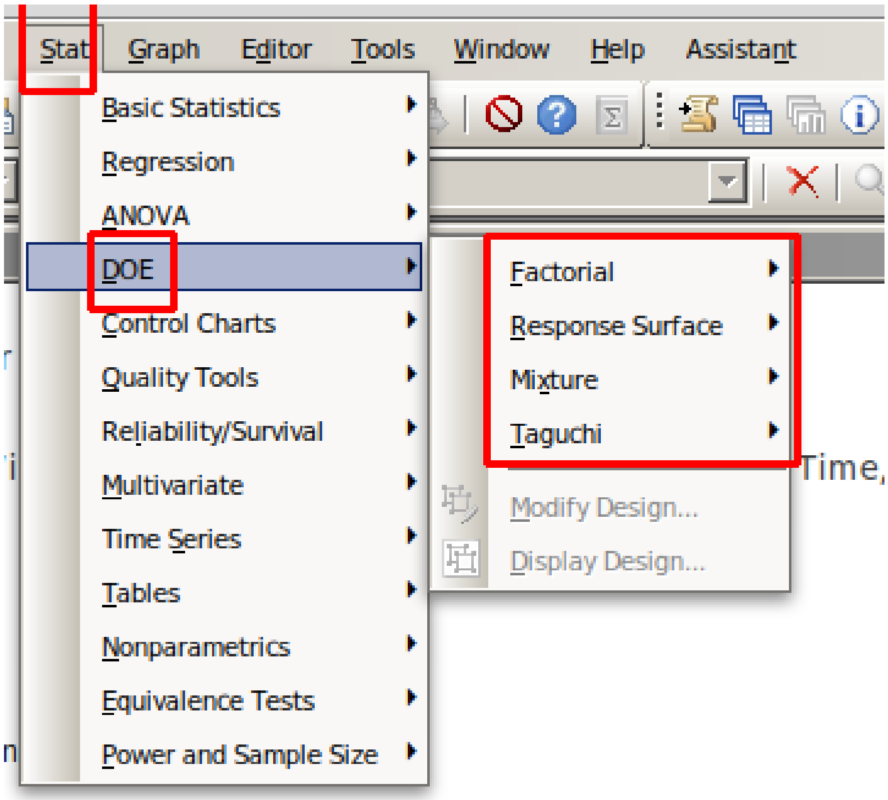
DESIGN OF EXPERIMENTS WITH MINITAB

DR. ALVIN ANG

CONTENTS



There are 4 types of DOEs in Minitab.

- Factorial (2 Levels)
    - Full Factorial
    - Fractional Factorial

- Response Surface Method (RSM) (>2 levels)
    - Central Composite Design (CCD)
    - Box-Behnken Design

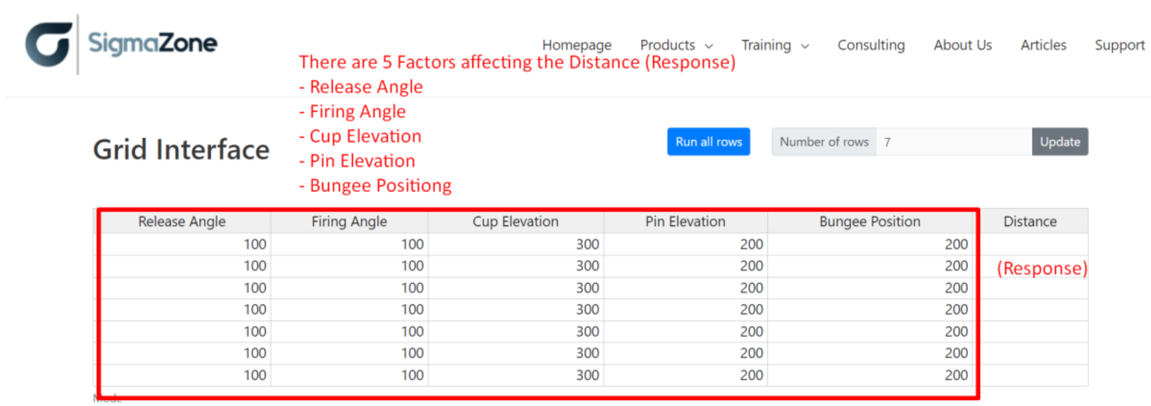
- Mixture
    - Simplex Centroid
    - Simplex Lattice
    - Extreme Vertices

- Taguchi
    - Larger is Better
    - Nominal is Best
    - Nominal is Best (Default)
    - Smaller is Better

Single Cup Catapult

Practice Design of Experiments (DOE)

Go to https://sigmazone.com/catapult-grid/

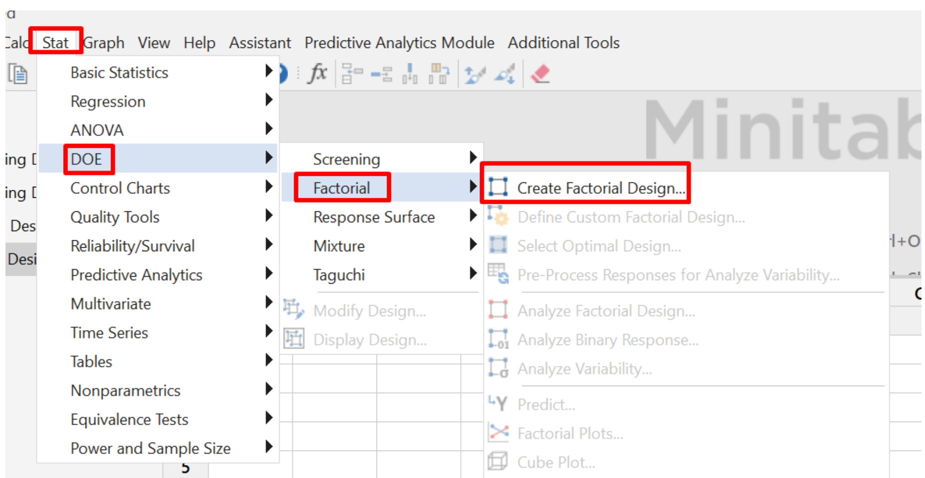


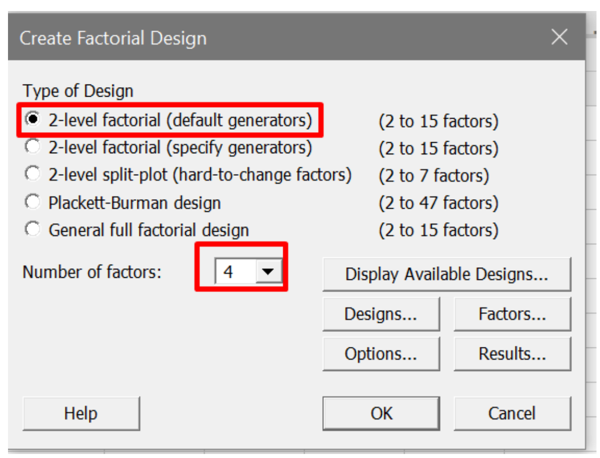
Release Angle	Firing Angle	Cup Elevation	Pin Elevation	Bungee Position	Distance
100	100	300	200	200	
100	100	300	200	200	
100	100	300	200	200	
100	100	300	200	200	
100	100	300	200	200	
100	100	300	200	200	
100	100	300	200	200	

