Calculating Main Effects

Step 3: The design matrix with the results column is as follows:

Temp	Time	Oil	Hardness
-1	-1	-1	60
1	-1	-1	72
-1	1	-1	54
1	1	-1	68
-1	-1	1	52
1	-1	1	83
-1	1	1	45
1	1	1	80

This is an example of 2^K Factorial Experiment with only one observation per treatment combination (experimental run).

Exercise: Calculating Main Effects

- Step 4: We will now calculate the effects of the experiment by hand. First, look at Temperature.
- We simply add the yields associated with (-1) and the yields associated with (1) and calculate the average (Sum/4). The “1’s” and “-1’s” in the temperature column are called the “contrast” for the main effect of temperature.

Exercise: Calculating Main Effects

Temp	Time	Oil	Hardness
-1	-1	-1	60
1	-1	-1	72
-1	1	-1	54
1	1	-1	68
-1	-1	1	52
1	-1	1	83
-1	1	1	45
1	1	1	80

$$TempMainEffect = \left(\frac{72+68+83+80}{4}\right) - \left(\frac{60+54+52+45}{4}\right)$$

$$= 75.75 - 52.75 = 23$$

Total -	-211
Total +	303
Sum	92
Avg Effect	23

The Hardness increases, on average, by 23 points as temperature moves from Low to High (160 to 180).

Exercise: Calculating Main Effects

- Now use the contrast for Time to calculate the effect Time has on Hardness.

$$TimeMainEffect = \left(\frac{54+68+45+80}{4}\right) - \left(\frac{60+72+52+83}{4}\right)$$

$$= 61.75 - 66.75 = -5$$

As the Time moves from 5 sec to 15 sec, the Hardness drops by 5 points on average.

Exercise: Calculating Main Effects

Temp	Time	Oil	Hardness
-1	-1	-1	60
1	-1	-1	72
-1	1	-1	54
1	1	-1	68
-1	-1	1	52
1	-1	1	83
-1	1	1	45
1	1	1	80

Total -	-211	-267	
Total +	303	247	
Sum	92	-20	
Avg Effect	23	-5	

Exercise: Calculating Main Effects

- Next use the contrast for Oil to calculate the effect Oil type has on Hardness.

Temp	Time	Oil	Hardness
-1	-1	-1	60
1	-1	-1	72
-1	1	-1	54
1	1	-1	68
-1	-1	1	52
1	-1	1	83
-1	1	1	45
1	1	1	80

-211	-267	
303	247	
92	-20	
23	-5	

Exercise: Calculating Main Effects

$$OilMainEffect = \left(\frac{\quad + \quad + \quad + \quad}{4}\right) - \left(\frac{\quad + \quad + \quad + \quad}{4}\right)$$

$$= \underline{\qquad\qquad} - \underline{\qquad\qquad} =$$

Interpretation: ____

Exercise: Calculating Interactions

- We have just finished calculating the Main Effects for this experiment. We've only investigated the independent effects of Temperature, Time and Oil Type. This is similar to conducting three 2-Sample T tests.
- The benefit of factorial experiments is that they provide the ability to assess "interactions" between factors. "Is there a particular combination of input settings that improve Hardness over and above the singular (main) effects?"

Exercise: Calculating Interactions

- The interaction contrast is derived by multiplying the columns to be represented.

Calculate the Interaction Contrasts below.

Temp(T)	Time (S)	Oil (O)	T*S	T*O	S*O	T*S*O	Hardness
-1	-1	-1					60
1	-1	-1					72
-1	1	-1					54
1	1	-1					68
-1	-1	1					52
1	-1	1					83
-1	1	1					45
1	1	1					80

