The Use of Designed Experiments in Process Development

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What is a Designed Experiment?

- In an experiment, we deliberately change one or more process variables (or factors) in order to observe the effect the changes have on one or more response variables. The (statistical) design of experiments (*DOE*) is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions.
  - Change Process Variables ➡ **Effect** on Response
  - Statistical Validity, signal-to-noise testing
  - Valid and Objective Conclusions
- Statistical Analysis Software
- Constraints
  - To randomize or not
  - What's manageable
  - How much does it COST???
  - How much material do I have available?

Pareto Diagrams

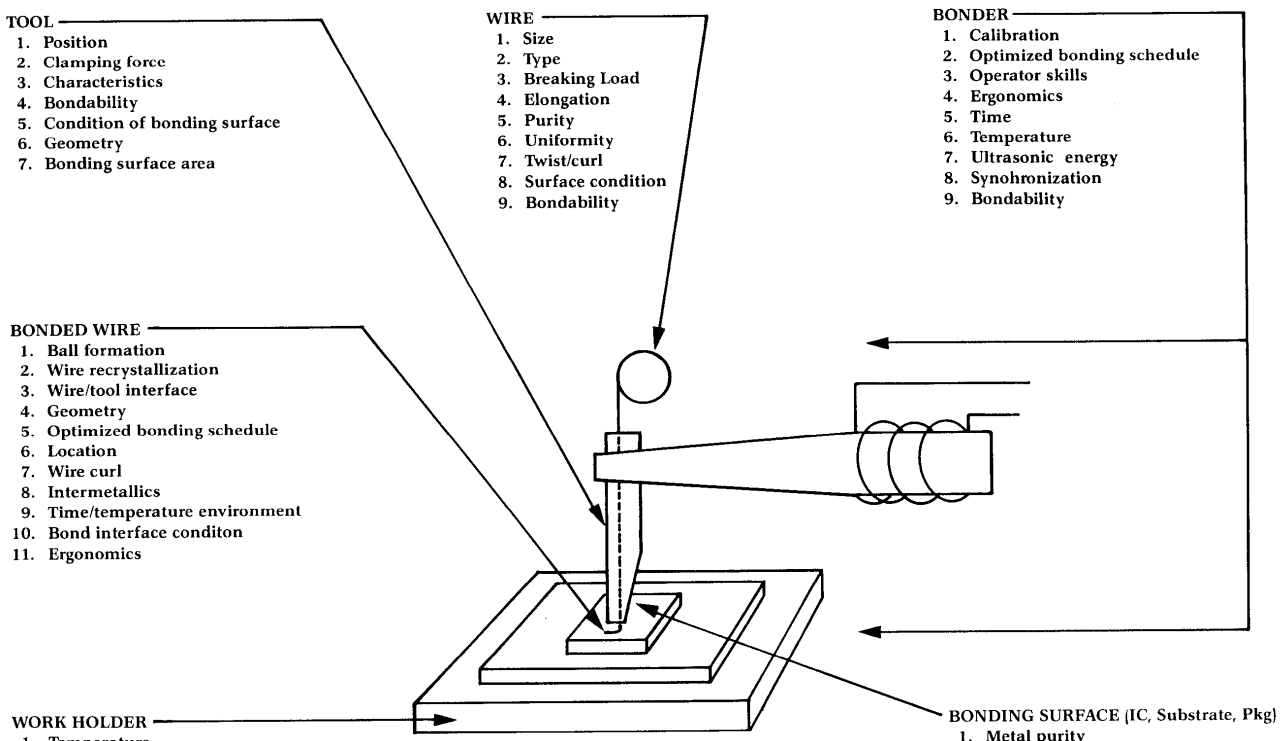
- Break the problem up into smaller components (PARETO)
- Analyze the Pareto data
- Find the MOST SIGNIFICANT DEFECTS
  - Most numerous
  - Most costly
  - Most dangerous- long-term reliability
- What is breaking and where is it breaking?
- Focus on what is most important
- What is EASIEST to fix?

Design of Experiments

- The best way to study a complicated process while you are waiting for INSPIRATION!!!

- Do designed experiments to understand the Process
- How do the process programmable parameters really effect the results
- Statistical significance and validity
  - Signal to Noise (F-test), More data can resolve smaller differences
  - Noisy data means that you can't resolve small signals
  - Is it real or just noisy data?
- Learn and Use the software that you have

50 Bonding Variables



(Figure 4)

50 BONDING VARIABLES

There are a number of variables that occur in either wedge or ball bonding. These are assembled for easy reference. (24)

Is this all of them…

Not even close!!!

- Complex processes often have HUNDREDS of possible variables
- What are the major process variables
- What is failing
- Pareto analysis of the defectives
- Focus on the biggest problem or easiest to solve?

