Design of Experiments (DOE) For Technicians

Presented by

Southwest Center for Microsystems Education

-SCME-

February 2013

SCME is a National Science Foundation Advanced Technological Education (ATE) Program at the University of New Mexico.

We offer professional development and educational materials to excite and engage high school, community college and university students in the field of Microsystems (MEMS) technology.

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SEM of Loop and Hinge System Courtesy of Sandia National Laboratories

Our Presenters

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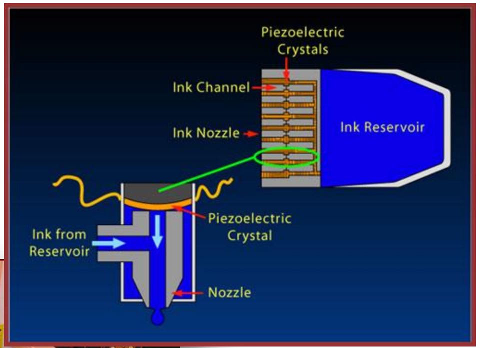
Instructional Designer, SCME and retired Chair for the Manufacturing Technology Program – Central New Mexico Community College

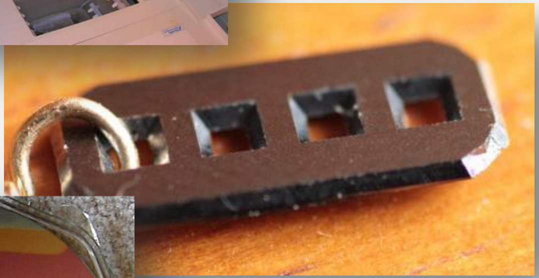
What will we cover today?

- What SCME can do for you
- What is DOE and Why do we Experiment?
- Factors, Factor Levels, and Responses
- Full Factorial Design
- Main and Interaction Effects
- Plan / Do / Check/ Act (PDCA) Cycle

Educational Materials

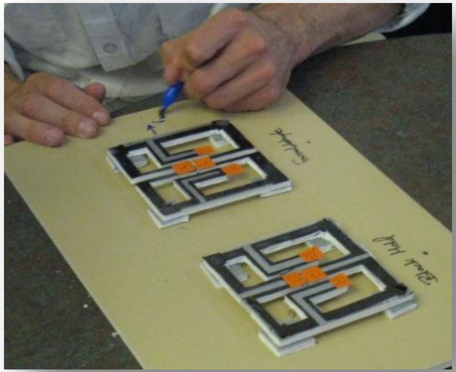
- SCME Learning Modules
  - Informational Units / lessons
  - Supporting activities
  - Supporting assessments
- ~40 Modules in the areas of
  - Safety
  - Microsystems Introduction
  - Microsystems Applications
  - Bio MEMS
  - Microsystems Fabrication
- 11 Instructional Kits
- All are available @ scme-nm.org





Professional Development

- 4 to 5-day workshops
- 2-day workshops
- 1-day workshop
- Conferences and conference workshops
- Create hubs at other colleges to teach our workshops
- Webinars
- SCME on YouTube (https://www.youtube.com/user/scme2012)



Let's talk Cake!

What Makes a "Good" Cake

What are some of those characteristics or attributes?

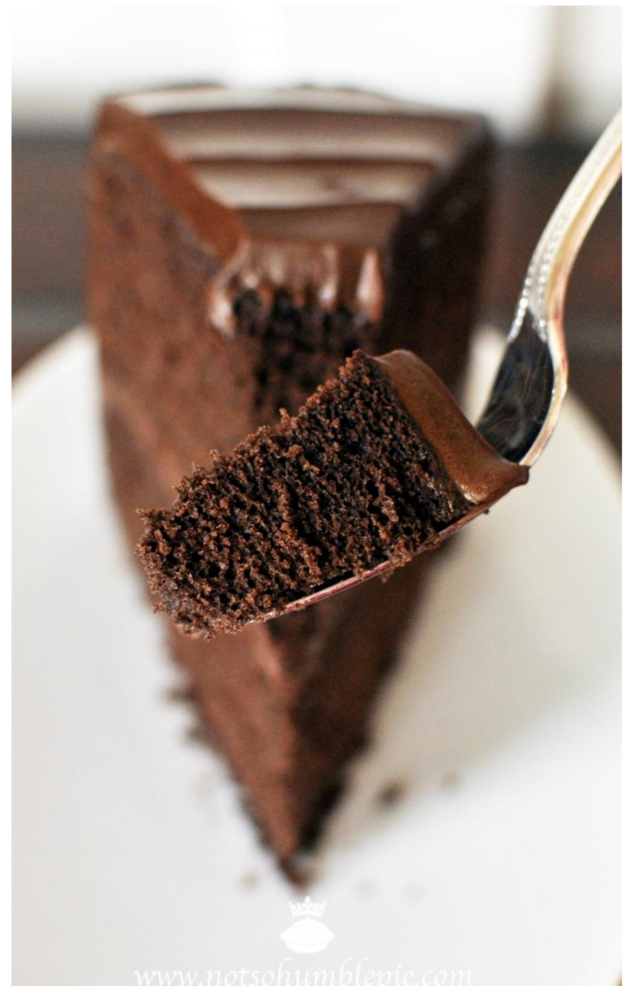
- Tastes Good
- Moist
- "Good" cake density
  - Not falling apart
  - Not like eating a brownie
- Look Good

What Factors Should I Consider?

Factors

- Oven Temperature
- Amount of Flour
- Amount of Sugar
- Amount of Butter/Oil
- Amount of Liquid (milk/H_20)
- Number of Eggs
- Amount of Leavening Agent
- Amount of Salt
- Baking Time

- Altitude
- Humidity



Wait - there's more?

Factors I could also consider

- Temperature of the ingredients
- Mixing method
- Sequence of mixing
- Who is doing the baking

What is DOE?

Factors

- Oven Temperature
- Flour
- Sugar
- Butter/Oil
- Liquid
- Eggs
- Baking Powder
- Salt
- Baking Time
- Altitude
- Humidity
- Temp of ingredients
- Mixing method
- Person baking

Responses

- Taste
- Moisture
- Density
- Appearance

Why do we need (DOE)
Design of Experiments

Screening

- Identify significant factors
- Identify factors that interact

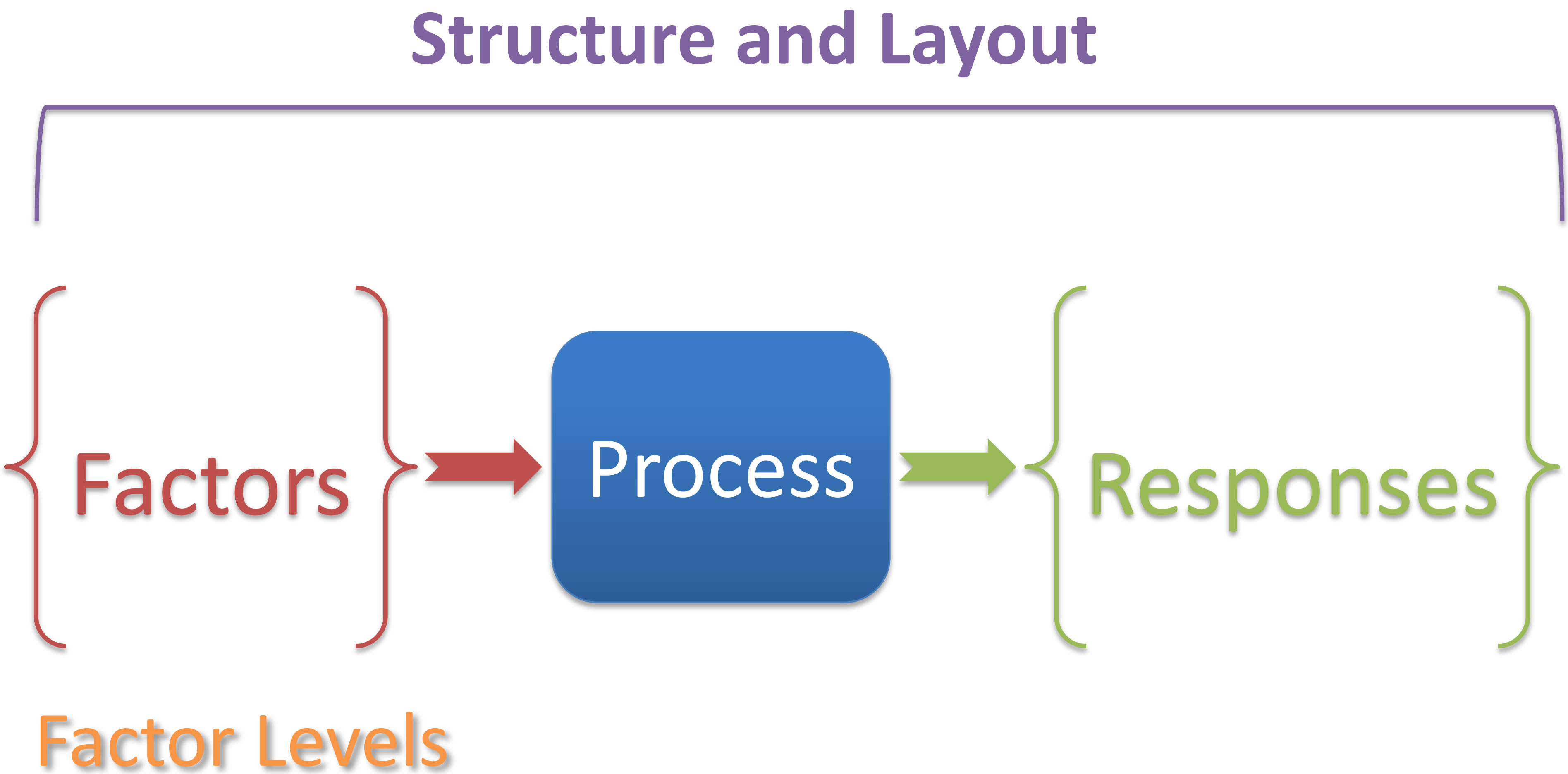
Characterize

- New piece of Equipment
- Different process conditions

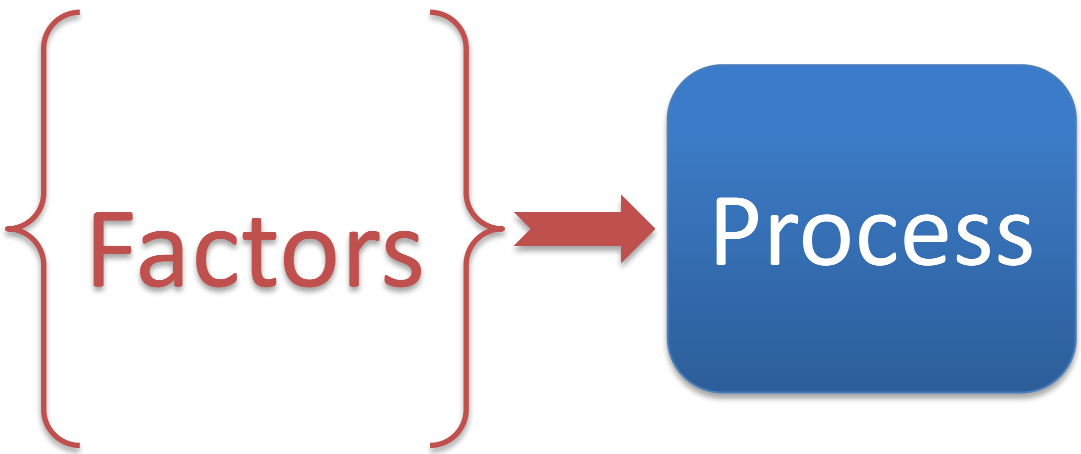
Optimization

- Fine Tune
- Compare alternatives
- Reduce process variability
- Improve process resilience