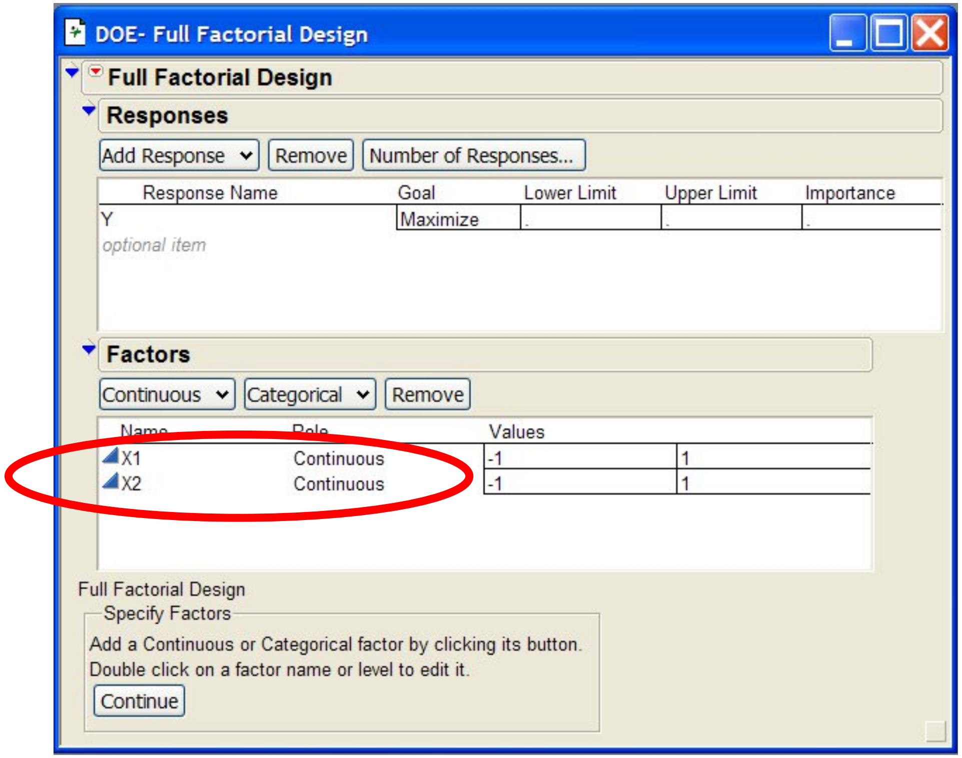
Exercise: Calculating Interactions

	-1	-1	-1	1	1	1	-1	60
	1	-1	-1	-1	-1	1	1	72
	-1	1	-1	-1	1	-1	1	54
	1	1	-1	1	-1	-1	-1	68
	-1	-1	1	1	-1	-1	1	52
	1	-1	1	-1	1	-1	-1	83
	-1	1	1	-1	-1	1	-1	45
	1	1	1	1	1	1	1	80
Total -	-211	-267						
Total +	303	247						
Sum	92	-20						
Effect	23	-5	1.5	1.5	10	0	0.5	
Estimate	11.5	-2.5	0.75	0.75	5	0	0.25	

- Verify the “Contrast” for each interaction using JMP.