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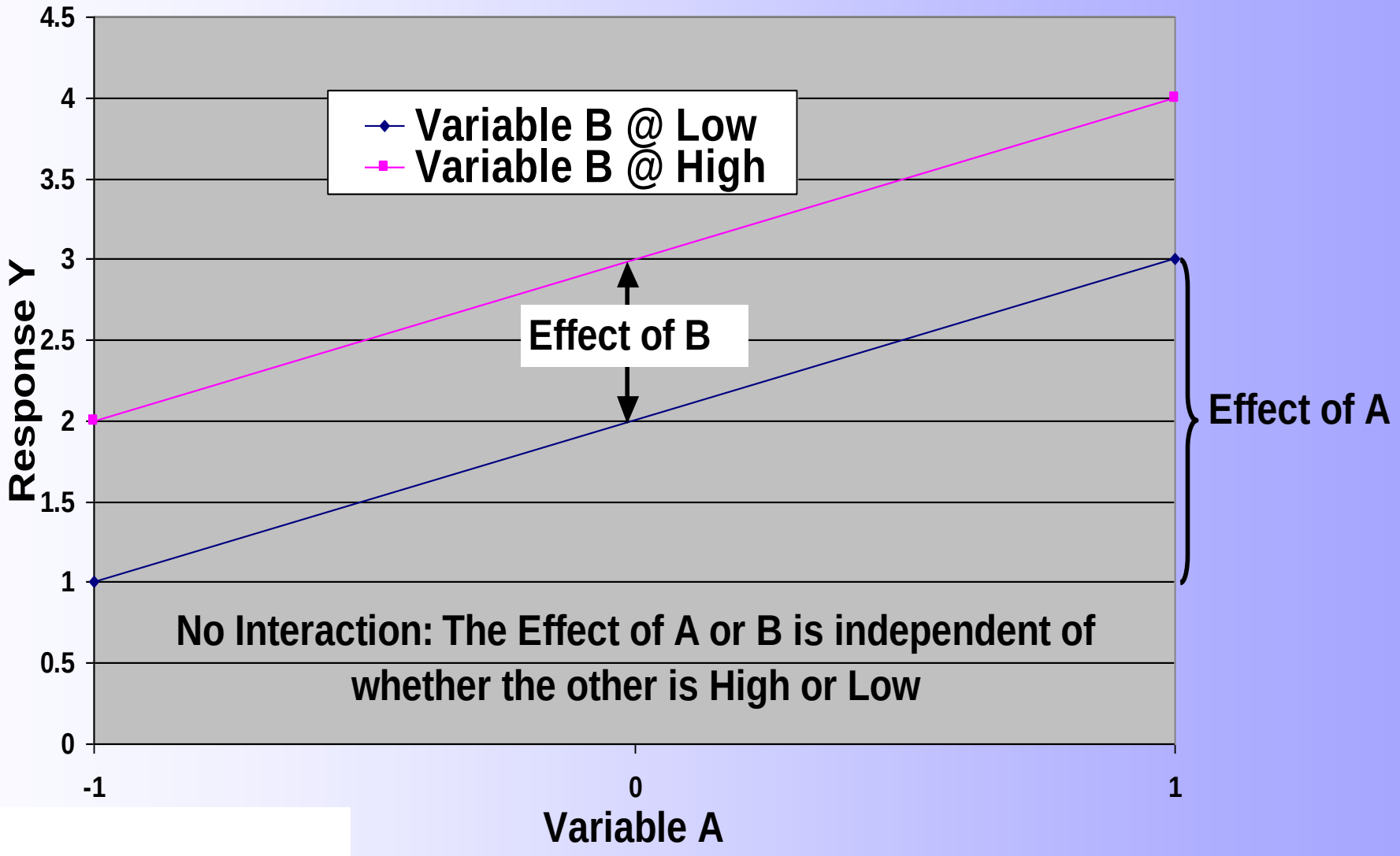
What's an Effect?