Elements of DOE



Factor Levels

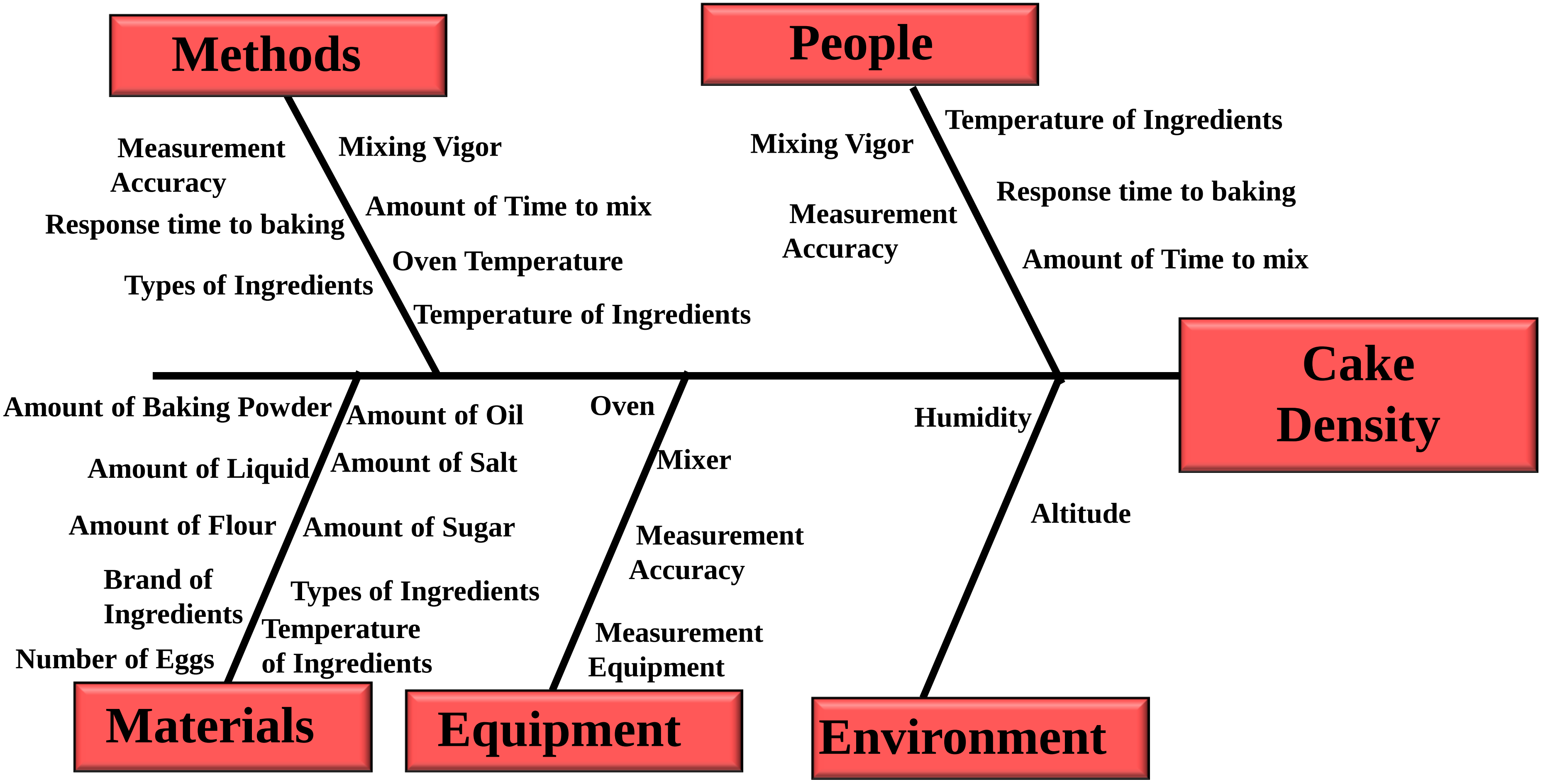


Controllable:
Ingredients
Oven Temp
Temp of Ingredients
Mixing Methods

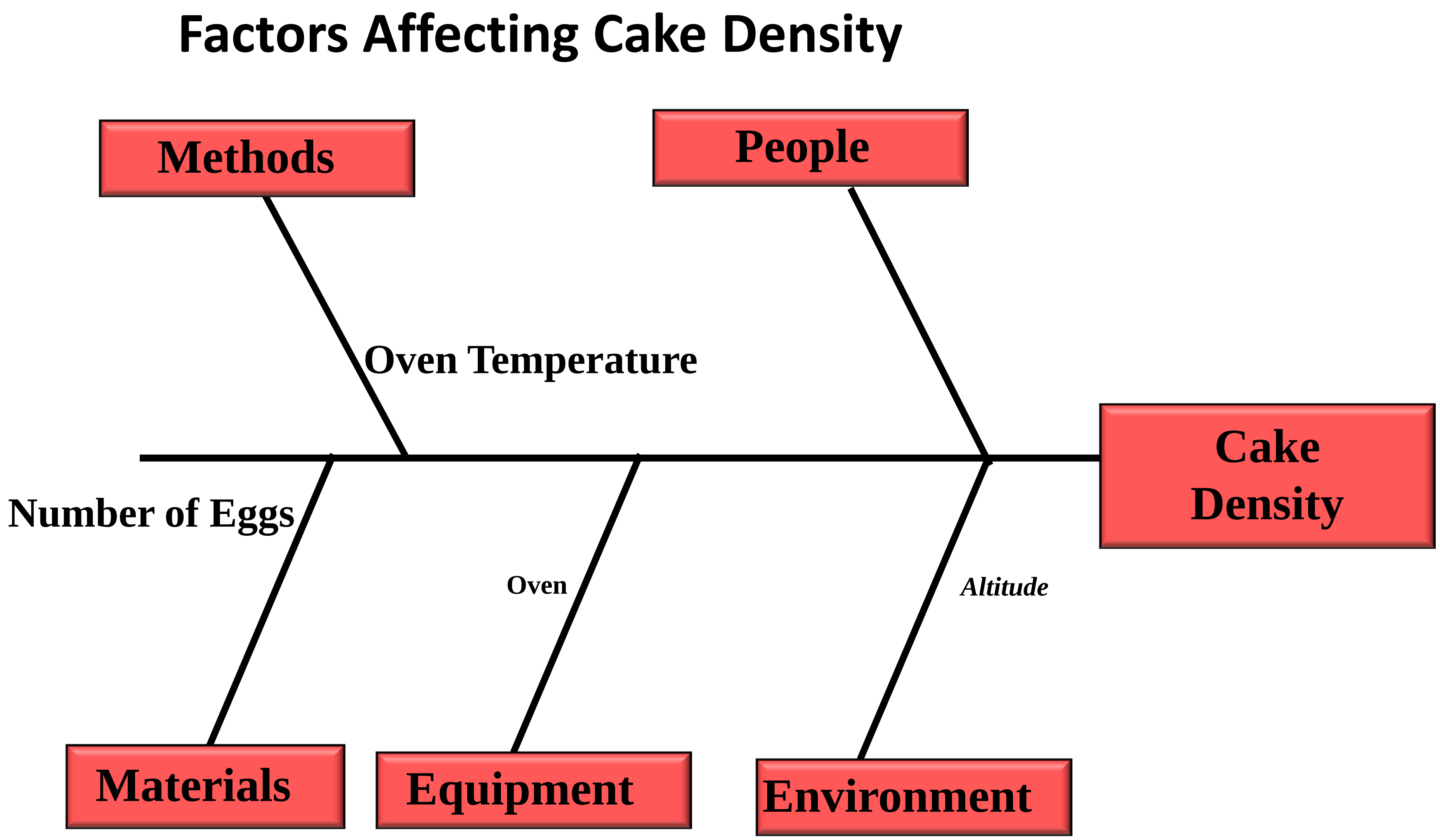
Uncontrollable:
Humidity
Altitude
Person performing process (Noise)

Factors: Cause and Effect Diagram

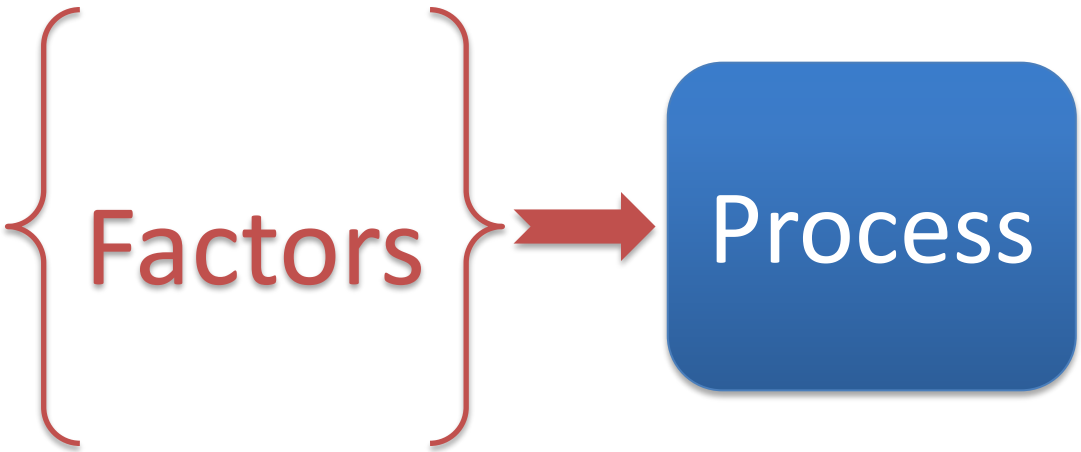
Factors Affecting Cake Density



Factors: Cause and Effect Diagram



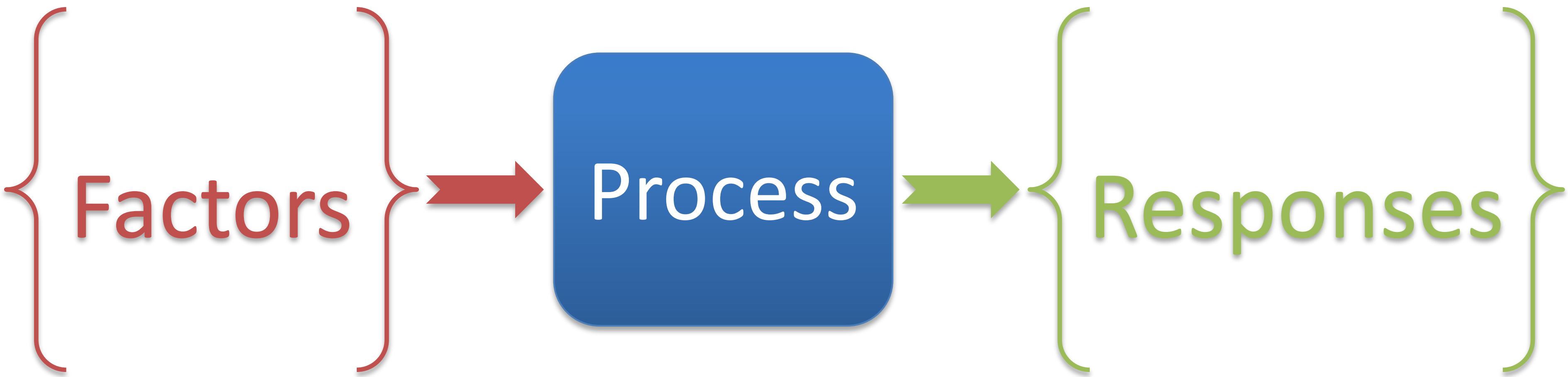
Factor Levels



Factor Levels

- **1 or 3 Eggs**
- **325 or 375 °F**

Responses



Factor Levels

Density

Structure and Layout

Structure and Layout

Factor Levels

Assumptions:

Altitude = 5204 ft

9 inch diameter cake pan

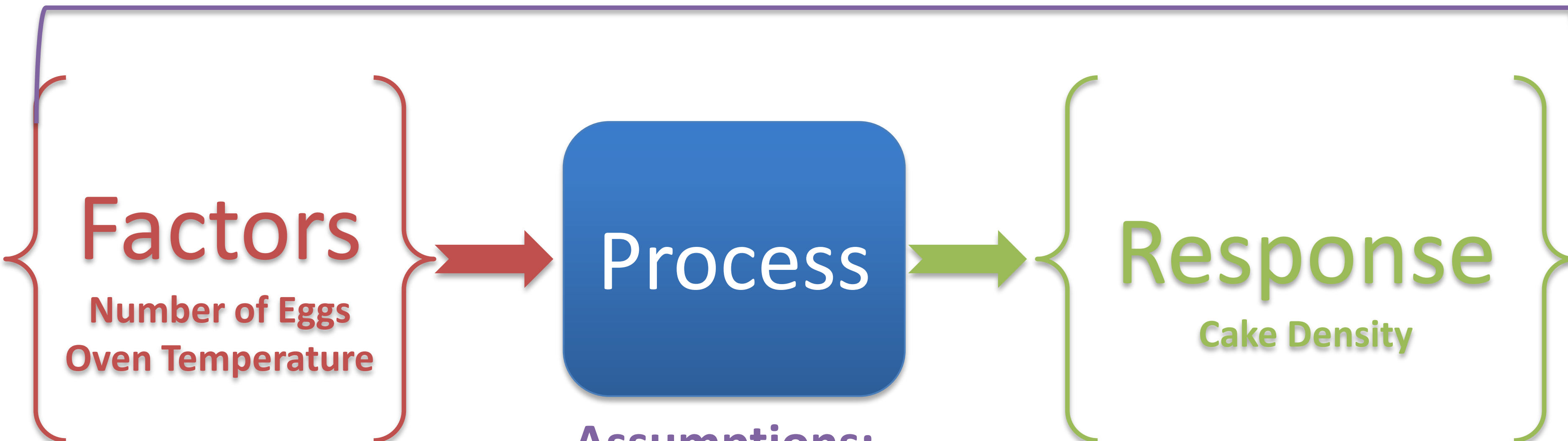
Measurement Standards for Density:

Density = Mass/Volume

Take notice of texture appearance – Crumbly, Sticky

Summary of our Cake Experiment

Two Factor Screening Experiment



Assumptions:

Altitude = 5204 ft

9 inch diameter cake pan

Factor Levels

- **1 or 3 Eggs**
- **325 or 375 °F**

Measurement Standards for Density:

Density = Mass/Volume

Take notice of texture appearance – Crumbly, Sticky

Types of Designed Experiments

- Single Factor Experiments
  - Changing only one factor at a time
  - Holding other factors constant
  - Only shows a factor’s main effect on response