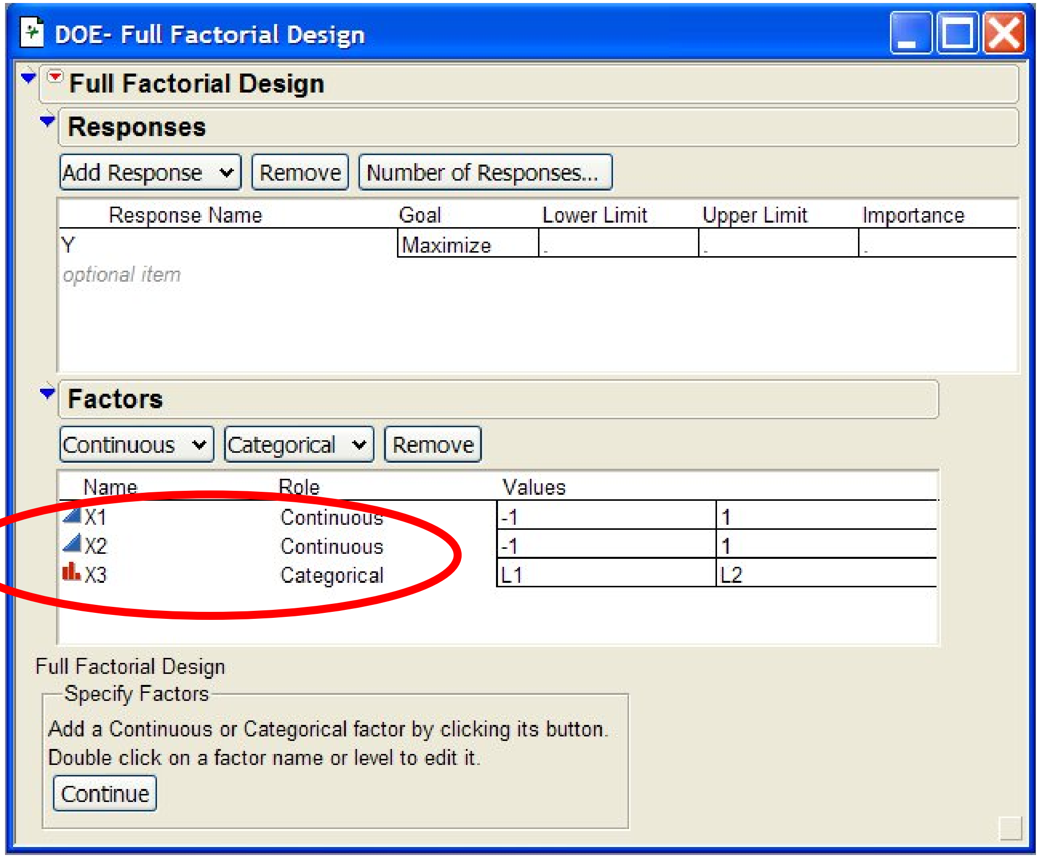
Design Matrix – Using JMP

- JMP> DOE > Classical > Full Factorial Design
  - **Continuous>2 Level**
    - Repeat the previous step (**Continuous>2 Level**)



Design Matrix – Using JMP

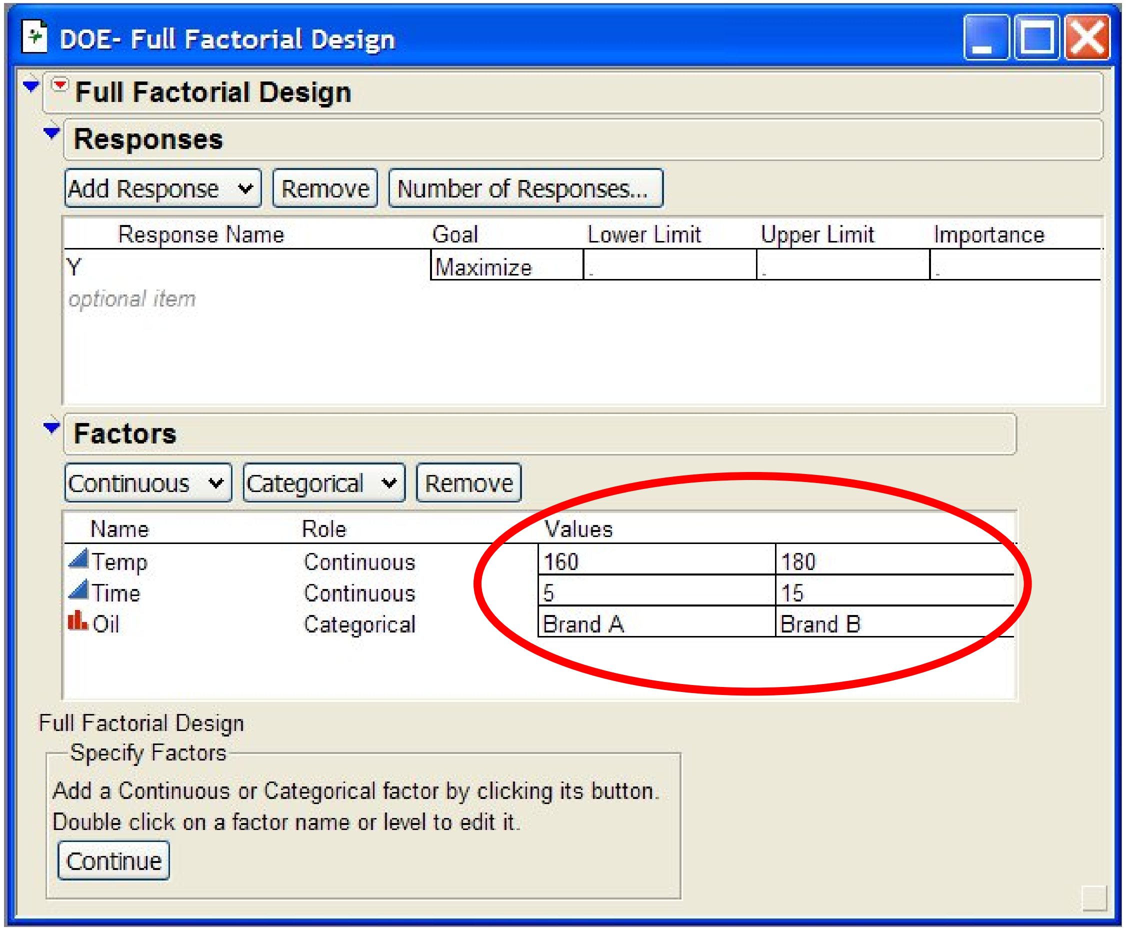
- JMP > DOE > Classical > Full Factorial Design
  - **Categorical>2 Level**