- We will test the following:
  - Release Angle: 140 / 180
  - Firing Angle: 110 (since this is constant, we will ignore it)
  - Cup Elevation: 220 / 280
  - Pin Elevation: 120 / 180
  - Bungee Position: 120 / 180

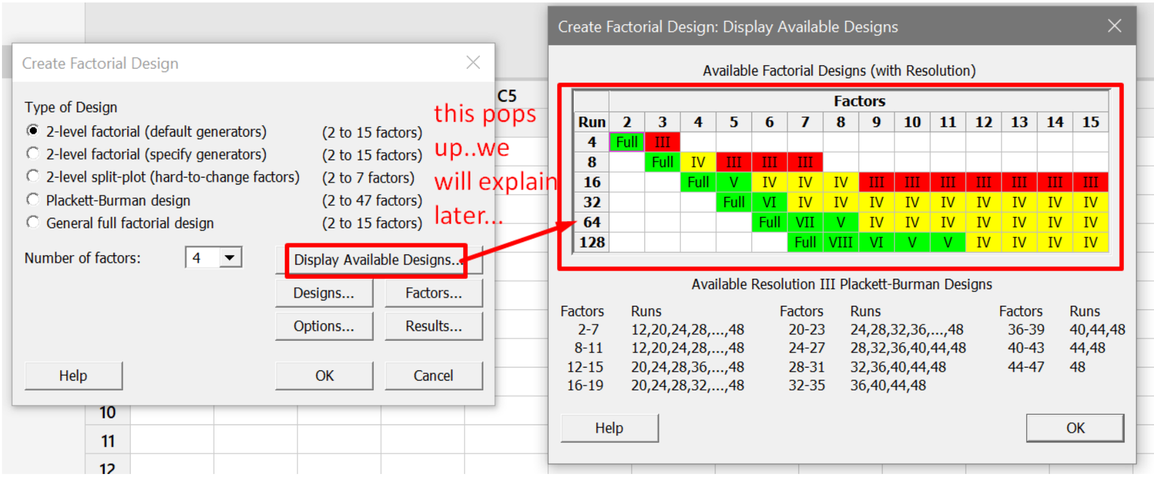
- 4 Factors 2 Levels, this is known as a 2^4 Factorial Design DOE.
- Total number of runs = 2^4 = 16 runs
- Now go to Minitab

A. CREATION OF EXPERIMENT





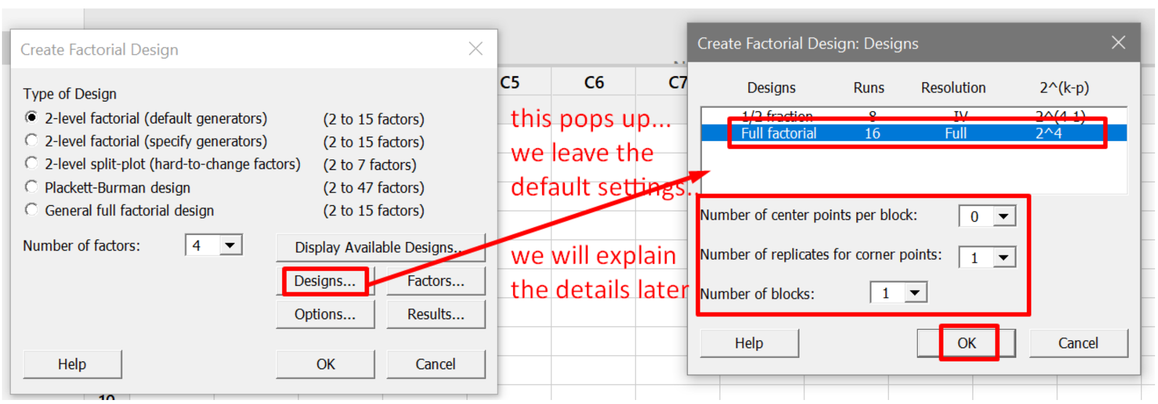
1. DISPLAY AVAILABLE DESIGNS



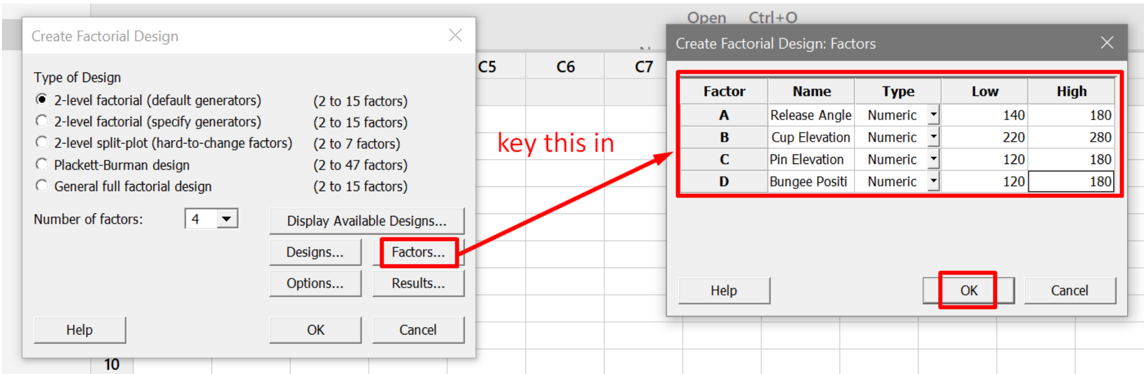
Run	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

