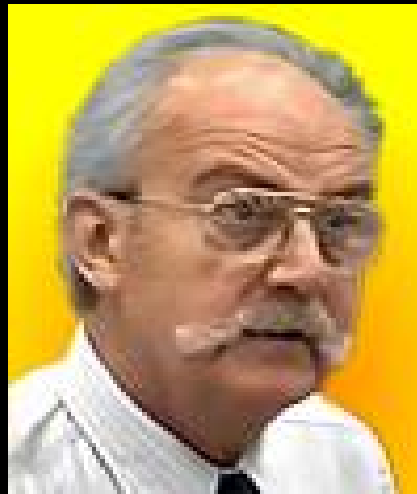


# *DOE in a Steel Mill*



# *A Very Simple Intro to DOE Theory*



George E.P. Box

# *Definitions*

- ◆ **DOE** - a systematic adjustment of factor variables carried out to learn which of those factors have the greatest effect on the resulting response variable(s).
- ◆ Factors are manipulated to measure their effect on the response variable(s).
  - Tests of hypothesis are conducted to see if those detected effects are significant.

# *Definitions*

- ◆ **Response variable** - a measure of resulting product or process quality that is of interest to the study
  - A DOE looks for the optimum factor variables at their ideal levels that will bring about the required behavior in the response variable

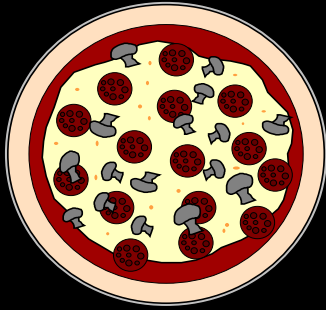
# *Definitions*

- ◆ **Factor variable** - a variable that can be positively adjusted to 2 or more levels and is believed to affect response variable behavior
  - Levels are usually chosen at high and low sides of expected tolerance or operating ranges (for 2-level designs)
  - May plan to test just outside normal range

# Definitions

## ◆ Factor level designations:

- Low level → '-'
- High level → '+'
- These designations make it possible to determine interaction and blocking effects on 2-level full and fractional factorial designs.



# *Design DOE Example*

- ◆ Pizza - Screening DOE
- ◆ Full Factorial, 3 Factors at 2 levels  
( $2^3$  design)
  - Pounds Cheese
  - Baking Time
  - Baking Temperature

# Definitions

- ◆ **Interaction** - Situation where one factor variable produces different effects on the response variable, depending on the different levels of another factor variable.
  - Ex. Drug interaction
  - Ex. Temperature & pressure effects on process yield
  - Interactions are **not** measured by Taguchi





# *Importance of Interactions*

## *- G. Box*

- ◆ “Because engineers have traditionally relied on one factor-at-a-time experimentation, main effects will often have already been put to use, and it will be the unexpected **INTERACTION** that is waiting to be discovered and sometimes can be **exploited** with dramatic results.”

# Definitions

- ◆ **Full Factorial:** Experiment which compares every factor level with every level of all other factor variables in the DOE.
  - Used to study 2 or more factor variables simultaneously
  - Vital for catching all interactions between factor variables

# Notation

## ◆ Experimental Design Notation:

- $k^n$  =  $n$  factor variables at  $k$  levels each
- $2^2$  = 2 factors at 2 levels =  $2*2 = 4$  runs
- $2^3$  = 3 factors at 2 levels =  $2*2*2 = 8$  runs
- $3^3$  = 3 factors at 3 levels =  $3*3*3 = 27$  runs

# $2^3$ Full Factorial

Run	Factor 1	Factor 2	Factor 3
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1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

# *2<sup>3</sup> Pizza Factorial*

<b>Run</b>	<b>Cheese</b>	<b>Time</b>	<b>Temperature</b>
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1	1	20	320
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2	3	20	320
---	---	----	-----

3	1	30	320
---	---	----	-----

4	3	30	320
---	---	----	-----

5	1	20	360
---	---	----	-----

6	3	20	360
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7	1	30	360
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8	3	30	360
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# Factors & Response Table