JMP DOE Design *(Cont.)*

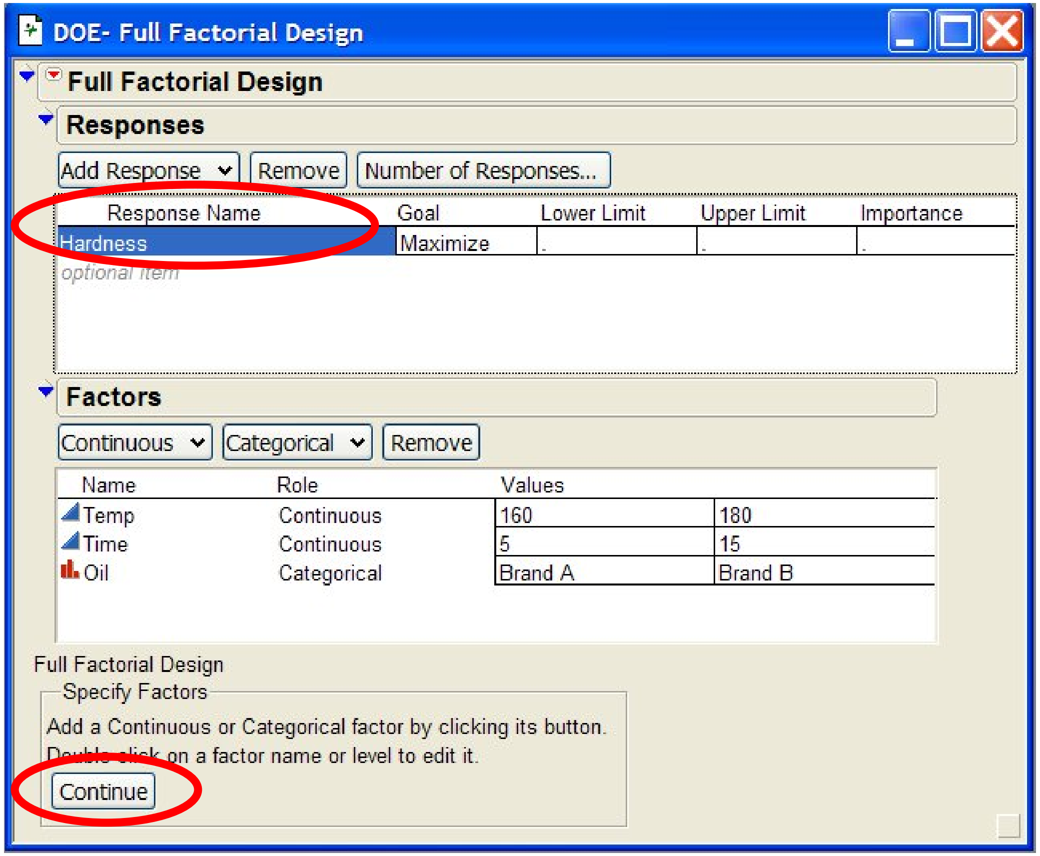
- Double-click in the Name Column to change X1, X2 and X3 to Temp, Time and Oil.
  - Quench Temp: 160° C (-1), 180° C (1)
  - Quench Time (sec): 5 (-1), 15 (1)
  - Quench Oil: Brand A (L1), Brand B (L2)
- Double-click in the Values Column to change the Temp row to 160 and 180, the Time row to 5 and 15, and the Oil row to Brand A and Brand B.