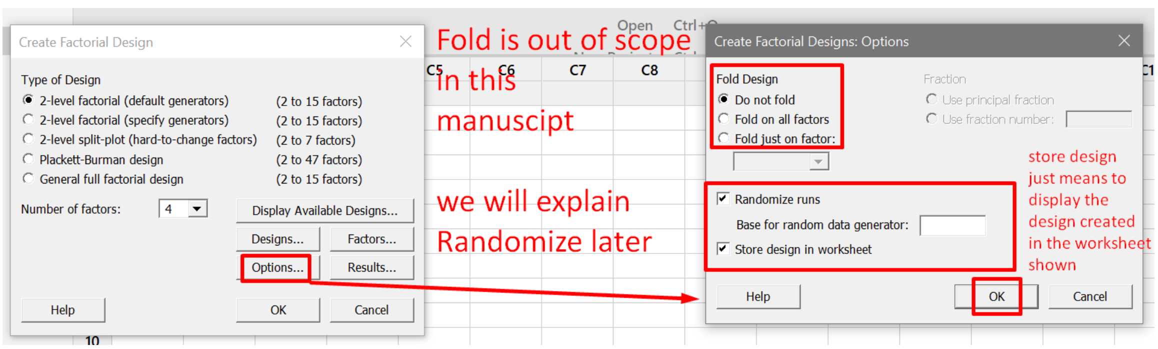
2. CREATE FACTORIAL DESIGNS

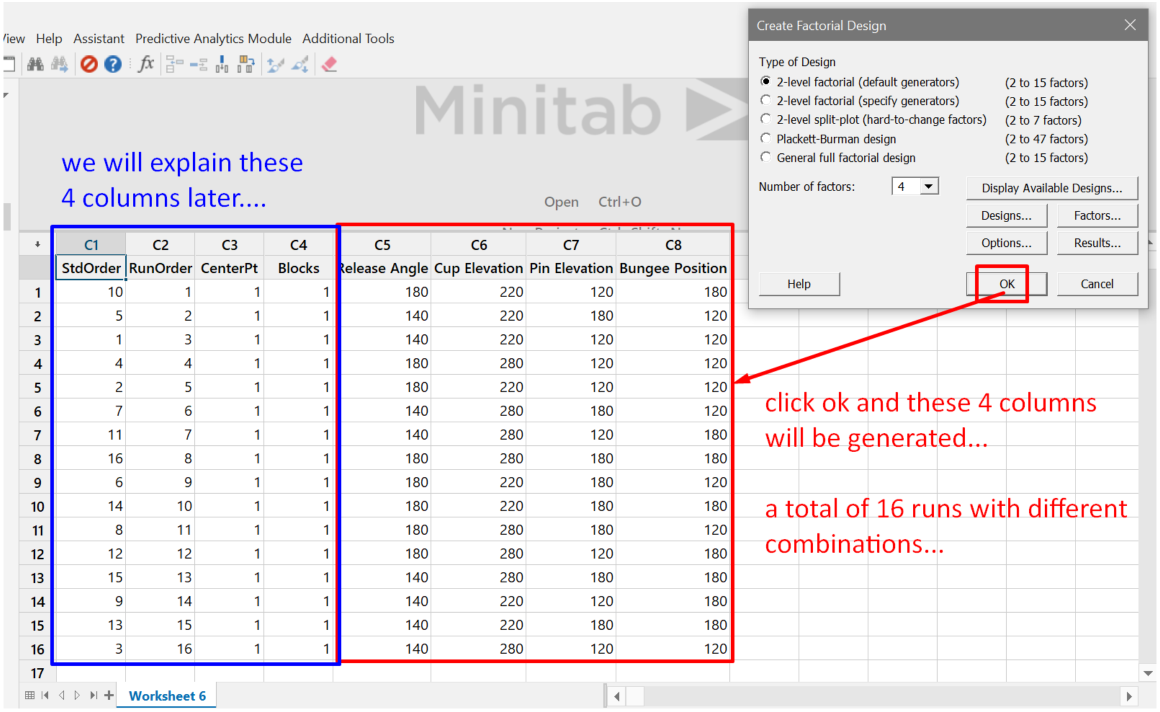


3. FACTORS

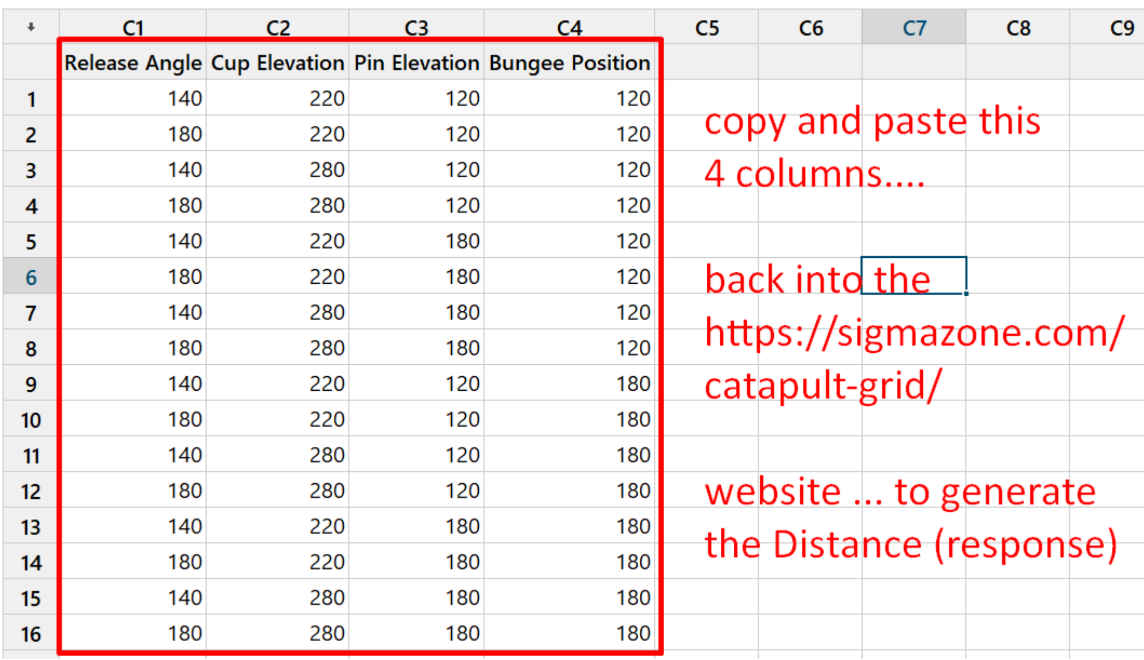


4. OPTIONS





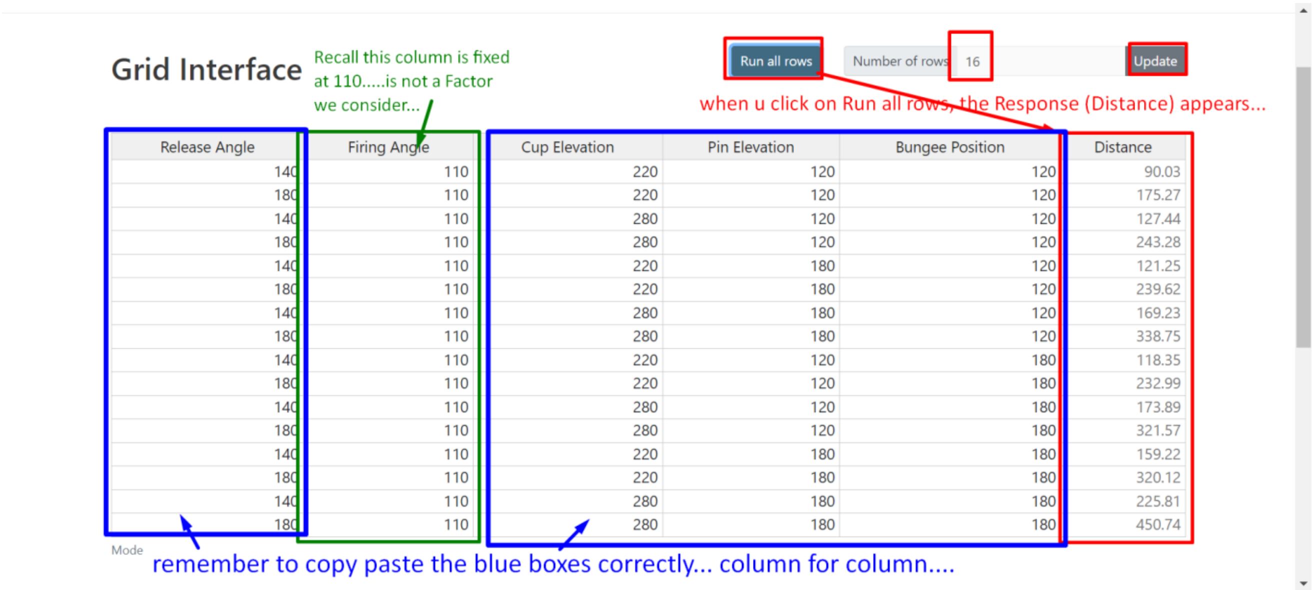
	C1 StdOrder	C2 RunOrder	C3 CenterPt	C4 Blocks	C5 Release Angle	C6 Cup Elevation	C7 Pin Elevation	C8 Bungee Position
1	10	1	1	1	180	220	120	180
2	5	2	1	1	140	220	180	120
3	1	3	1	1	140	220	120	120
4	4	4	1	1	180	280	120	120
5	2	5	1	1	180	220	120	120
6	7	6	1	1	140	280	180	120
7	11	7	1	1	140	280	120	180
8	16	8	1	1	180	280	180	180
9	6	9	1	1	180	220	180	120
10	14	10	1	1	180	220	180	180
11	8	11	1	1	180	280	180	120
12	12	12	1	1	180	280	120	180
13	15	13	1	1	140	280	180	180
14	9	14	1	1	140	220	120	180
15	13	15	1	1	140	220	180	180
16	3	16	1	1	140	280	120	120



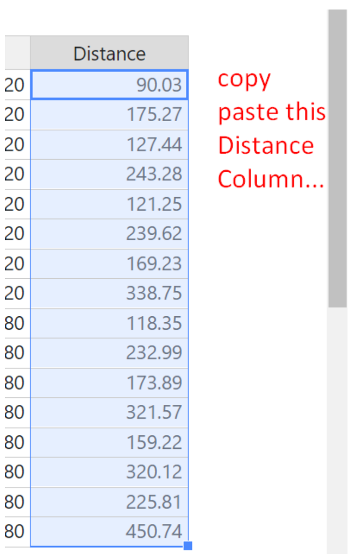
	C1 Release Angle	C2 Cup Elevation	C3 Pin Elevation	C4 Bungee Position
1	140	220	120	120
2	180	220	120	120