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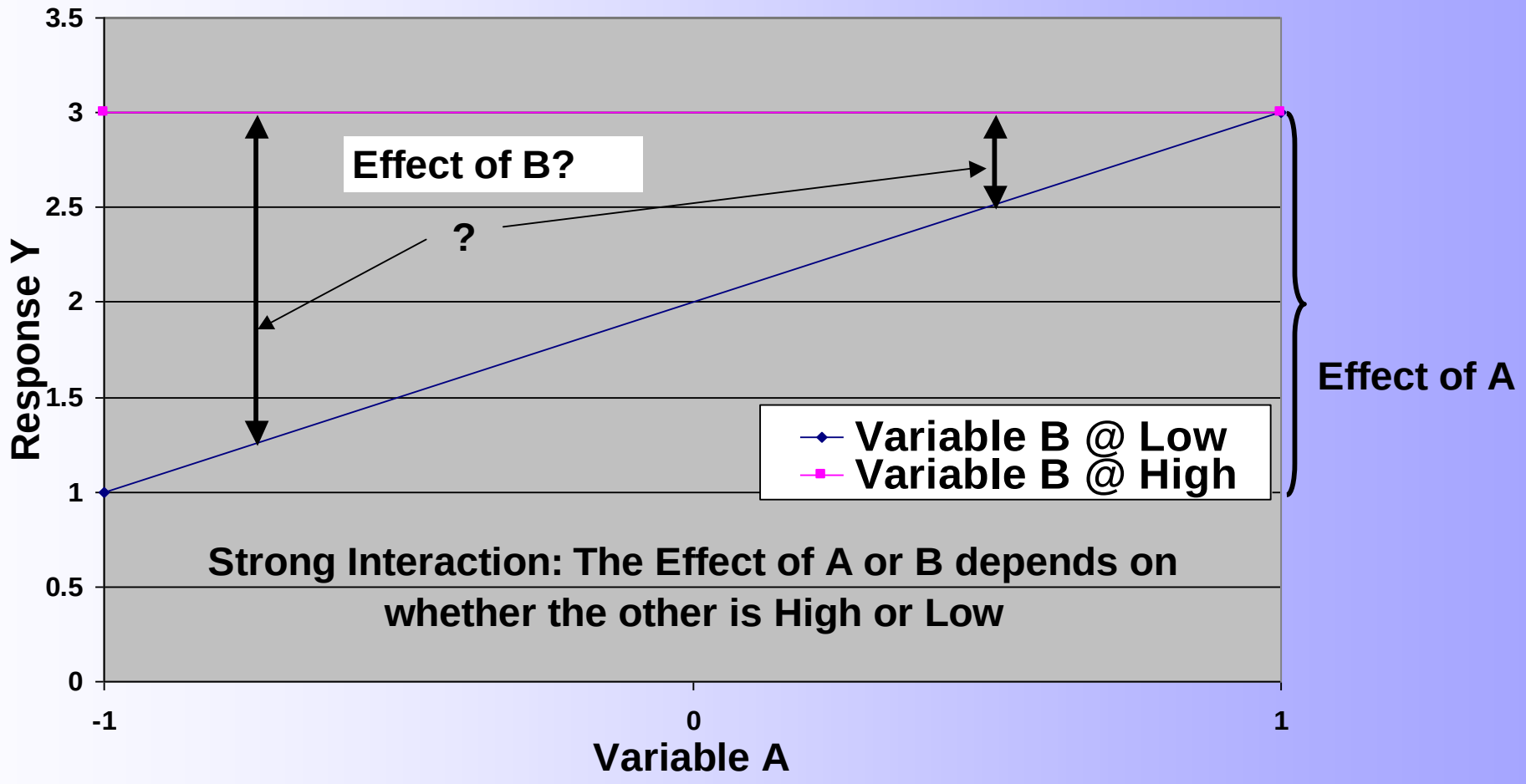
Whats an Interaction?



One of the important benefits of DOE is that we not only learn the effects and interactions, but also get a statistical validity? Are they real or just random variations in the data?