JMP DOE Design *(Cont.)*



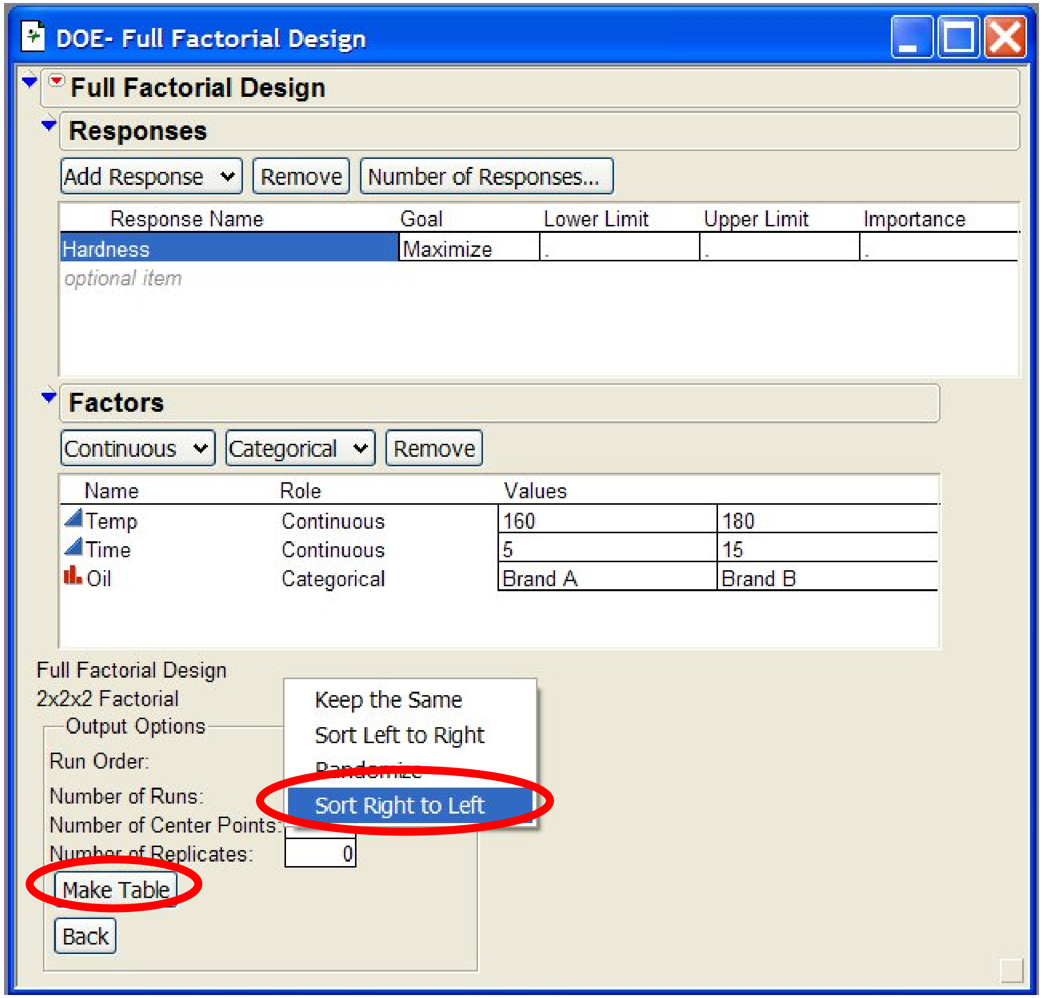
Design Matrix – Using JMP

- Enter the Response column heading.
- Enter *Hardness* as the Response Name.
- Select **Continue.**