3	140	280	120	120
4	180	280	120	120
5	140	220	180	120
6	180	220	180	120
7	140	280	180	120
8	180	280	180	120
9	140	220	120	180
10	180	220	120	180
11	140	280	120	180
12	180	280	120	180
13	140	220	180	180
14	180	220	180	180
15	140	280	180	180
16	180	280	180	180

B. RUNNING THE EXPERIMENTS & GETTING THE RESULTS (RESPONSE)

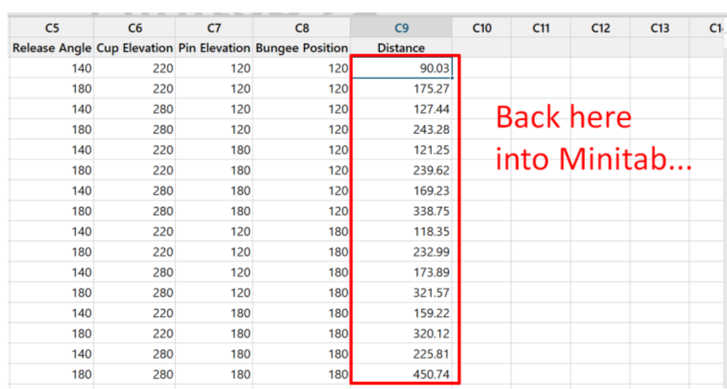
- Go to https://sigmazone.com/catapult-grid/



Release Angle	Firing Angle	Cup Elevation	Pin Elevation	Bungee Position	Distance
140	110	220	120	120	90.03
180	110	220	120	120	175.27
140	110	280	120	120	127.44
180	110	280	120	120	243.28
140	110	220	180	120	121.25
180	110	220	180	120	239.62
140	110	280	180	120	169.23
180	110	280	180	120	338.75
140	110	220	120	180	118.35
180	110	220	120	180	232.99
140	110	280	120	180	173.89
180	110	280	120	180	321.57
140	110	220	180	180	159.22
180	110	220	180	180	320.12
140	110	280	180	180	225.81
180	110	280	180	180	450.74