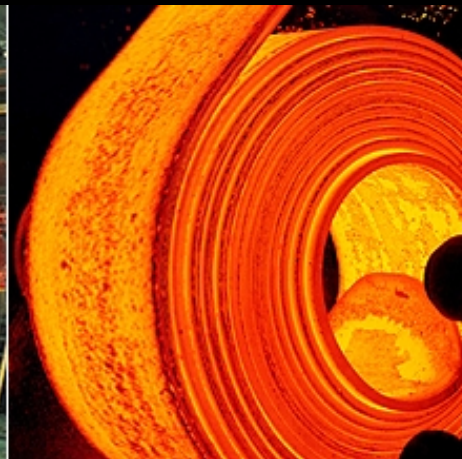
Run	A	B	C	AB ...	ABC	R
1	-	-	-	+	-	-
2	+	-	-	-	+	+
3	-	+	-	-	+	+
4	+	+	-	+	-	-
5	-	-	+	+	+	+
6	+	-	+	-	-	-
7	-	+	+	-	-	-
8	+	+	+	+	+	+



*Questions?*

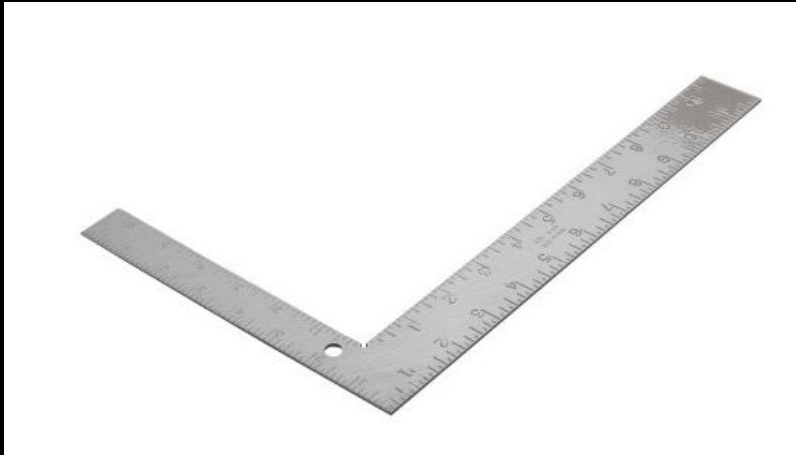


*But how easily does the theory work when you try it at home on real problems?*



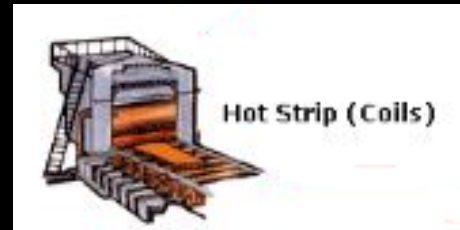


# Carpenters Square Reality



- ◆ Limited end use info  
- cooperation
- ◆ “Paint it black” until see red (now urgent)
- ◆ Penny wise, ton foolish – unusual processing
- ◆ Unloved by mill
- ◆ 3-4 day incubation

# Normal Steel Process



# Odyssey of Discovery

- ◆ Unrolled rejects to study **stain & slobber**
- ◆ Defect pattern length → **Tandem rolls!**
- ◆ Customer meetings to learn final processing → **Brushed salvage**
- ◆ Chemical analysis of stained areas
  - “Air wipes” & contamination
  - Rolling oil inhibitor (**Fu-Fu Dust**)
  - Tandem mill operating variables



# Full Factorial Design

Factor	Low Level -	High Level +
Tandem Speed	Slow	Fast
FFD ppm	0	500
Anneal Hours	0	5

- ◆ Created **visual rating scale** for stain 0 - 24
  - Color intensity
  - Spots versus continuous areas
  - Feet of stain from ends