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Accuracy vs Repeatability

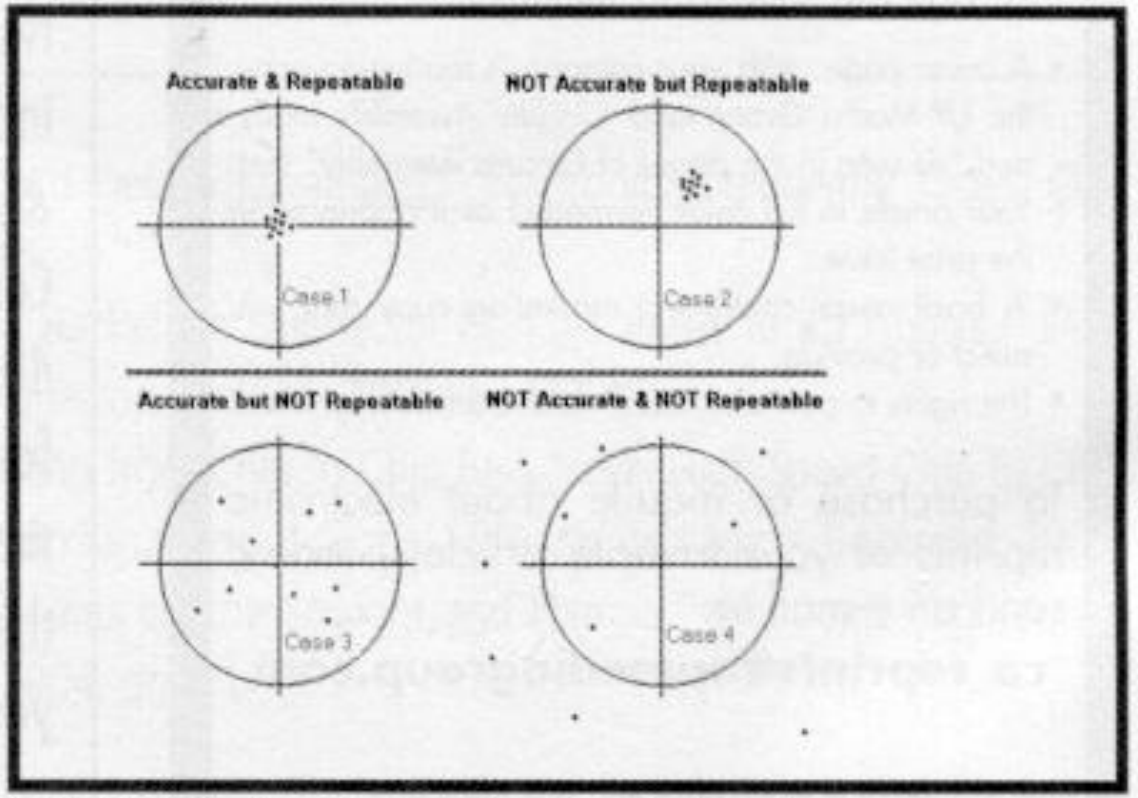
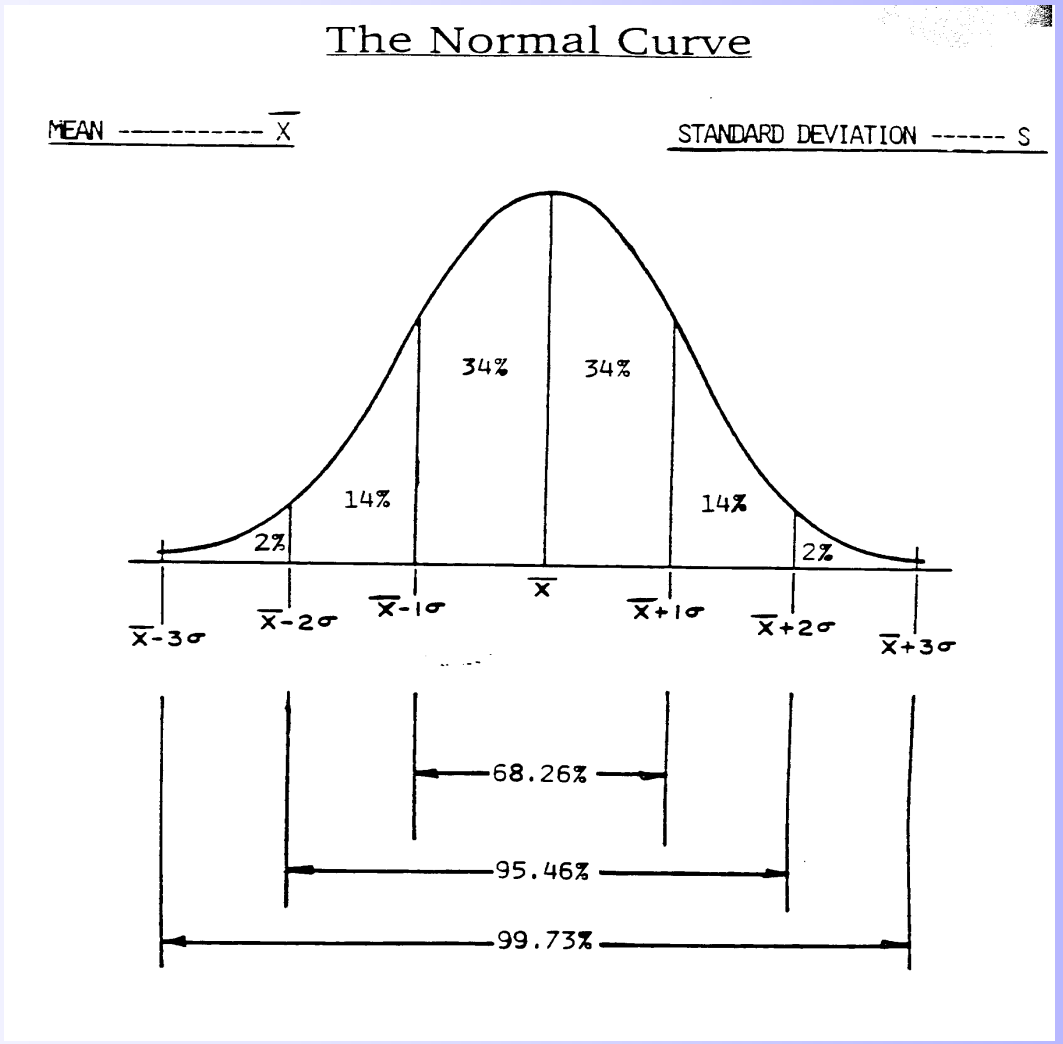


FIGURE 1: Small standard deviation does not guarantee accuracy. Case 1 shows a repeatable machine, Case 2 a repeatable machine that is not very accurate.

A Histogram Describes the Variation of Normal Data



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$$Cp = \frac{(USL - LSL)}{6\sigma}$$

= Design Variation

Process Variation

$$Cpk_{Upper} = \frac{(USL - \overline{X})}{3\sigma}$$

$$Cpk_{Lower} = \frac{(\overline{X} - LSL)}{3\sigma}$$

$$Cpk = Smaller\ of\ Cpk_{Upper}\ and\ Cpk_{Lower}$$

Screening Vs. Response Surface

- SCREENING:
  - Sift out of many control variables the critical few
  - Less cells, less time, less cost, assumes planar response (linear)
  - No interactions
- RESPONSE SURFACE:
  - Obtain map of process that accurately predicts
  - Includes quadratic and interaction terms of the model

Benefits of using Response Surface Experimental Design

- Most information in fewest trials
- Pictorial & numerical understanding
- “What if …?” questions answered (predictions)
- Optimization is easy
- Interactions accounted for

Recommended Designs

- Taguchi for Screening (L-9 + center)
- LINEAR WITH CENTER POINT (screening)
- QUADRATIC (response surfaces)

Other Designs

- Factorial
- Fractional Factorial
- Taguchi
- Central Composite
- …..