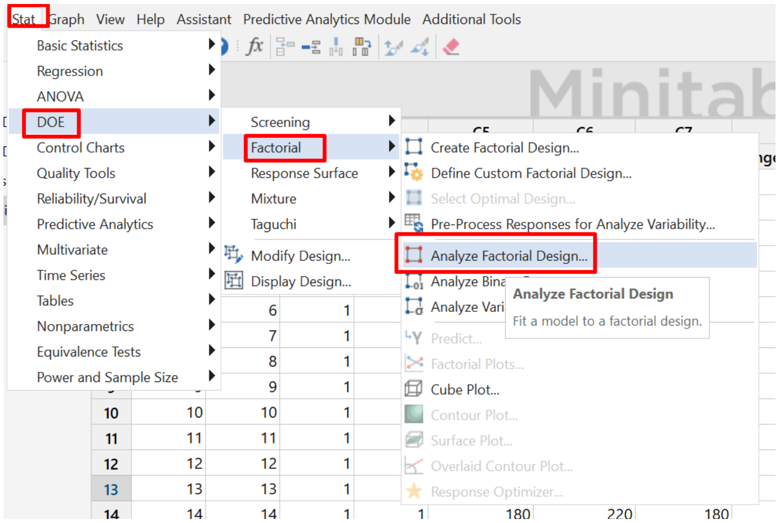


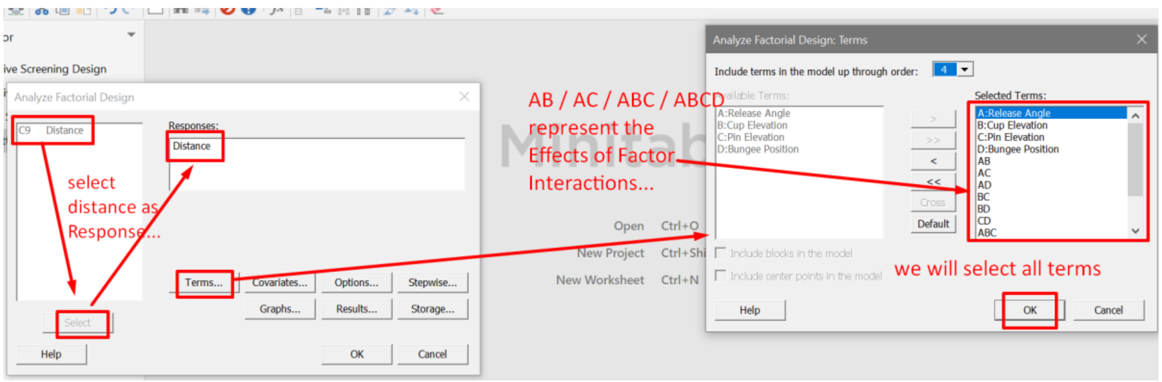
	Distance
20	90.03
20	175.27
20	127.44
20	243.28
20	121.25
20	239.62
20	169.23
20	338.75
80	118.35
80	232.99
80	173.89
80	321.57
80	159.22
80	320.12
80	225.81
80	450.74

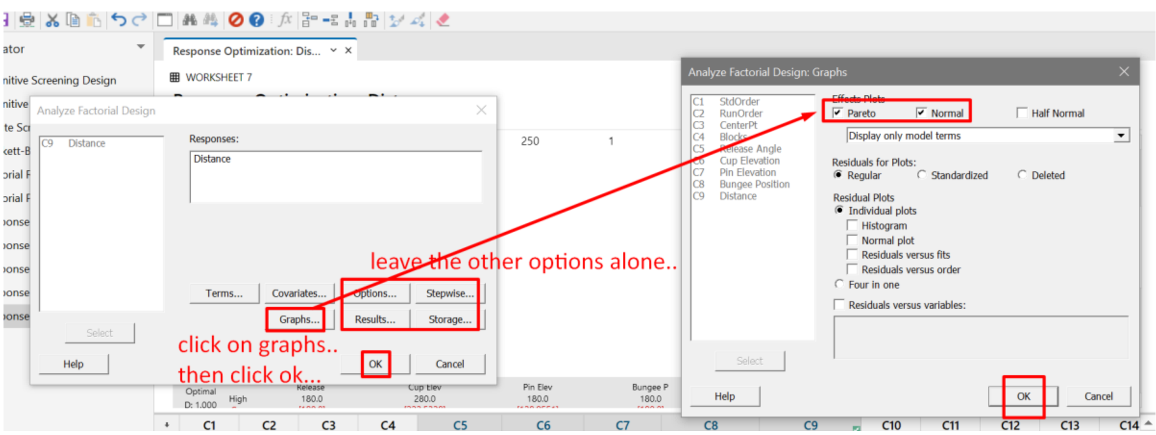


C5 Release Angle	C6 Cup Elevation	C7 Pin Elevation	C8 Bungee Position	C9 Distance
140	220	120	120	90.03
180	220	120	120	175.27
140	280	120	120	127.44
180	280	120	120	243.28
140	220	180	120	121.25
180	220	180	120	239.62
140	280	180	120	169.23
180	280	180	120	338.75
140	220	120	180	118.35
180	220	120	180	232.99
140	280	120	180	173.89
180	280	120	180	321.57
140	220	180	180	159.22
180	220	180	180	320.12
140	280	180	180	225.81
180	280	180	180	450.74