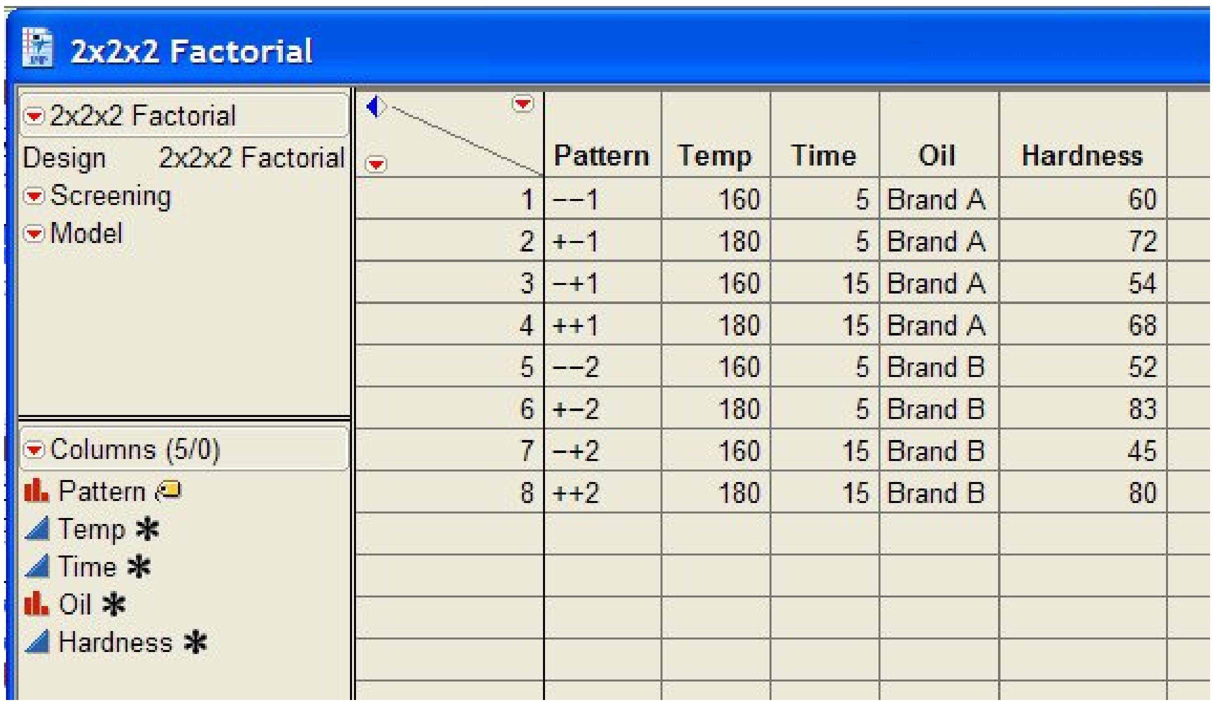
JMP DOE Design *(Cont.)*

- Number of Replicates = Number of Additional Replicates
- For this example, there are no additional replicates.
- Change **Randomize** to **Sort Right to Left** for teaching purposes.
- Click **Make Table.**



JMP DOE Design *(Cont.)*

- Use the table to enter in the Y-values.



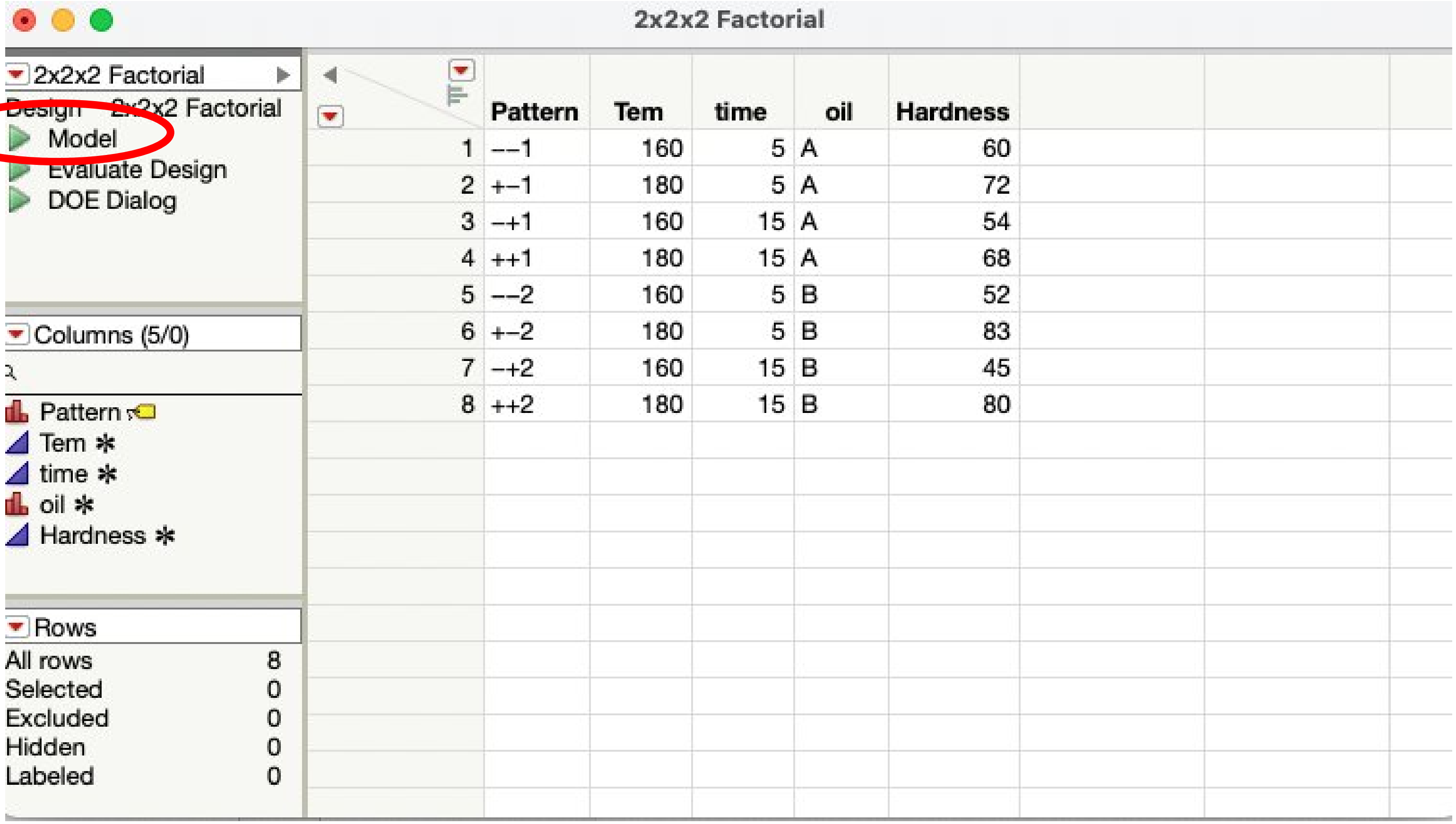
	Pattern	Temp	Time	Oil	Hardness
1	−−1	160	5	Brand A	60
2	+−1	180	5	Brand A	72
3	−+1	160	15	Brand A	54
4	++1	180	15	Brand A	68
5	−−2	160	5	Brand B	52
6	+−2	180	5	Brand B	83
7	−+2	160	15	Brand B	45
8	++2	180	15	Brand B	80