- Main Effect
- Interaction Effect

Types of Designed Experiments

- Multiple Factor Experiments

$$\text{Number of Runs} = L^F$$

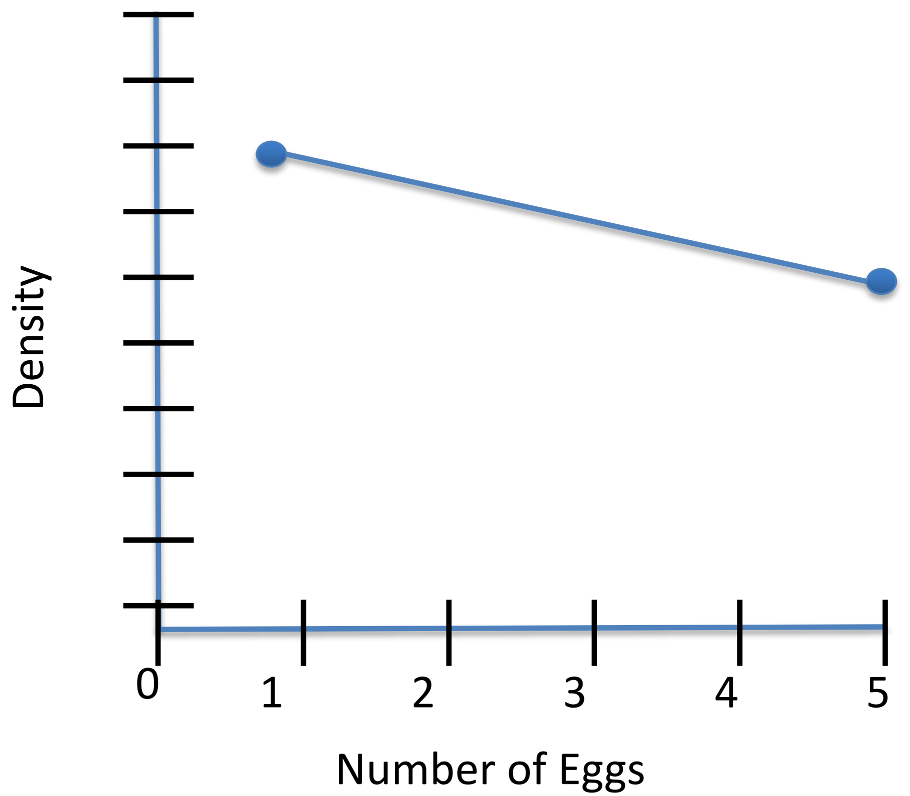
Factors = F

Levels = L

- Two Factors, Two Factor Levels
  - $2^2 = 4$ Runs
- Three Factors, Two Factor Levels
  - $2^3 = 8$ Runs
- Three Factors, Four Factor Levels
  - $4^3 = 64$ Runs

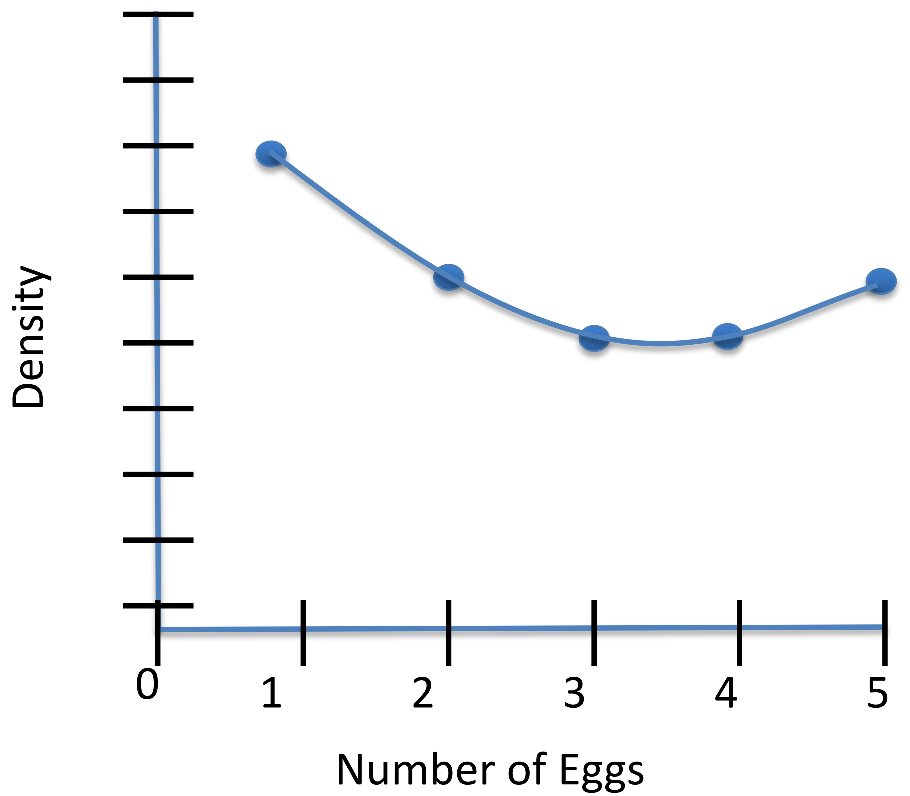
Types of Designed Experiments

- Experiments with factors varied at 2 levels measure the linear effects the factors have on a process



Types of Designed Experiments

- Experiments with factors varied at more than 2 levels measure the non-linear effects of the factors



Types of Designed Experiments

- Screening Experiments

  Full Factorial Experiment

  4 Factors, 2 Factor Levels, $2^4 = 16$ Runs

  ➢ 14 Factors, 2 Factor Levels, $2^{14} = 16{,}384$ Runs

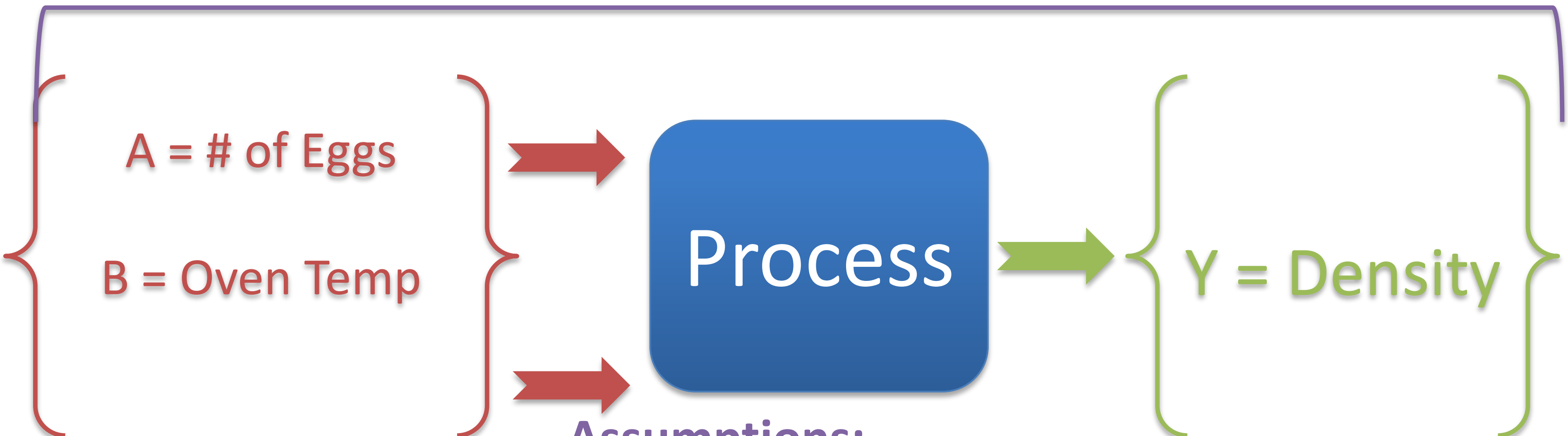
  Fractional Factorial Experiment

  4 Factors, 2 Factor Levels, $2^{(4-1)} = 2^3 = 8$ Runs OR

  4 Factors, 2 Factor Levels, $2^{(4-2)} = 2^2 = 4$ Runs

A Two Factor Design

Structure and Layout



Assumptions:

Altitude = 5204 ft

9 inch diameter cake pan

Measurement Standards for Density:

Density = Mass/Volume

Factor Levels

A_L = 1 Egg A_H = 3 Eggs

B_L = 325°F B_H = 375°F

A Two Factor Design

This 2 Factor Design at 2 Levels will be a 2^2 Factorial = 4 Runs

Combination	Level of A	Level of B	Response
1	Low	Low	Y_1
2	High	Low	Y_2
3	Low	High	Y_3
4	High	High	Y_4

Combination	Level of A	Level of B	Response
3	Low	High	Y_3
2	High	Low	Y_2
4	High	High	Y_4
1	Low	Low	Y_1

Question

If you were running this experiment, which one would you use?

Combination	Level of A (# of Eggs)	Level of B (Temp °F)	Density
1	1	325	Y_1
2	3	325	Y_2
3	1	375	Y_3
4	3	375	Y_4

Combination	Level of A (# of Eggs)	Level of B (Temp °F)	Density
3	1	375	Y_3
2	3	325	Y_2
4	3	375	Y_4
1	1	325	Y_1

A Two Factor Design

This 2 Factor Design at 2 Levels will be a 2^2 Factorial = 4 Runs

Combination	Level of A	Level of B	Response
1	Low	Low	Y_1
2	High	Low	Y_2
3	Low	High	Y_3
4	High	High	Y_4

Combination	Level of A (# of Eggs)	Level of B (Temp °F)	Density
1	1	325	Y_1
2	3	325	Y_2
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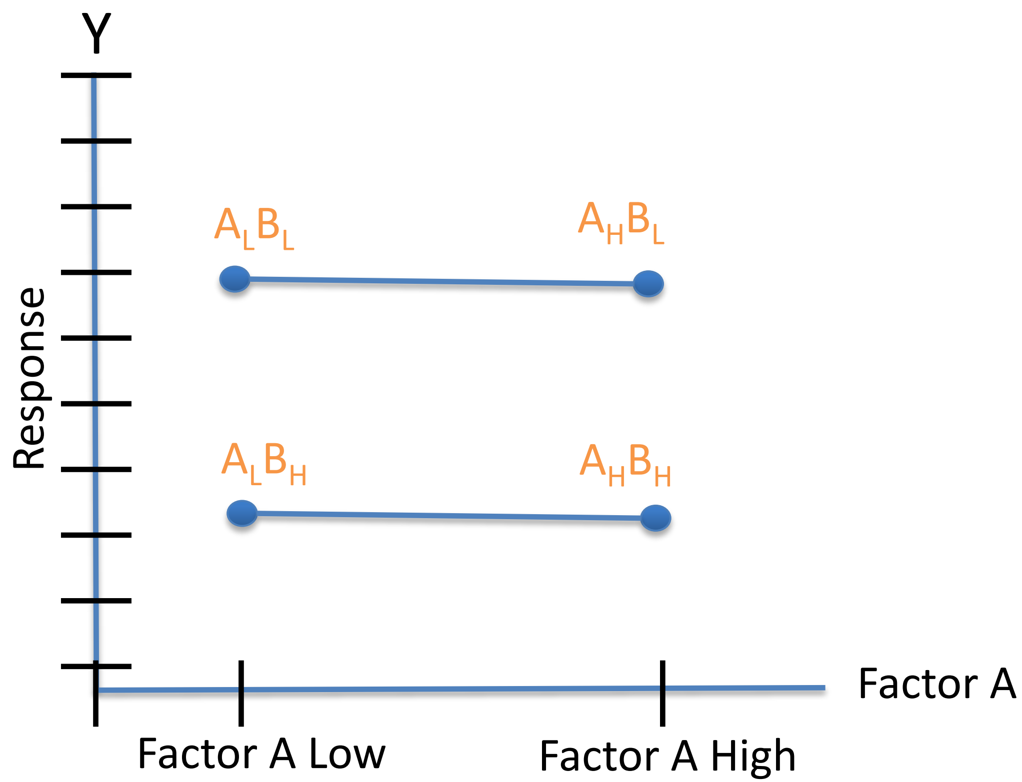
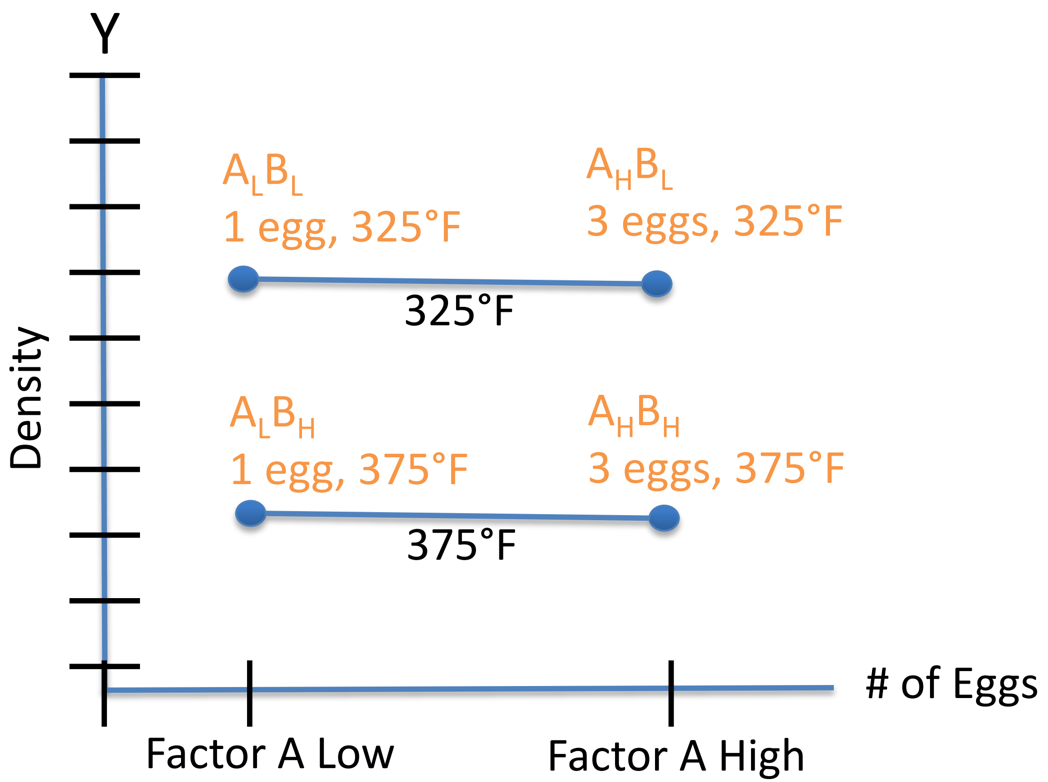
4	3	375	Y_4