- There are Pros and Cons to All of Them

Taguchi L-9 + Center Point

	A	B	C	D
Taguchi	-1	-1	-1	-1
	-1	0	0	0
	-1	1	1	1
	0	-1	0	1
	0	0	1	-1
	0	1	-1	0
	1	-1	1	0
	1	0	-1	1
	1	1	0	-1
CP	0	0	0	0

- Benefits
  - Small # cells
  - 3 Levels
  - Center Point
- Disadvantages
  - Regression
  - No Interactions
  - Highly Saturated

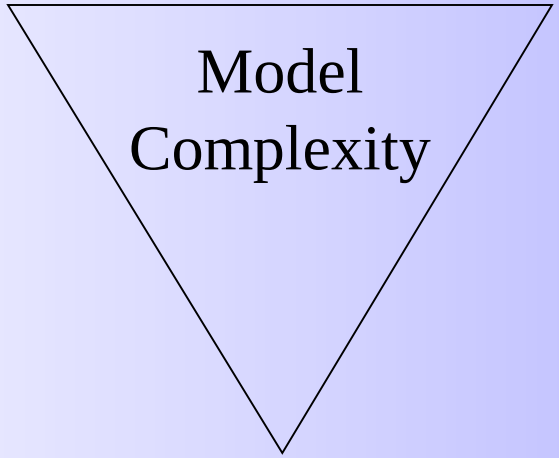
Fractional Factorial w Center Points

	A	B	C	D	E
Factorial	-1	-1	-1	-1	1
	1	-1	-1	-1	-1
	-1	1	-1	-1	-1
	1	1	-1	-1	1
	-1	-1	1	-1	-1
	1	-1	1	-1	1
	-1	1	1	-1	1
	1	1	1	-1	-1
	-1	-1	-1	1	-1
	1	-1	-1	1	1
	-1	1	-1	1	1
	1	1	-1	1	-1
	-1	-1	1	1	1
	1	-1	1	1	-1
	-1	1	1	1	-1
	1	1	1	1	1
Center	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0

- Advantages
  - Interactions
  - Centerpoints
- Disadvantages
  - Not as efficient as ECHIP
  - Regression or special S/W
- Should be randomized

What size sample is best?

Sample Variation
(Standard Deviation)



Least Significant
Difference

Number of Samples

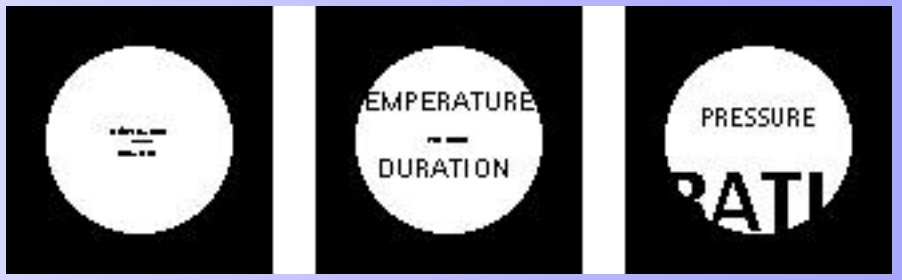
What is the cost/sample?

How many are available?

RESOLVING POWER - tradeoff desired resolution and number of trials needed

RESOLVING POWER

30X 100X 300X



More trials: More magnification

Smaller *effects* can be "seen"

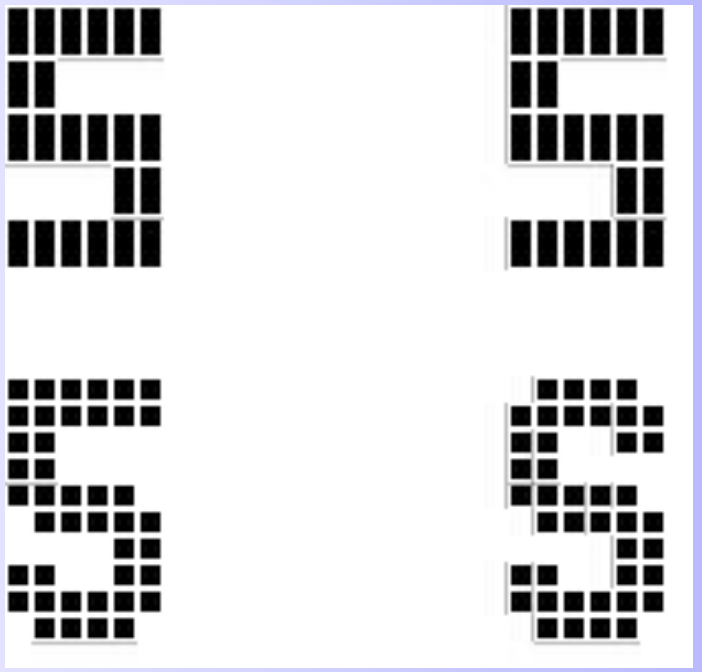
30 observations are not always enough to see what we want!