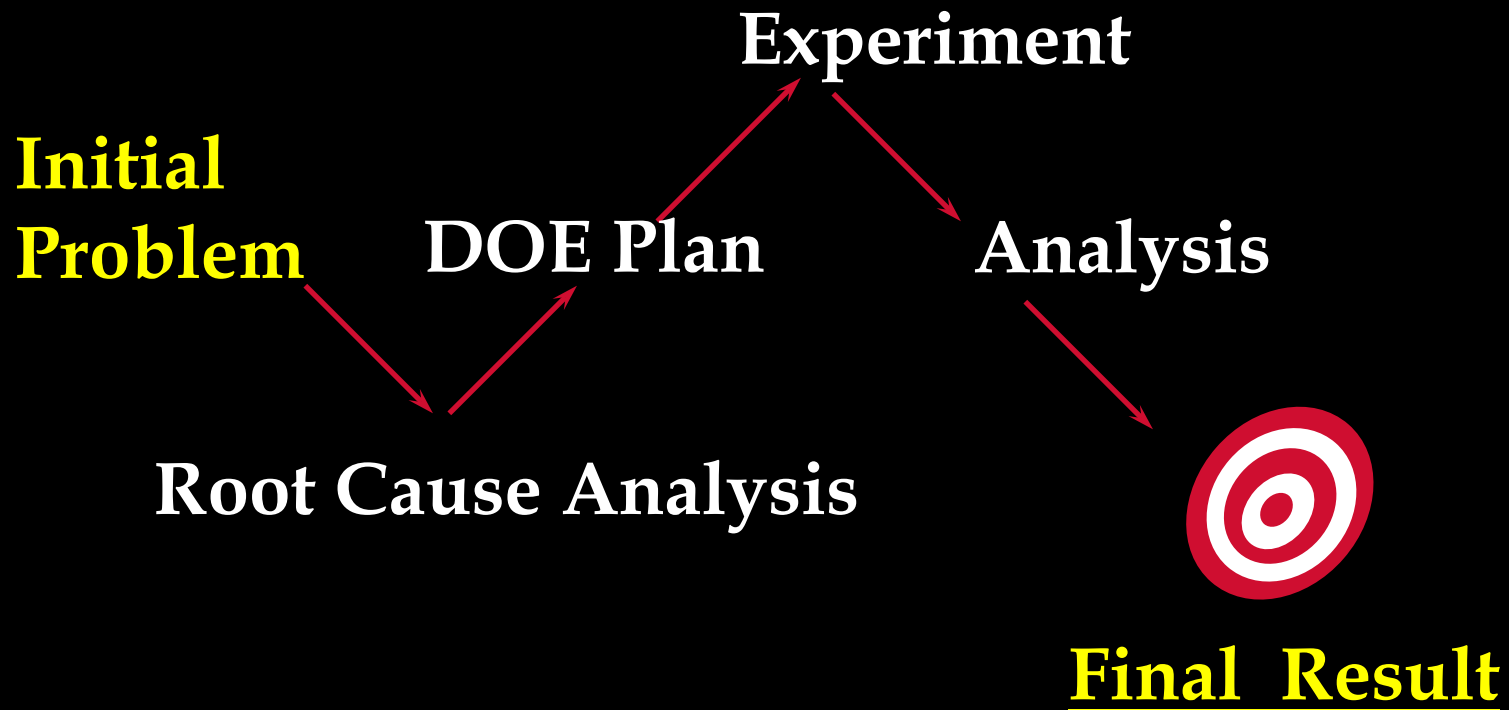
# Factors & Response Table

Run	S	F	A	SF ...	SFA	Stain
1	-	-	-	+	-	+
2	+	-	-	-	+	-
3	-	+	-	-	+	-
4	+	+	-	+	-	+
5	-	-	+	+	+	+
6	+	-	+	-	-	-
7	-	+	+	-	-	-
8	+	+	+	+	+	+

# Results of DOE

- ◆ Rolling oil inhibitor (**Fu-Fu Dust**) – highly significant
- ◆ **Fast mill speed** significantly prevented stain
  - Air wipes reduced contamination
- ◆ Adding **costly** drying **anneal** after tandem mill – **not** significant
- ◆ Small trials continued to fine-tune SOP
  - Tandem mill operating variables optimized
  - Inspection continued using 0-24 stain codes

# DOE Method



# *AFTER THE DOE*







*Questions?*