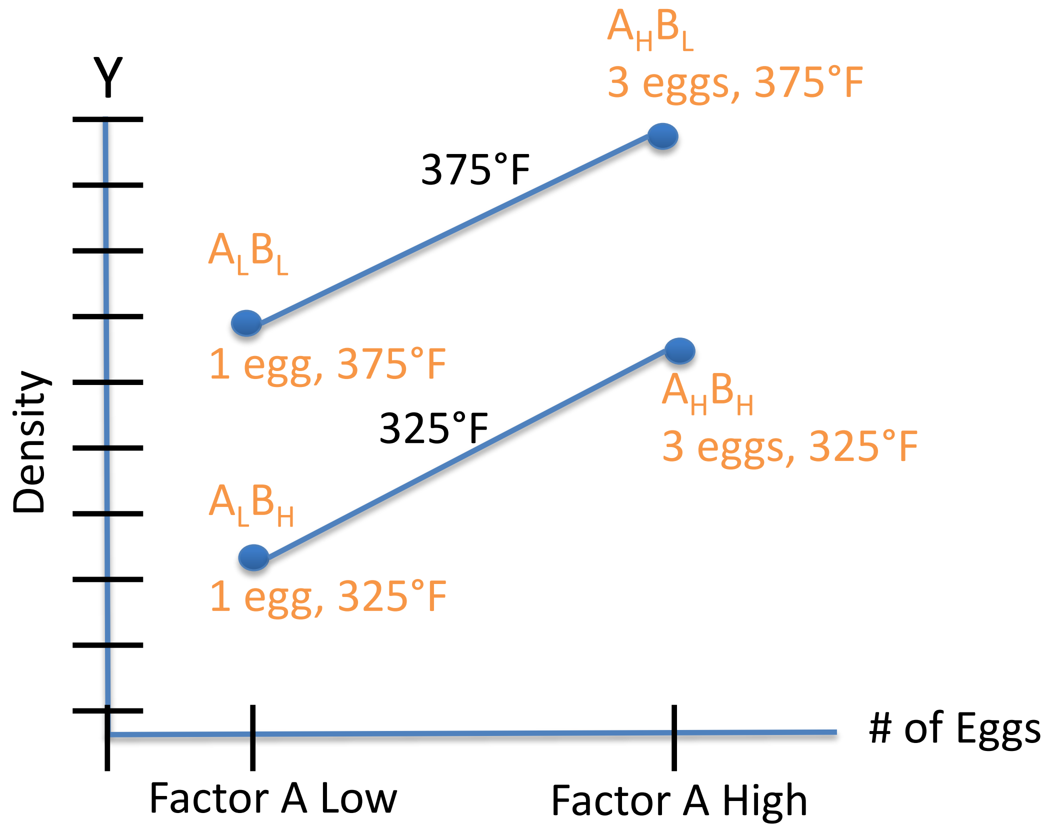
Effect Plots



Main Effects

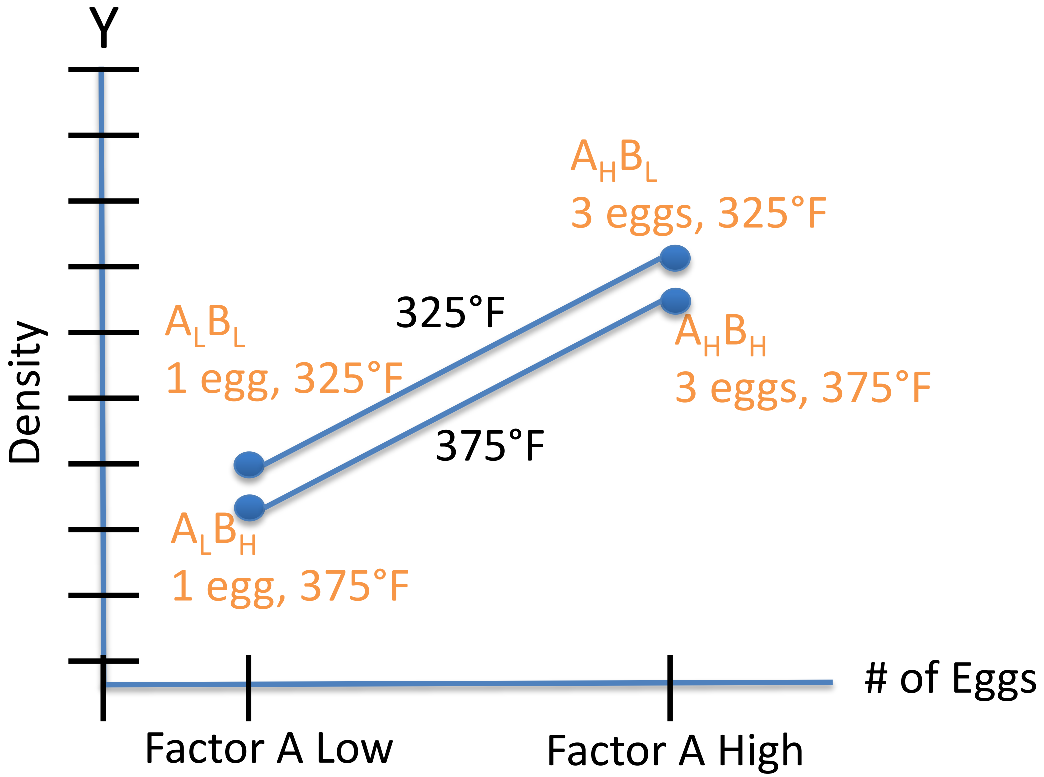


Question



Y
Density
$A_H B_L$
3 eggs, 375°F
375°F
$A_L B_L$
1 egg, 375°F
$A_H B_H$
3 eggs, 325°F
325°F
$A_L B_H$
1 egg, 325°F
# of Eggs
Factor A Low
Factor A High

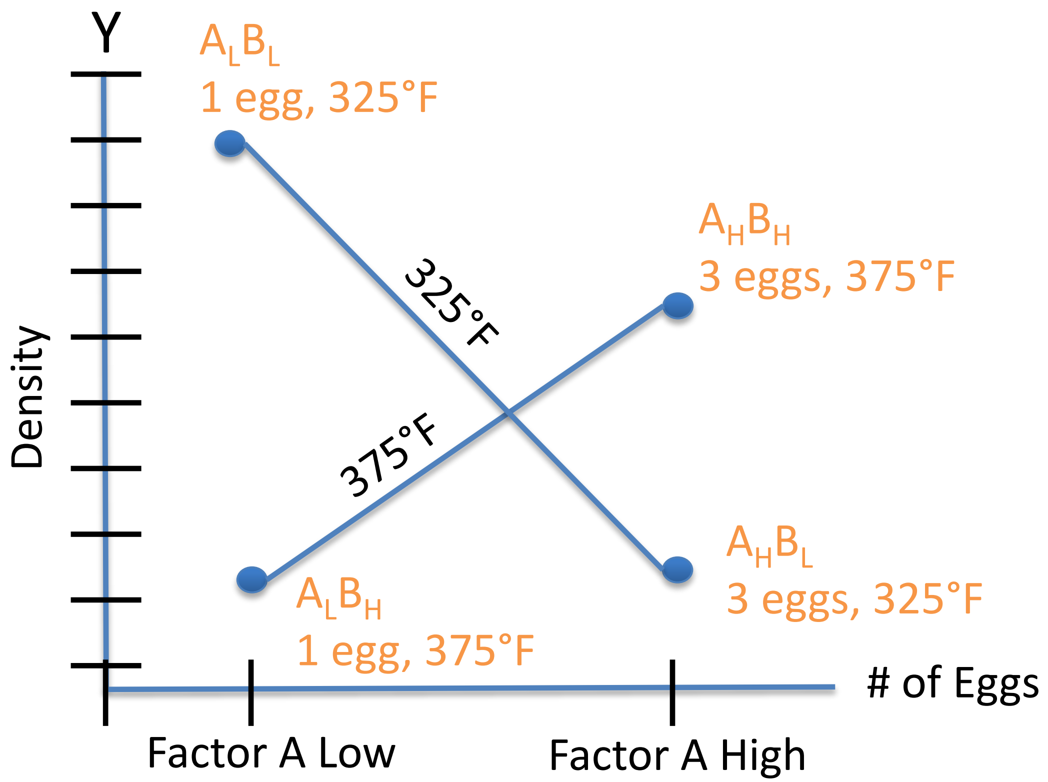
Another Question



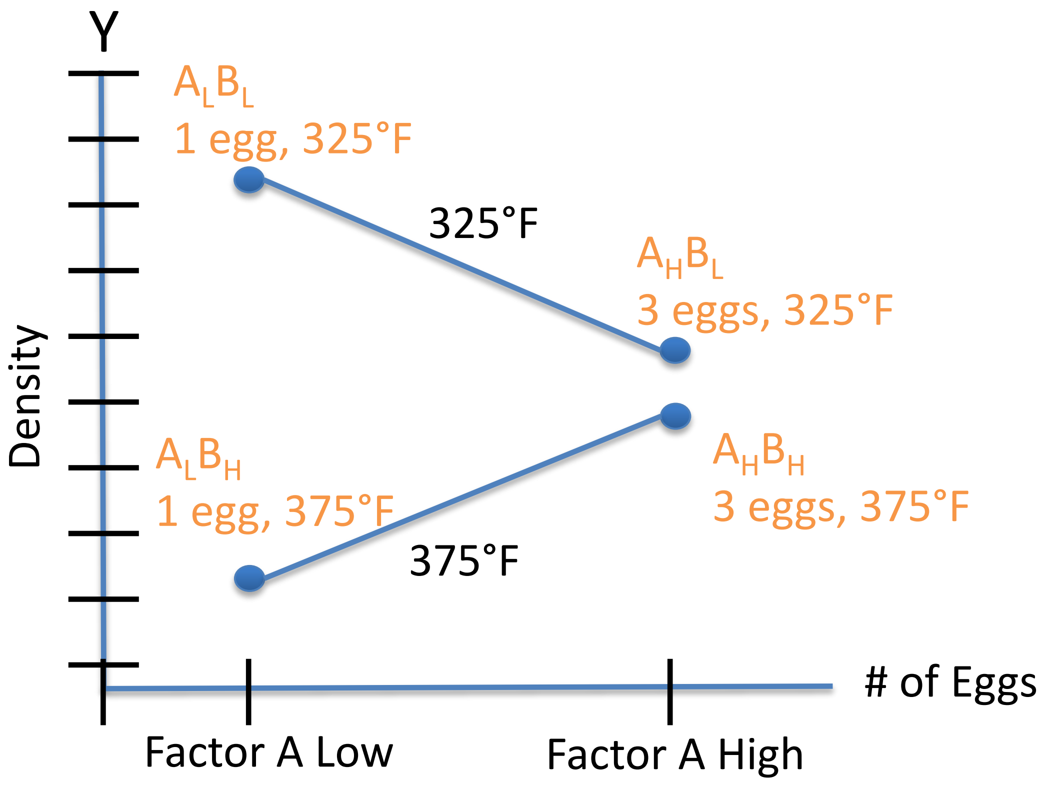
Interaction Effects

Which of following yields the densest cake?