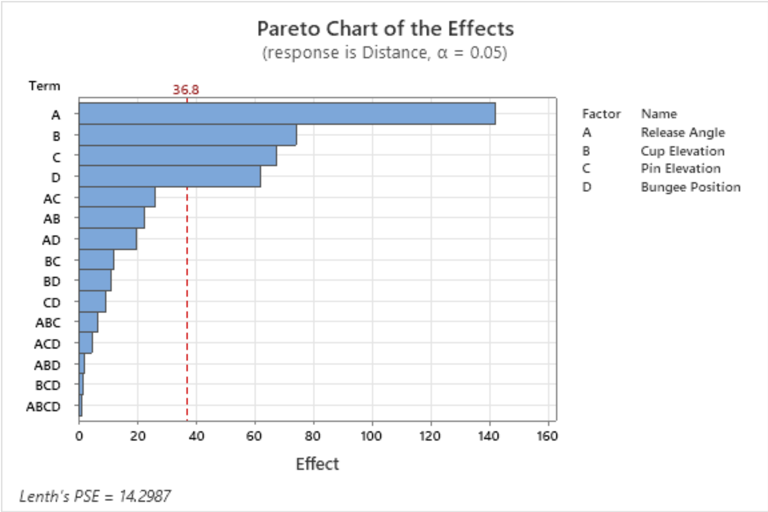
C. ANALYZING THE RESULTS





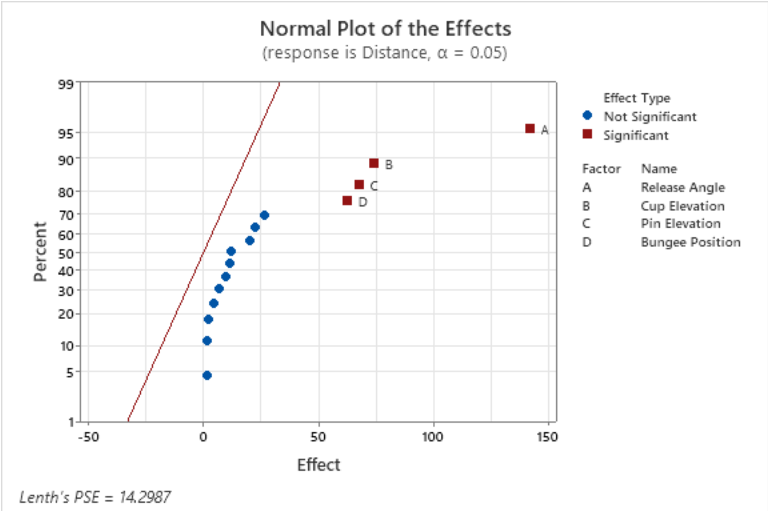


1. PARETO CHART



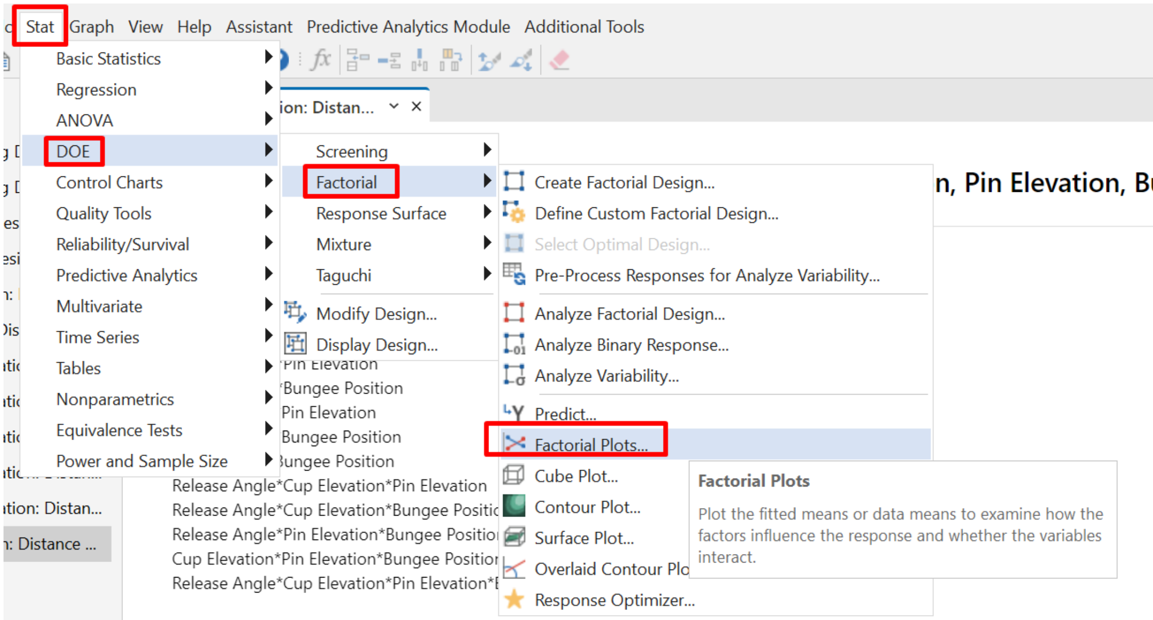
- We see that the Main Effects are: A, B, C and D.
- Anything that surpasses 36.8 is an important effect.
- We see that all other interaction effects fall below 36.8 (thus unimportant)

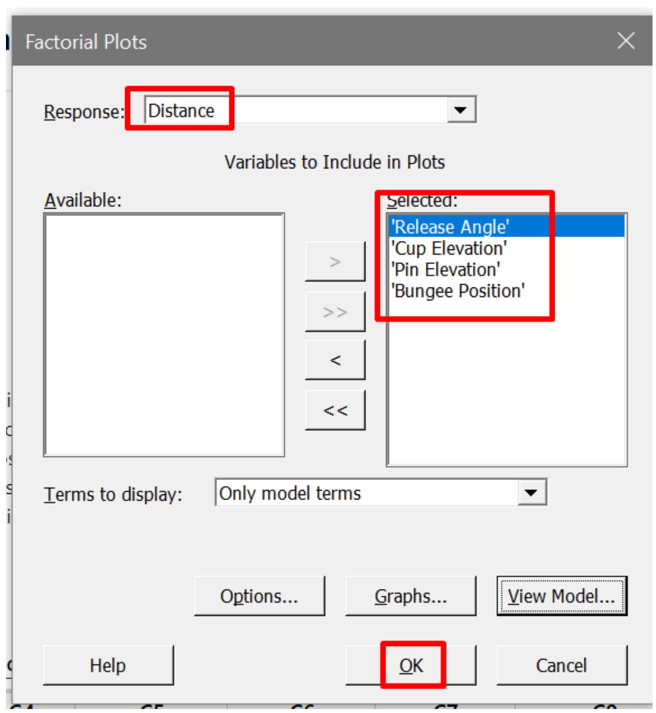
2. NORMAL PLOT

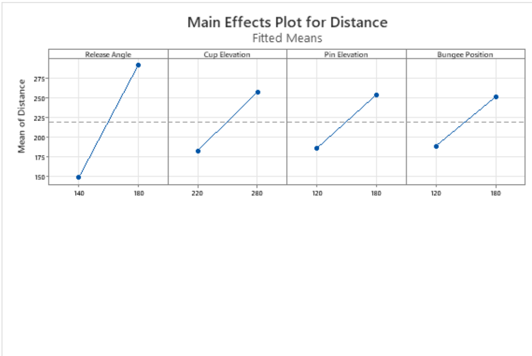


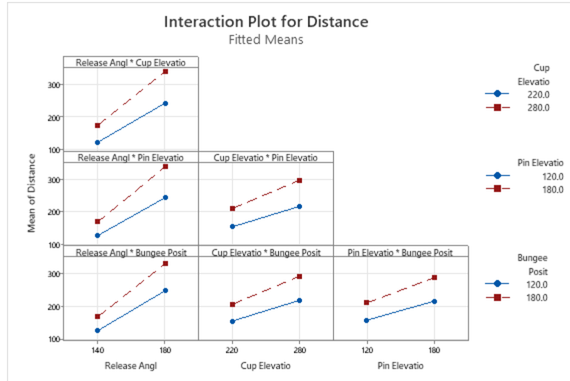
- Normal plot shows us the same thing.