RESOLUTION: Smallest detectable effect

e.g. FAX machines transmit in regular and fine modes. Compare the characters "**5**" & "**S**"

Regular

Fine



More data = better resolution

The ability to see smaller effects

The resolution equals the dot size.

What Do You Do If You Have Lack-Of-Fit?

Try a data transformation

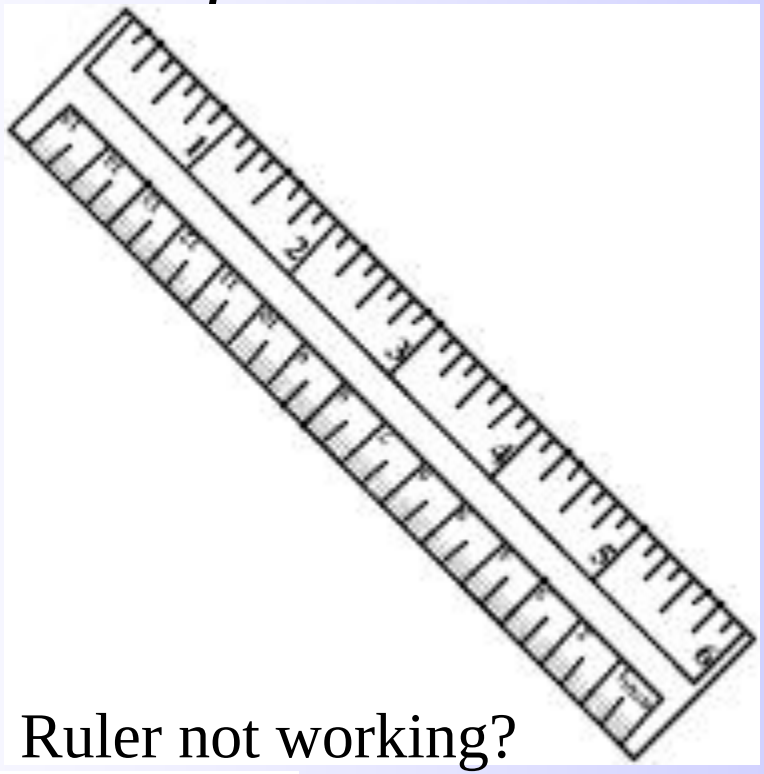
Try a more complex model

These remedies assume your lack-of-fit is not due to one or more “bad data” points in your set of observations.

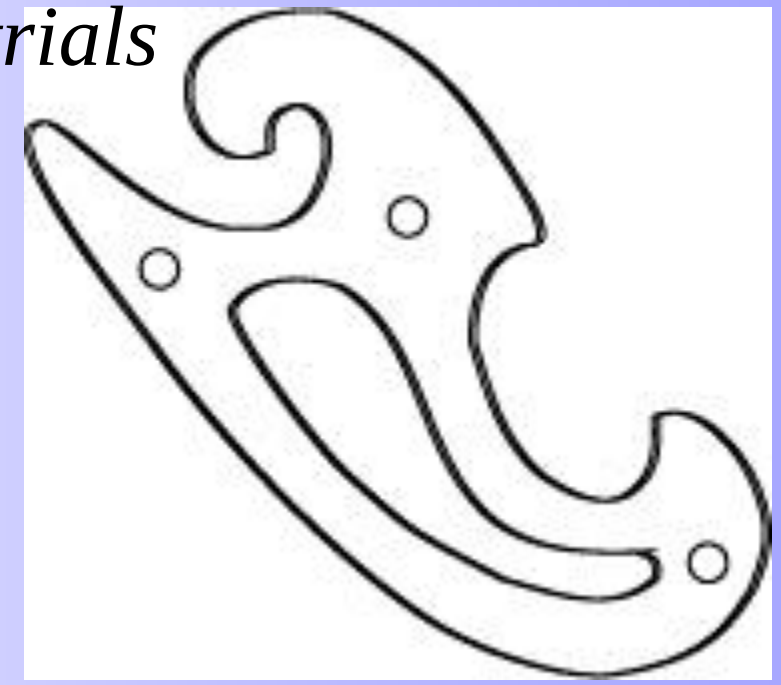
Remedies for Lack-Of-Fit

More complex model

Requires additional trials



Ruler not working?