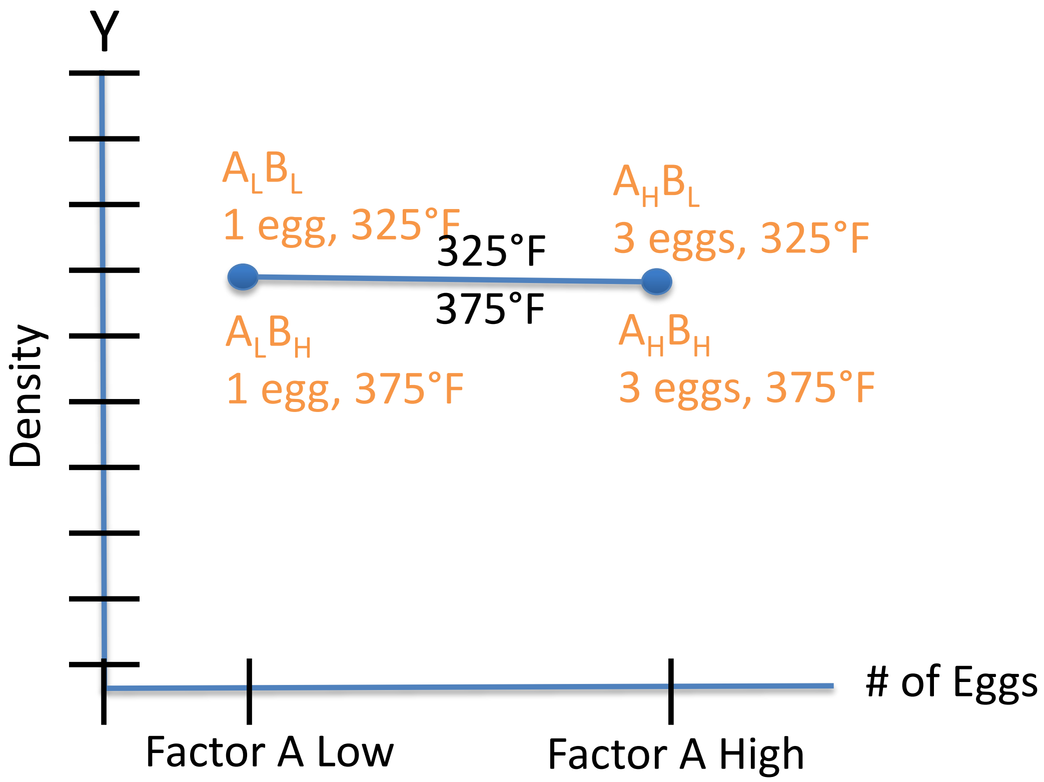
a. 1 egg and 375
b. 1 egg and 325
c. 3 eggs and 325
d. 3 eggs and 375



Interaction Effects



WHAT DOES THIS SHOW?



PDCA Cycle

Plan

- Define the Problem & Purpose
- Determine the Objectives
- Determine Factors to test
- Determine the Factor levels
- Pick the design
- Design the Experiment

Is an experiment really necessary?

Define Responses being tested & standards to test by

Consider Cost!

Define Runs and Conditions

Define assumptions

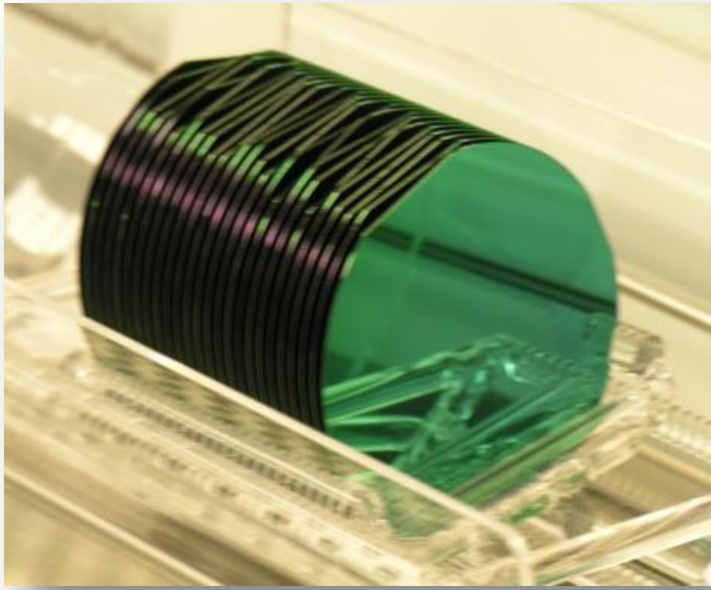
Plan

EXAMPLE – SiO_2 Deposition

Define Problem:
Characterize an Oxidation Process for the growth of a Silicon Dioxide layer on a Silicon Substrate on a NEW Oxidation Furnace.

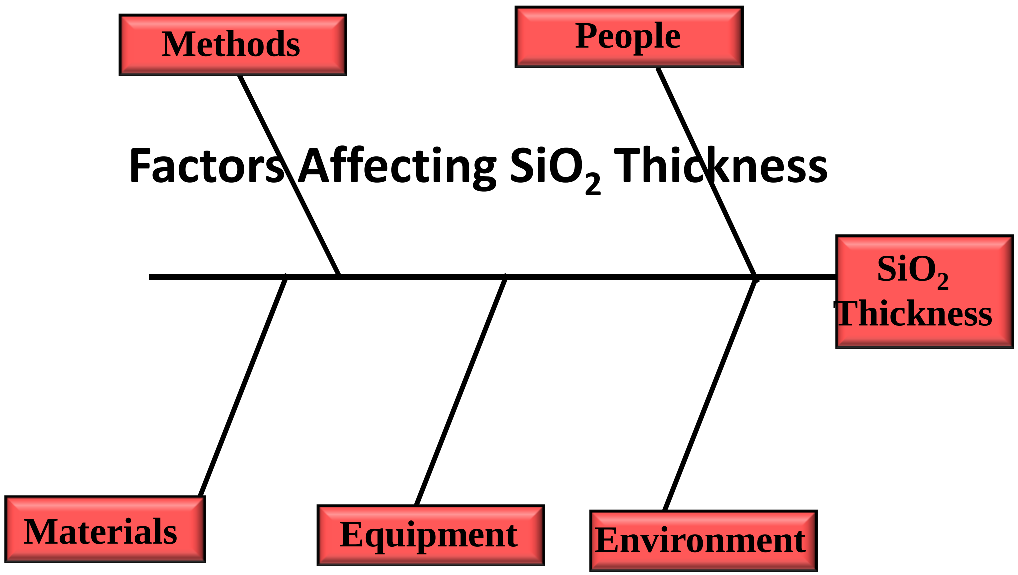
Objective:
Grow 1000 Angstroms of high quality SiO_2 on the wafer surface in a minimum amount of time.