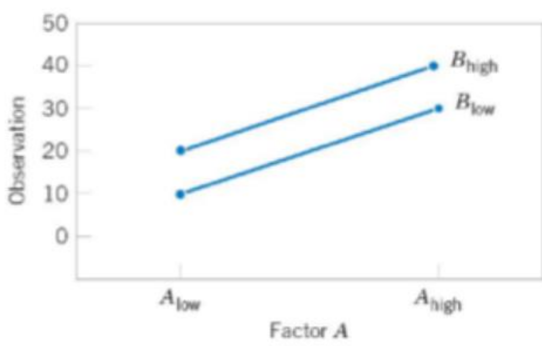
3. FACTORIAL PLOT

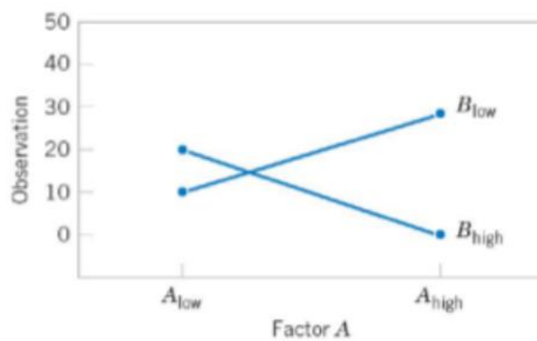












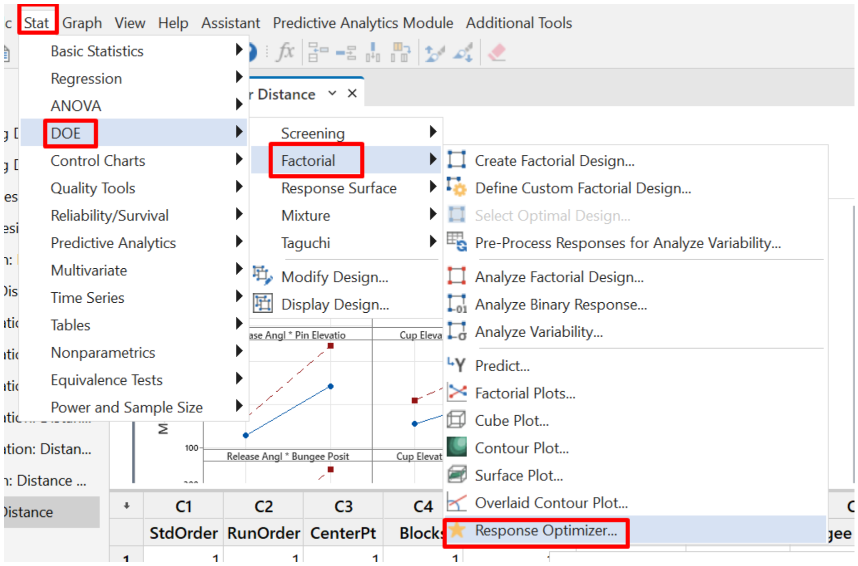
No Interaction

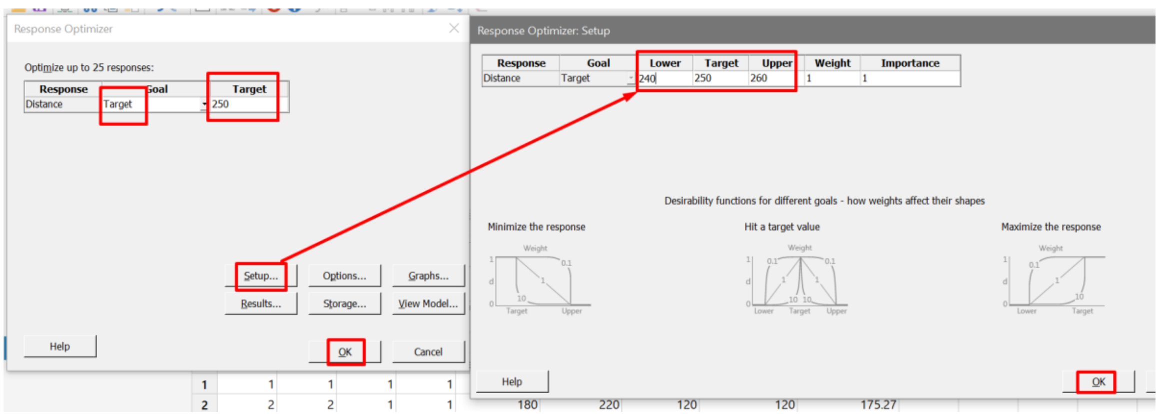
With Interaction

If there is a overlap / cross of the lines, there is interaction between the Factors.

However, we see that all 4 Factors have no relationship with each other.

D. PREDICTING RESULTS





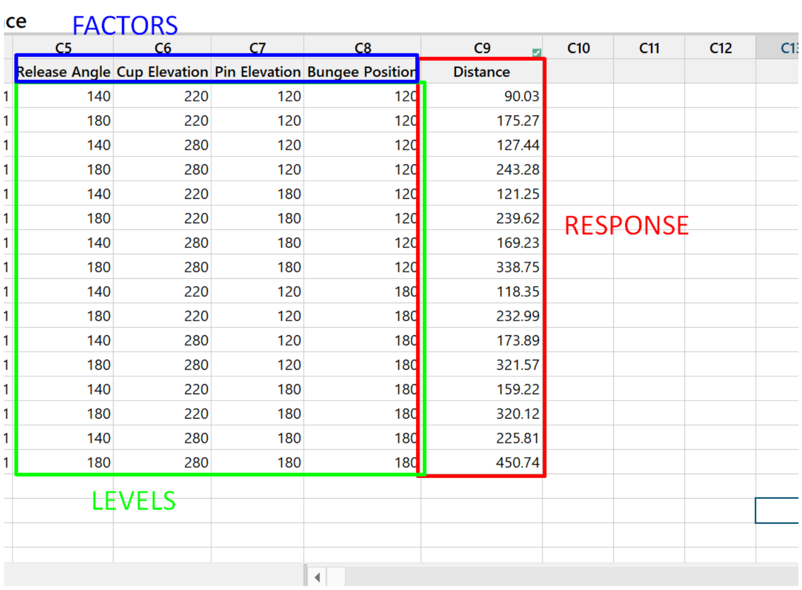
Multiple Response Prediction

Variable	Setting
Release Angle	180
Cup Elevation	222.534
Pin Elevation	128.955
Bungee Position	180

we need to set these Factor at these settings should we want to hit 250 as Distance

Response	Fit	SE Fit	95% CI	95% PI
Distance	250.0	*	(*, *)	(*, *)