Analysis With JMP

- This experiment only has one observation per treatment combination. Therefore, we can't analyze the "full factorial" using the ANOVA procedure until we learn a few analysis tricks.
- When there is only one observation per treatment combination, we use the Normal Probability Plot or Pareto Chart to interpret which effects are likely to be significant.
- If a factor or its interaction is insignificant (the null hypothesis, effect = 0, is true), then we expect to see the effects normally distributed around a mean of zero. Any outlying effect is considered significant.

Analysis With JMP *(Cont.)*

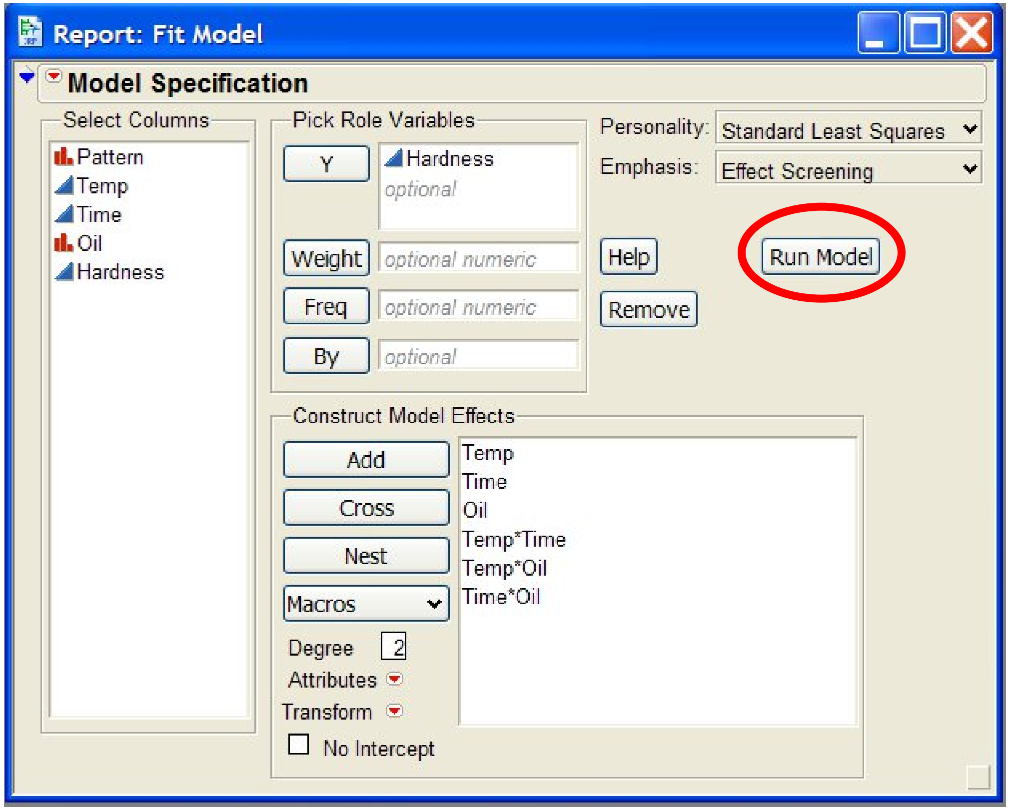
Step 4: From the **Model**, select the **Green Triangle**