Response:
Oxide Thickness



Plan

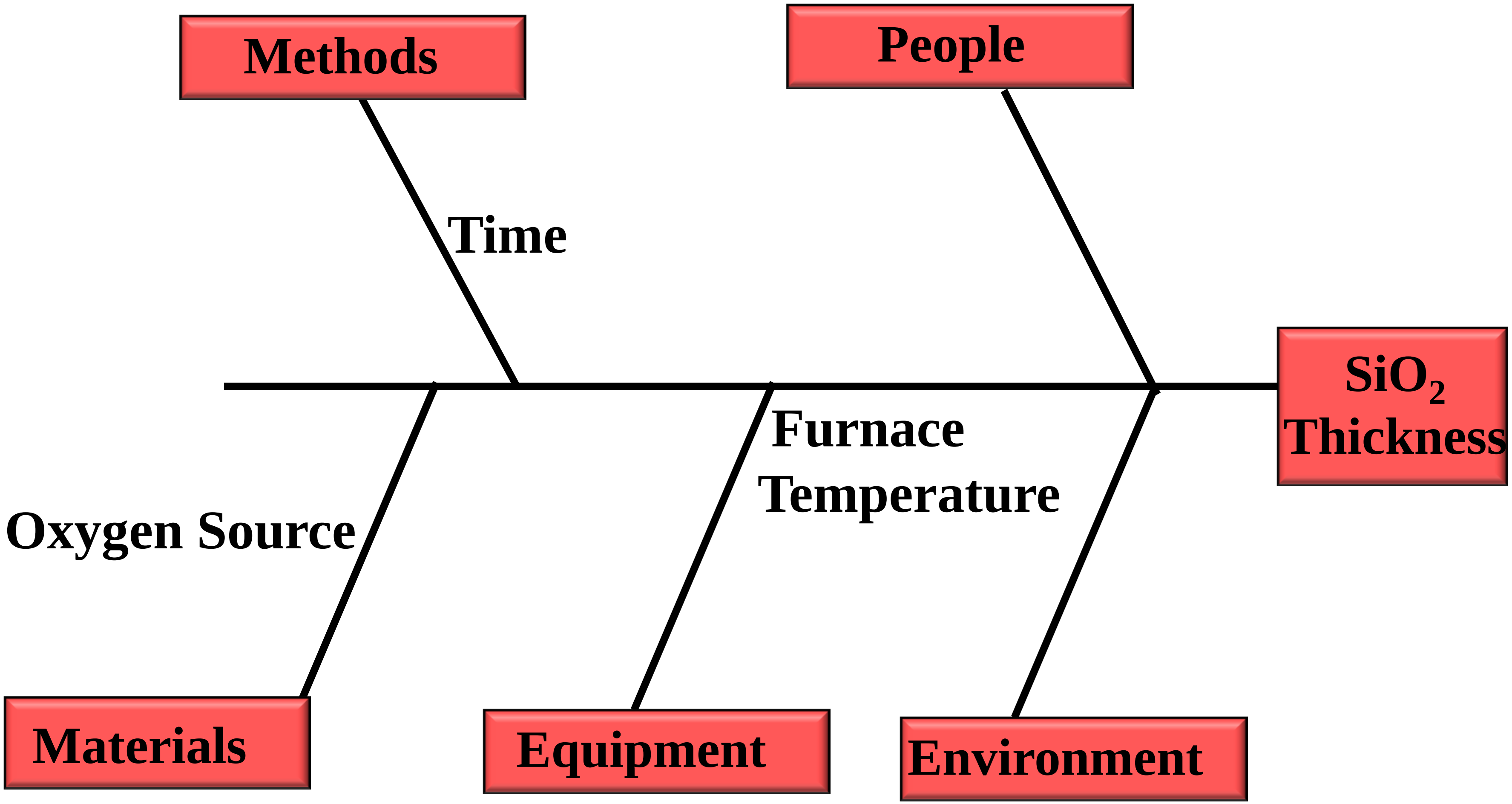
Brainstorm Factors

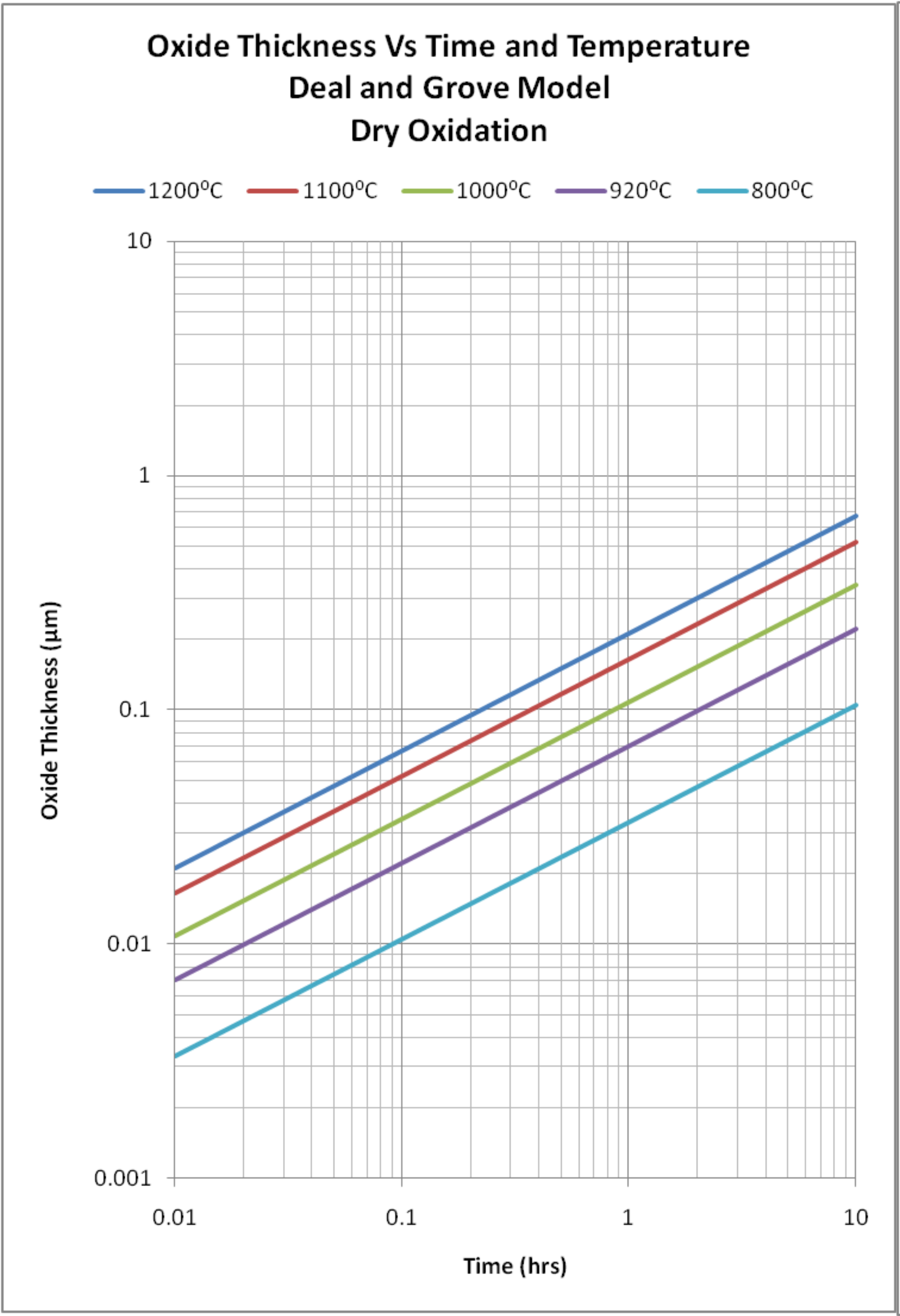


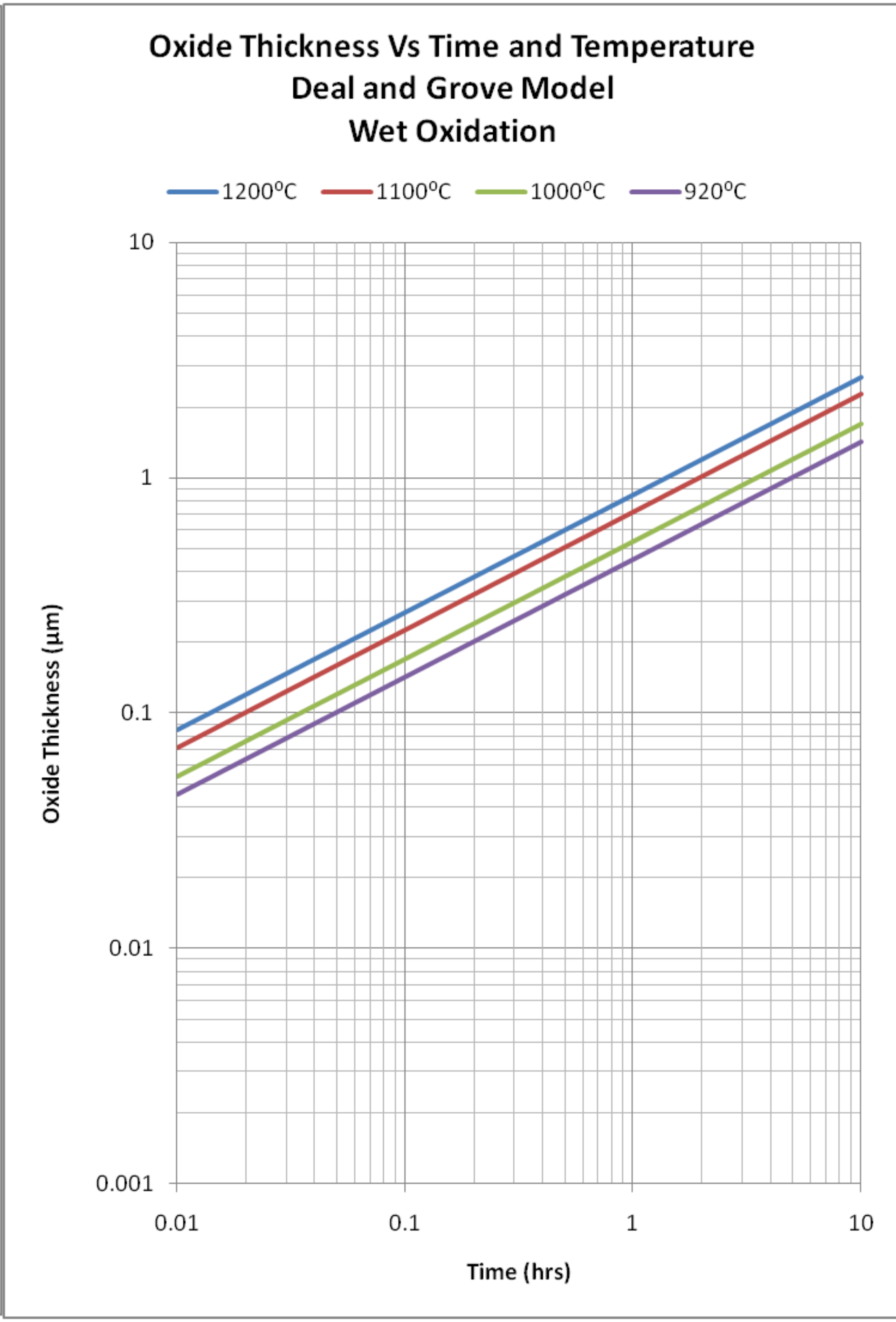
Plan

Brainstorm Factors

Factors Affecting SiO_2 Thickness




Oxide Thickness Vs Time and Temperature
Deal and Grove Model
Dry Oxidation
1200ºC
1100ºC
1000ºC
920ºC
800ºC
10
1
0.1
0.01
0.001
Oxide Thickness (µm)
0.01
0.1
1
10
Time (hrs)


Oxide Thickness Vs Time and Temperature
Deal and Grove Model
Wet Oxidation
1200ºC
1100ºC
1000ºC
920ºC
10
1
0.1
0.01
0.001
Oxide Thickness (µm)
0.01
0.1
1
10
Time (hrs)

Plan

Choose Factors & Levels

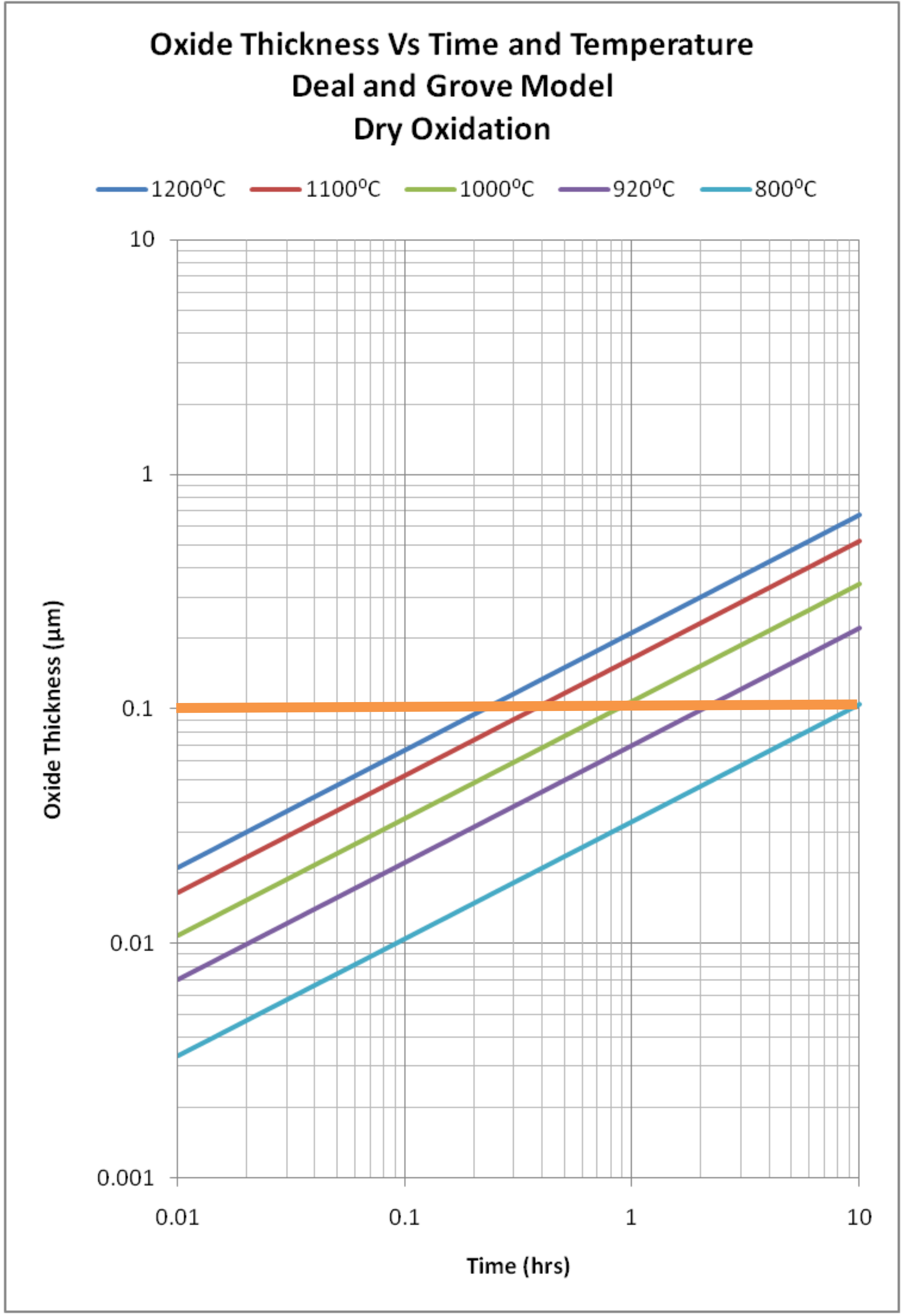
The Process: Dry Oxidation

Two Factors that affect SiO_2 Thickness:

1. Furnace Temperature
2. Time

Measurement Criteria:

- Quality of the oxide
- Oxidation rate
- Oxidation variation
  - Within a single wafer
  - Within a full run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10
1
0.1
0.01
0.001
Oxide Thickness (µm)
0.01
0.1
1
10
Time (hrs)

Plan

Choose Factors & Levels

Two Factors that affect SiO_2 Thickness:

1. Furnace Temperature
   - Low – 920 C
   - High – 1100 C
2. Time
   - Low – 0.3 Hour (18 minutes)
   - High – 2 Hours

Plan

Design Experiment

Full Factorial – Characterization Experiment

- Two Factors
- Two Levels
- $2^2 = 4$ Runs

Assumptions

- Dry Oxidation

Considerations

- Cost
- Time to run

Plan

Design Experiment

Option 1

Combo	Time (Hrs)	Temp (C)	Thickness (μm)
1	0.3	920	Y_1
2	2	920	Y_2
3	0.3	1100	Y_3
4	2	1100	Y_4

Option 2

Combo	Time (Hrs)	Temp (C)	Thickness (μm)
3	0.3	1100	Y_1
2	2	920	Y_2
4	2	1100	Y_3
1	0.3	920	Y_4

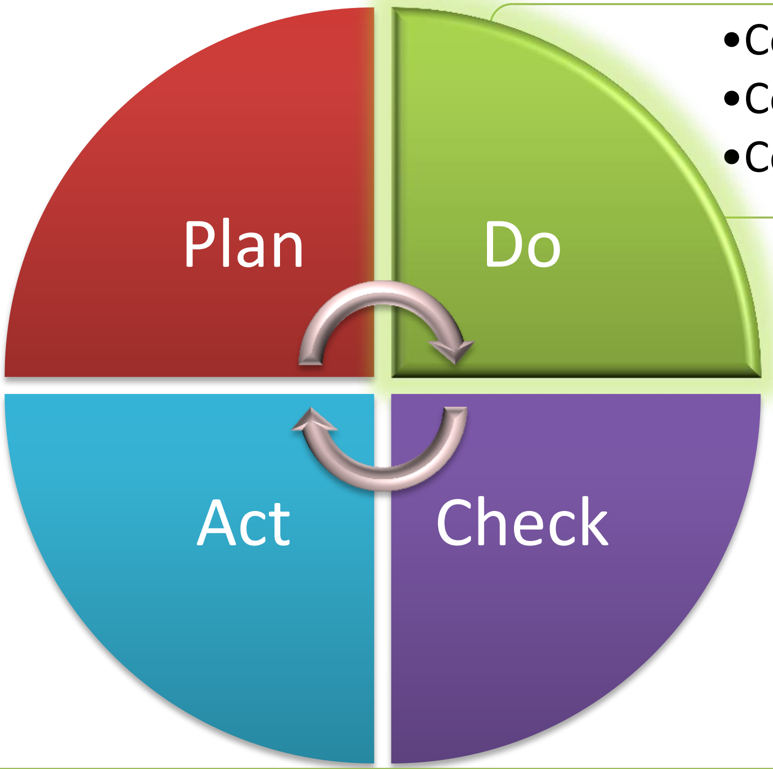
Option 3

Combo	Time (Hrs)	Temp (C)	Thickness (μm)
1	0.3	920	Y_1
3	0.3	1100	Y_3
2	2	920	Y_2
4	2	1100	Y_4

Option 4

Combo	Time (Hrs)	Temp (C)	Thickness (μm)
3	0.3	1100	Y_3
4	2	1100	Y_4
1	0.3	920	Y_1
2	2	920	Y_2

Do



- Conduct Experiment
- Collect Data
- Communicate!

How is it being monitored?
Data collection should be consistent.
Make sure equipment is calibrated.
Is a data backup necessary?
Is your experiment free from outside influence?