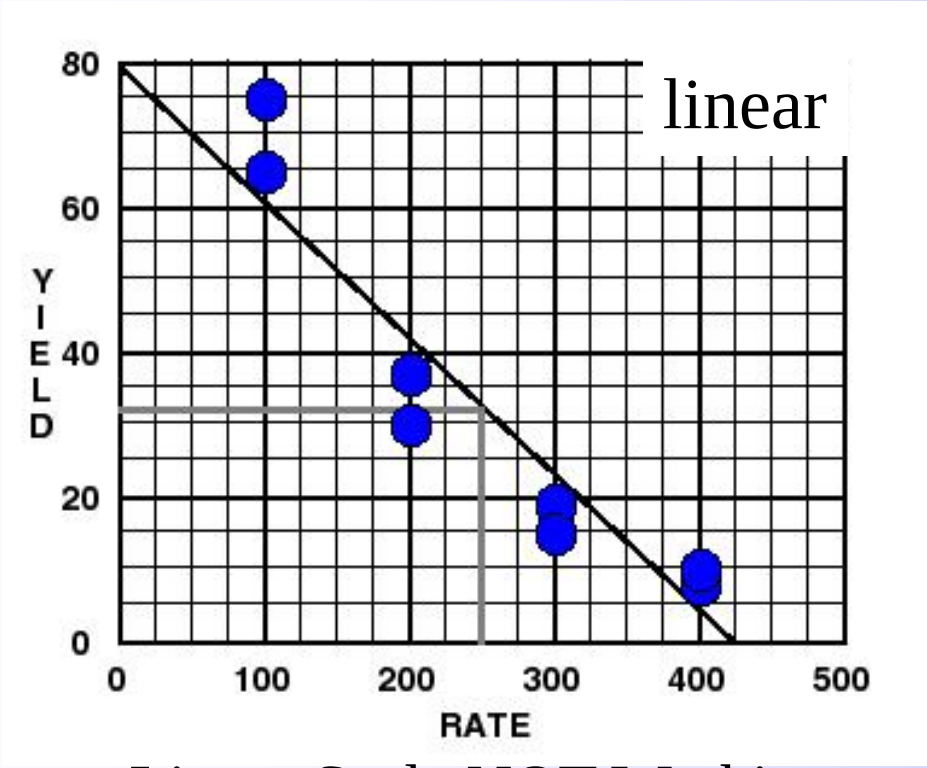


Try a French Curve

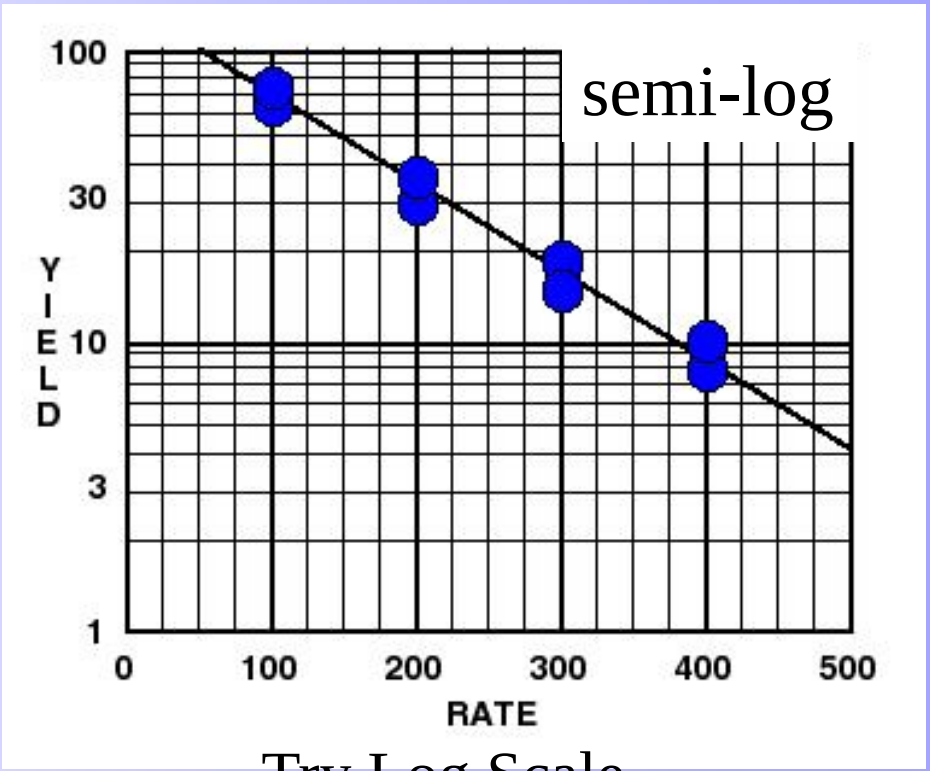
Remedies for Lack-Of-Fit

Data transformation

Requires additional expertise



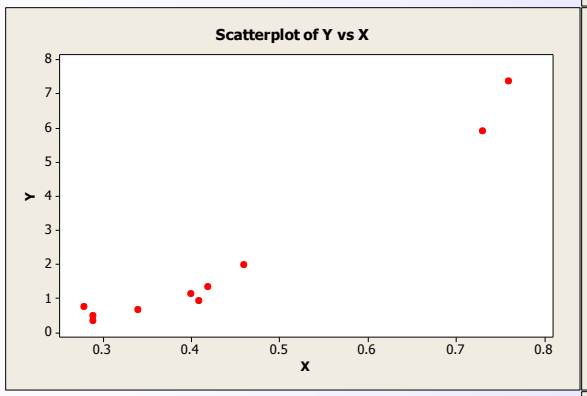
Linear Scale NOT Working



Try Log Scale

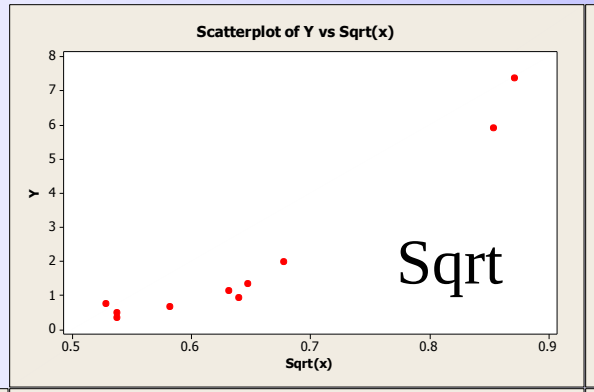
Transformations

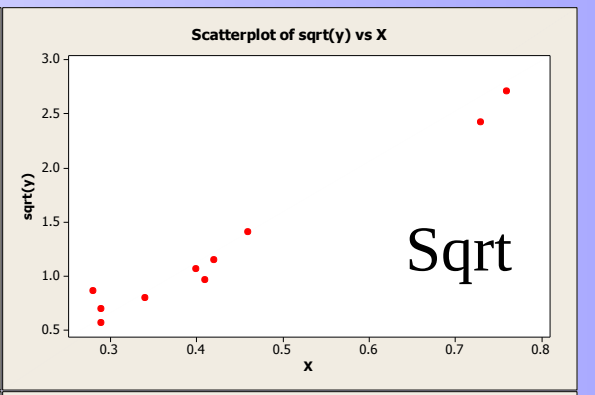
Transformations just change the grid of the graph paper

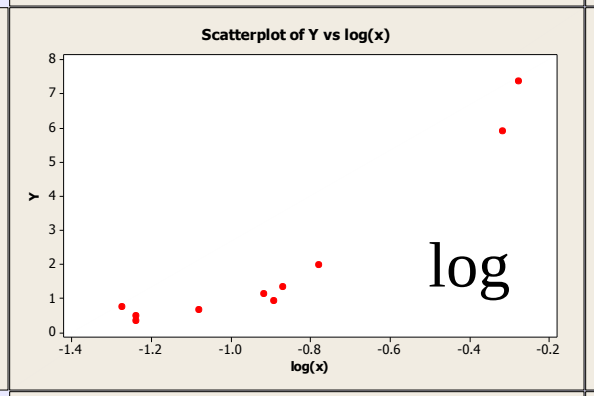


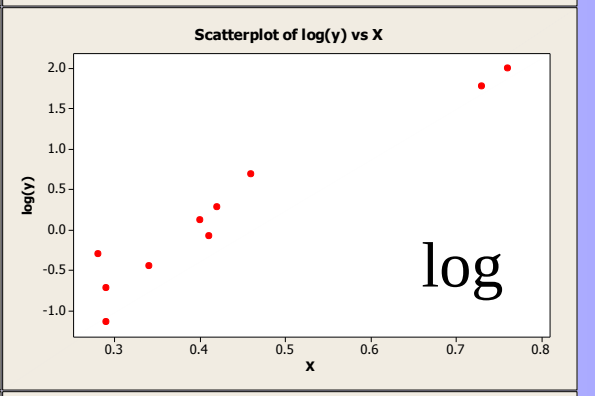
Y vs X

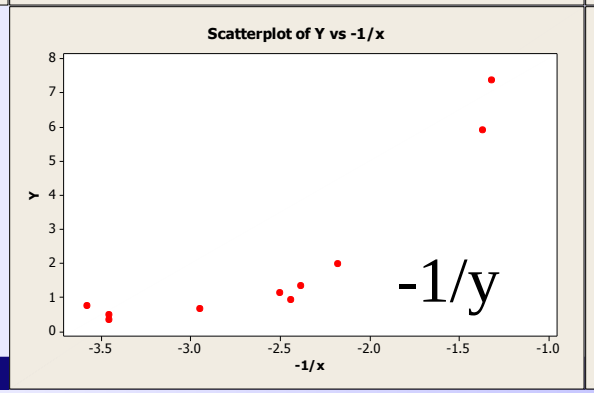
Goal is to fit a straight line AFTER transformation

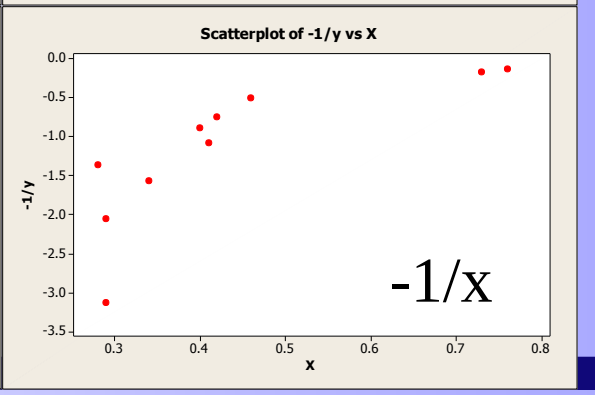












Y Transforms

X Transforms

What's a process capability study?

- A designed experiment with just one variable- TIME
- It captures all of the natural and unnatural variation in the process
- It includes drift, operators, shifts, machines… ALL of the variation that the process can see.

Conclusions

- Best method for understanding complex processes
- Best for resolving yield and reliability problems
- Provides statistical validity to know what REALLY matters
- Allows understanding the interactions between process parameters
- Required for High Reliability processes