	Pattern	Tem	time	oil	Hardness
1	−−1	160	5	A	60
2	+−1	180	5	A	72
3	−+1	160	15	A	54
4	++1	180	15	A	68
5	−−2	160	5	B	52
6	+−2	180	5	B	83
7	−+2	160	15	B	45
8	++2	180	15	B	80

JMP Analysis *(Cont.)*

- Click **Run**



JMP Analysis *(Cont.)*

JMP Output (Use Red Triangle under Response)>
Regression Report>summary of Fit
Regression Report> Analysis of Variance

Summary of Fit

RSquare	0.99962
RSquare Adj	0.997343
Root Mean Square Error	0.707107
Mean of Response	64.25
Observations (or Sum Wgts)	8

Analysis of Variance

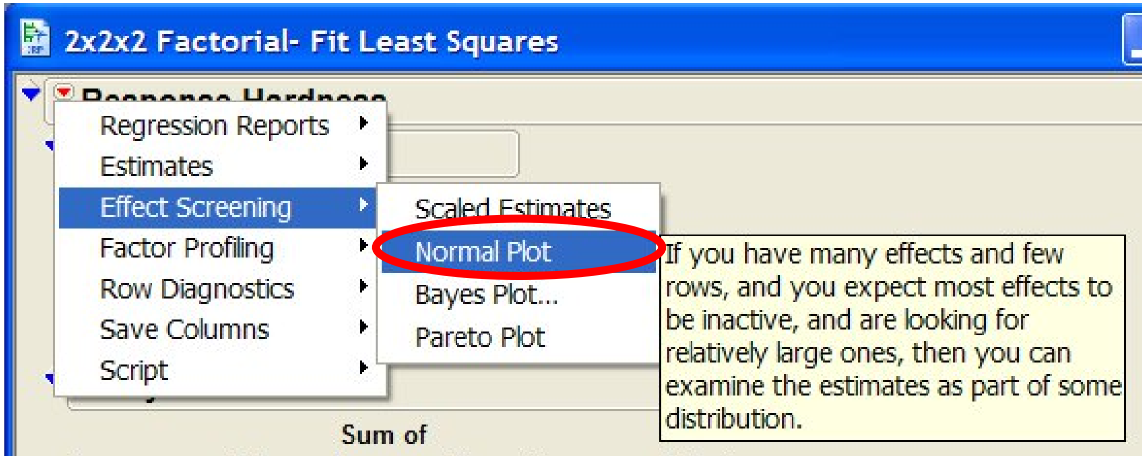
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	1317.0000	219.500	439.0000
Error	1	0.5000	0.500	**Prob > F**
C. Total	7	1317.5000		0.0365*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	64.25	0.25	257.00	0.0025*
Temp(160,180)	11.5	0.25	46.00	0.0138*
Time(5,15)	-2.5	0.25	-10.00	0.0635
Oil[Brand A]	-0.75	0.25	-3.00	0.2048
Temp*Time	0.75	0.25	3.00	0.2048
Temp*Oil[Brand A]	-5	0.25	-20.00	0.0318*
Time*Oil[Brand A]	0	0.25	0.00	1.0000

JMP Analysis *(Cont.)*

- Step 5: Identify the most significant Model Effects or **Estimates** by looking at the Normal Plot and Pareto Plot of the Estimates.



Normal Plot

- The Normal Plot shows that **Temperature, Time**, and the interaction of **Temperature and Oil** are the most significant model estimates.