Conduct Experiment

Do

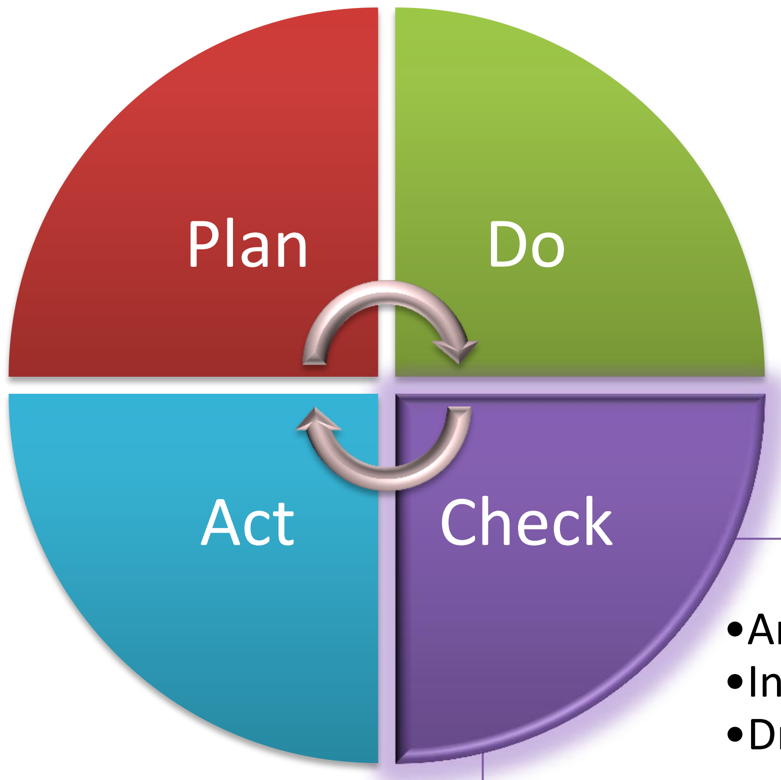
Run Plan

Combo	Time (Hrs)	Temp (C)	Thickness (µm)
1	0.3	920	Y_1
2	2	920	Y_2
3	0.3	1100	Y_3
4	2	1100	Y_4

Results

Combo	Time (Hrs)	Temp (C)	Thickness (µm)
1	0.3	920	**0.025**
2	2	920	**0.065**
3	0.3	1100	**0.08**
4	2	1100	**0.180**

Check



- Analyze Data
- Interpret Results
- Draw Conclusions

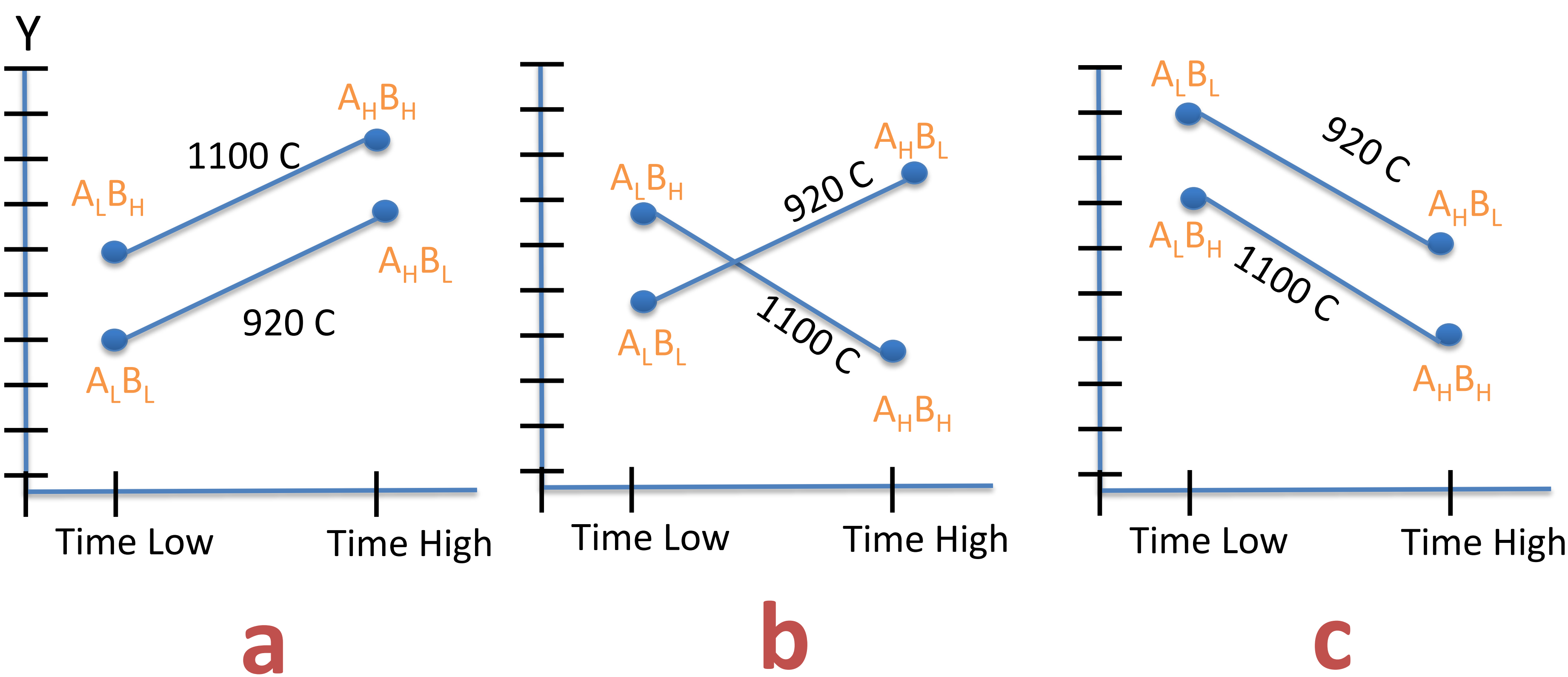
Computer Analysis is usually done for in depth interpretation
Include problems or unexpected occurrences in your study
Communication is KEY!! Talk to members of your team!

Check

Analyze Data

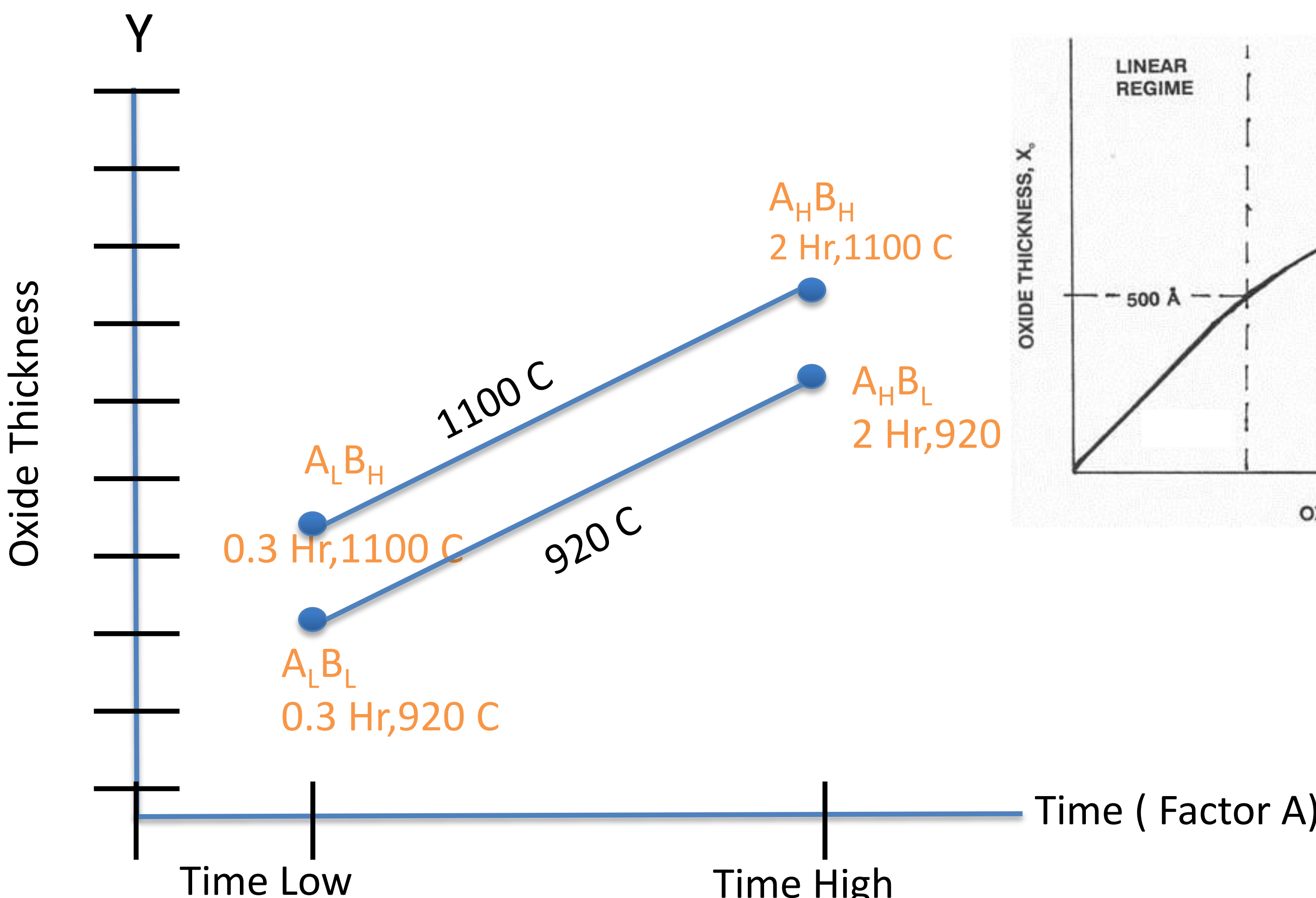
A = Time

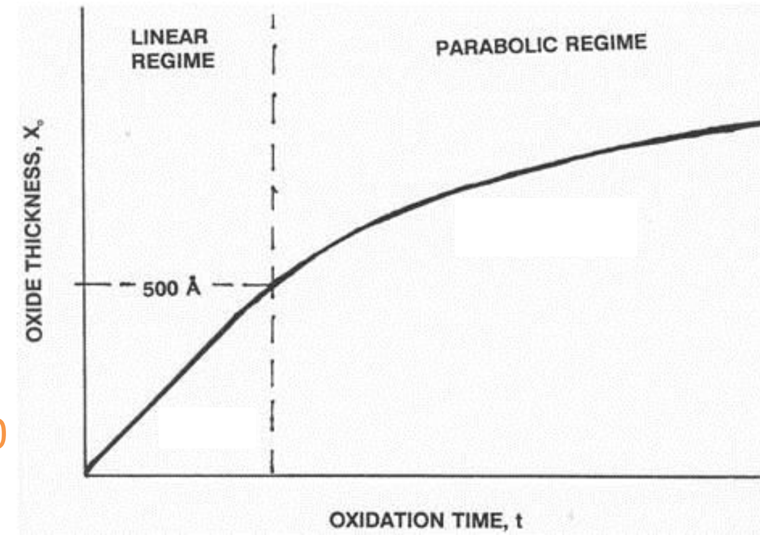
B = Temperature



Check

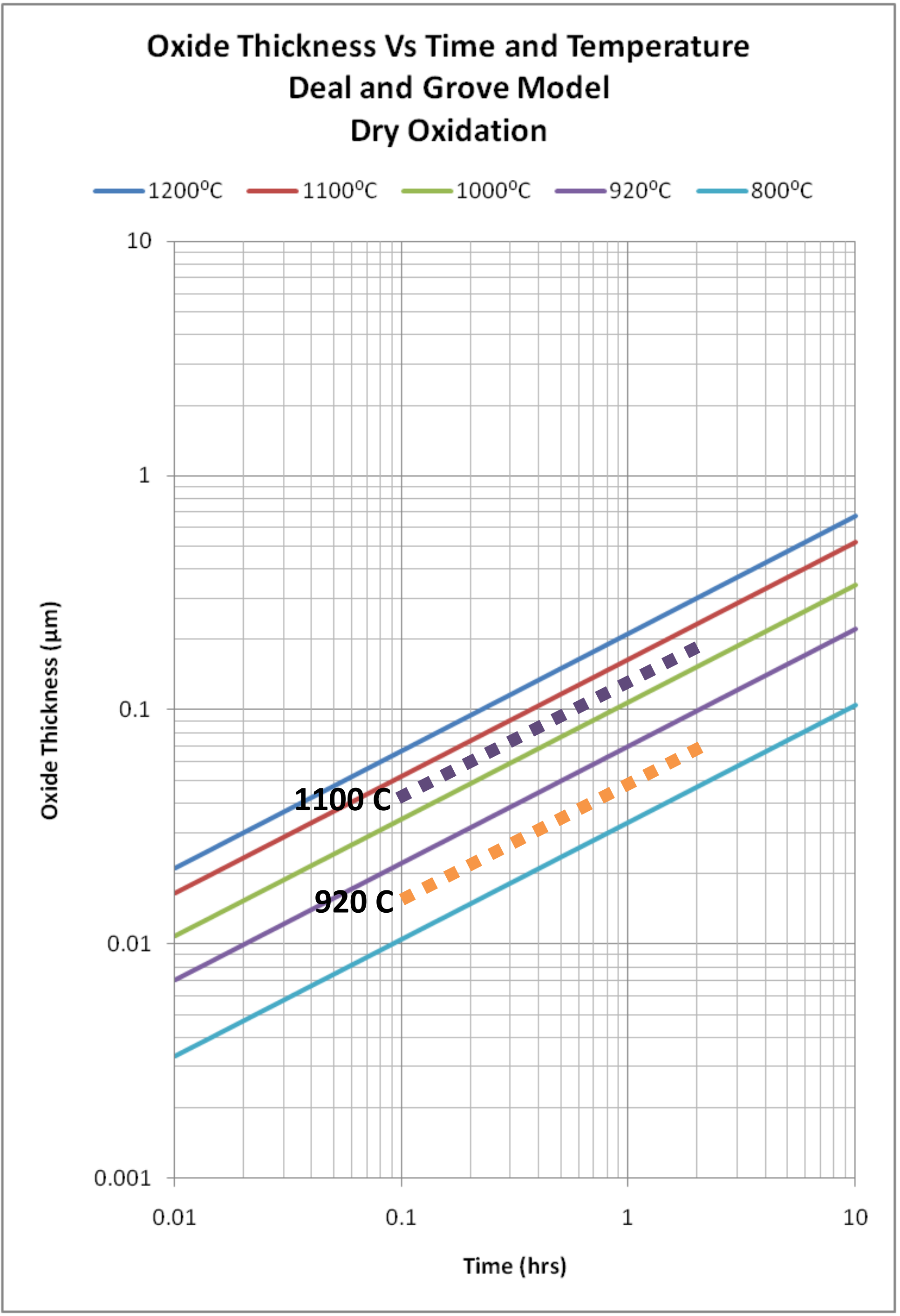
Analyze Data





a

Check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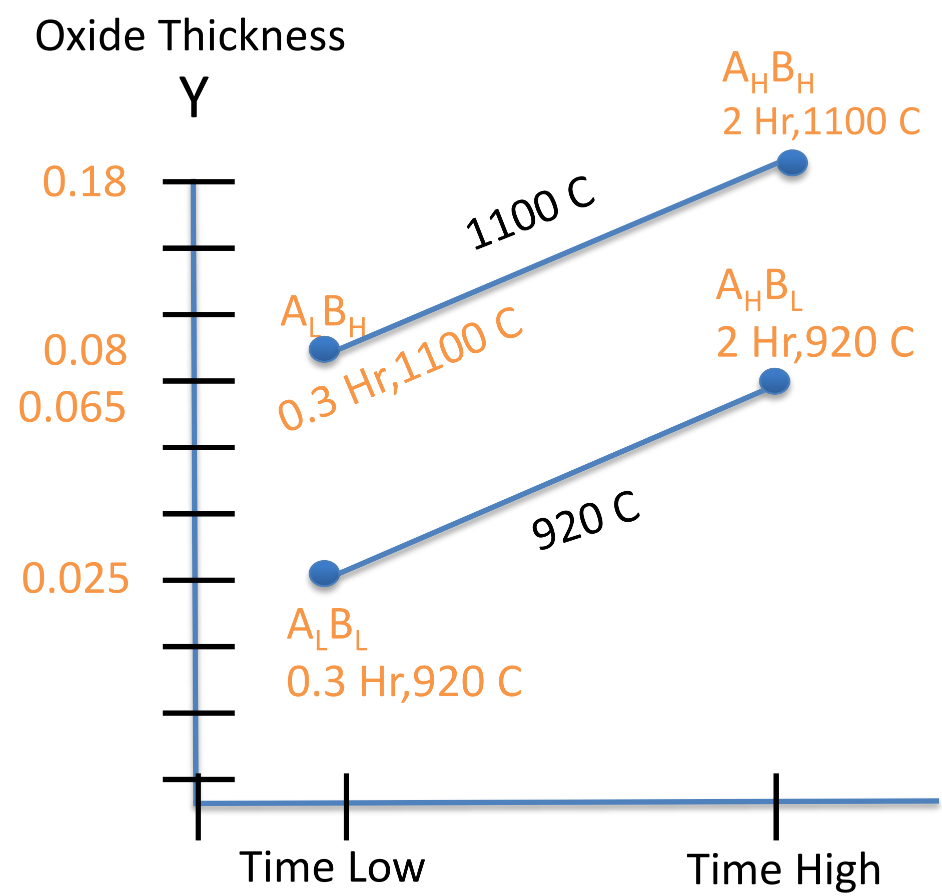
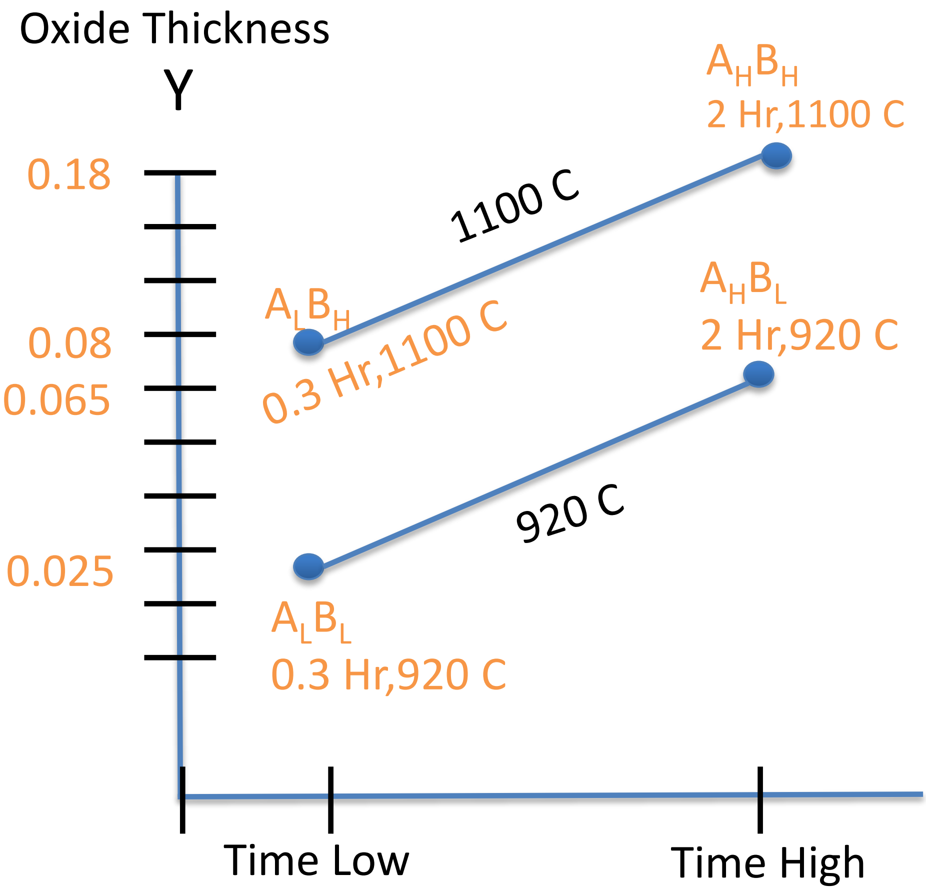
Oxide Thickness (µm)
10
1
0.1
0.01
0.001
0.01
0.1
1
10
Time (hrs)
1100 C
920 C


Oxide Thickness
Y
0.18
0.08
0.065
0.025
A_HB_H
2 Hr,1100 C
1100 C
A_LB_H
0.3 Hr,1100 C
A_HB_L
2 Hr,920 C
920 C
A_LB_L
0.3 Hr,920 C
Time Low
Time High

Check

Draw Conclusions

Combo	Time (Hrs)	Temp (C)	Thickness (µm)
1	0.3	920	**0.025**
2	2	920	**0.065**
3	0.3	1100	**0.08**
4	2	1100	**0.180**



Check

Draw Conclusions

Combo	Time (Hrs)	Temp (C)	Thickness (μm)
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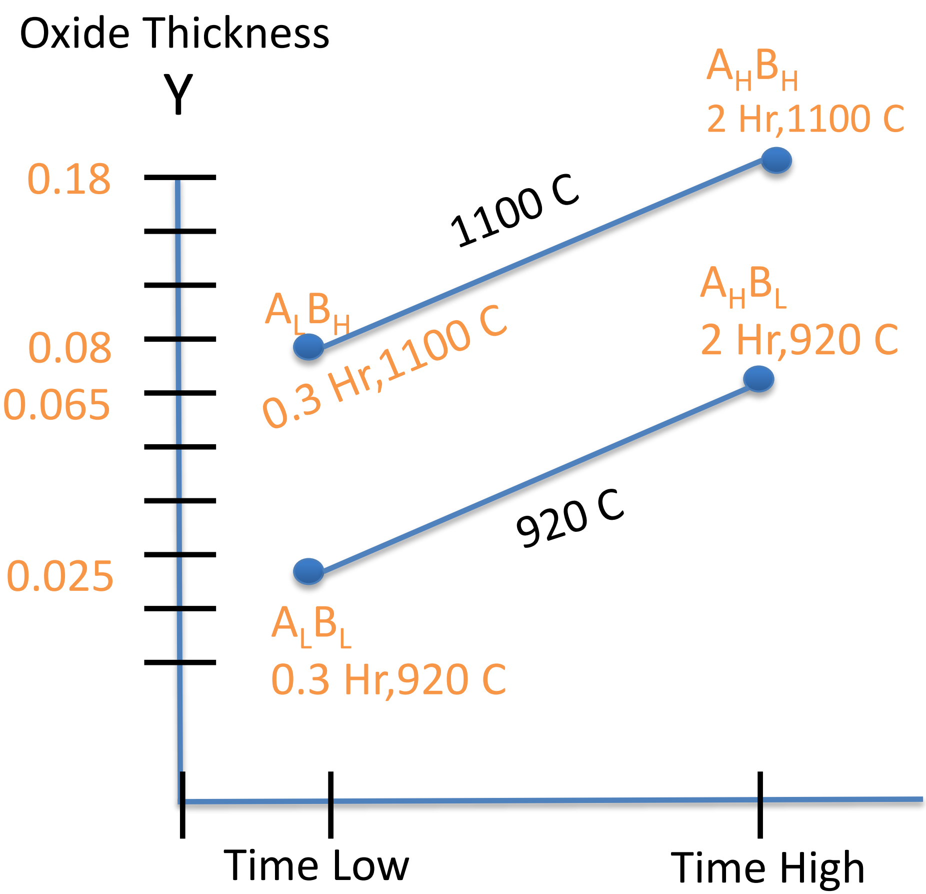
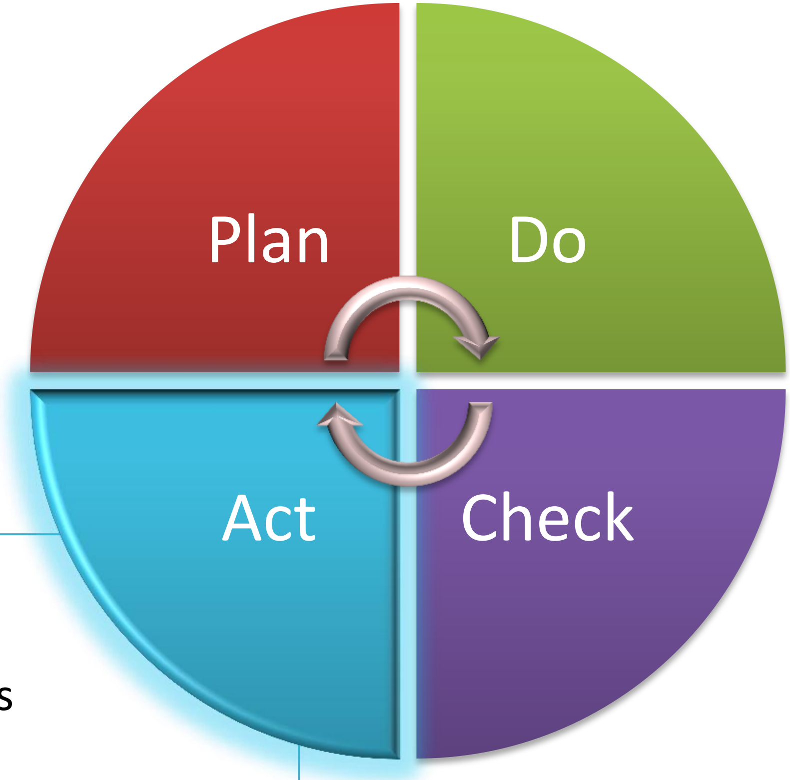


Number of Runs = L^F

Factors = F

Levels = L

Act



- Verify the results
- Communicate Results

New factor levels may be required
New experiments may need to be run
Results may lead to changes in the process or training of personnel

Act

- Examine the SiO_2 Quality of all of the experimental runs
- Design a NEW experiment based upon the quality exam
- Fine Tune the Levels of the two factors
  - 2 Factors
  - 3 Levels for Temperature and Time
  - # of Runs = L^F
  - What will the Number of Runs be?

Thank You
For Joining Us

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Webinar Resources

To access this webinar recording, slides, and handout, please visit

www.scme-nm.org

SCME Upcoming Webinars

SCME
Southwest Center for Microsystems Education

March 28, 2013: Problem-solving Tools Applied to Microfabrication

NOTE: To see previously recorded webinars, visit scme-nm.org.

All Webinars on Thursday @ 1 PM ET

It was Fun!

Thank you for attending this SCME Webinar

Design of Experiments for Technicians