A. FACTORS / LEVELS / RESPONSES



C5 Release Angle	C6 Cup Elevation	C7 Pin Elevation	C8 Bungee Position	C9 Distance
140	220	120	120	90.03
180	220	120	120	175.27
140	280	120	120	127.44
180	280	120	120	243.28
140	220	180	120	121.25
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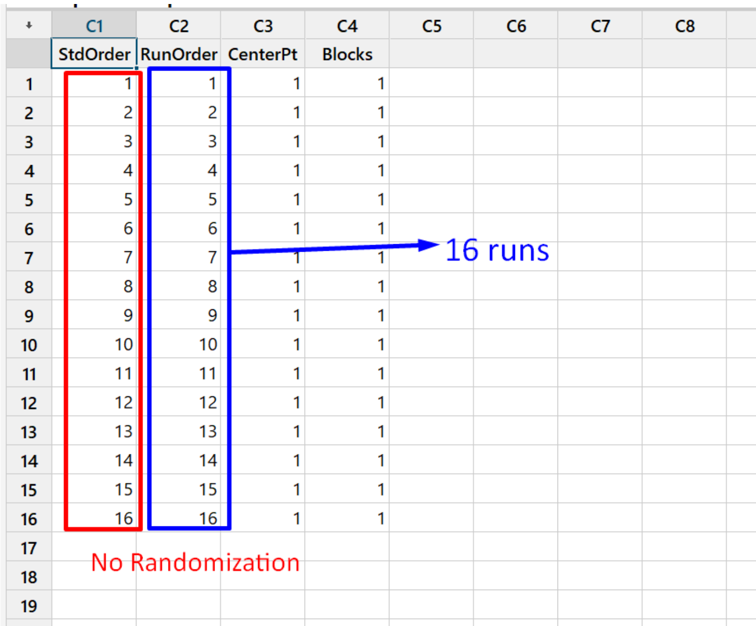
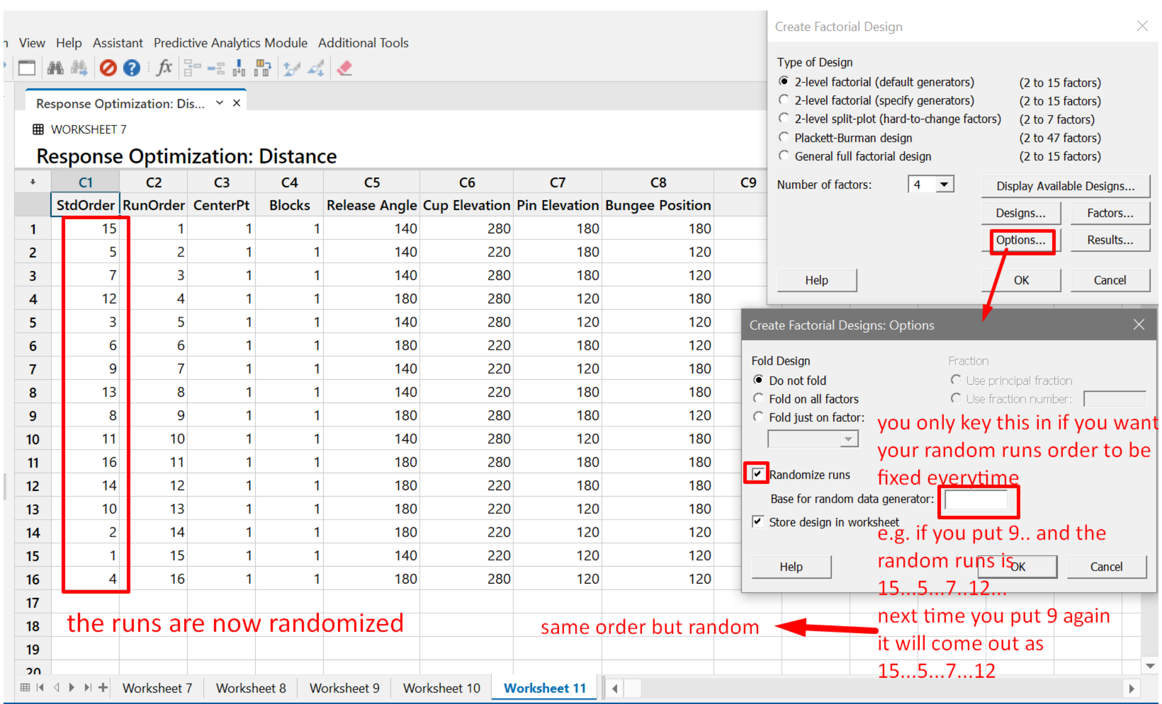
180	220	120	180	232.99
140	280	120	180	173.89
180	280	120	180	321.57
140	220	180	180	159.22
180	220	180	180	320.12
140	280	180	180	225.81
180	280	180	180	450.74

- Earlier, we did this test:
  - Release Angle: 140 / 180 → LOW / HI
  - Firing Angle: 110 (since this is constant, we will ignore it)
  - Cup Elevation: 220 / 280 → LOW / HI
  - Pin Elevation: 120 / 180 → LOW / HI
  - Bungee Position: 120 / 180 → LOW / HI
- 4 Factors 2 Levels, this is known as a 2^4 Factorial Design DOE.
- Total number of runs = 2^4 = 16 runs

B. RUN / RANDOMIZATION

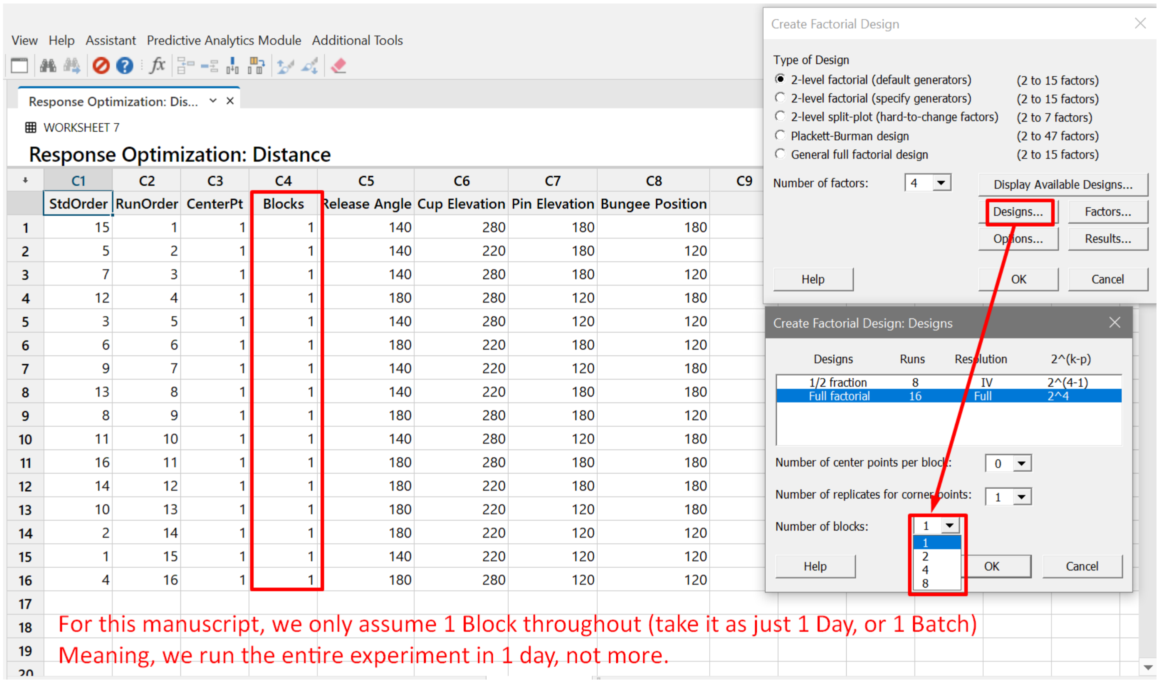




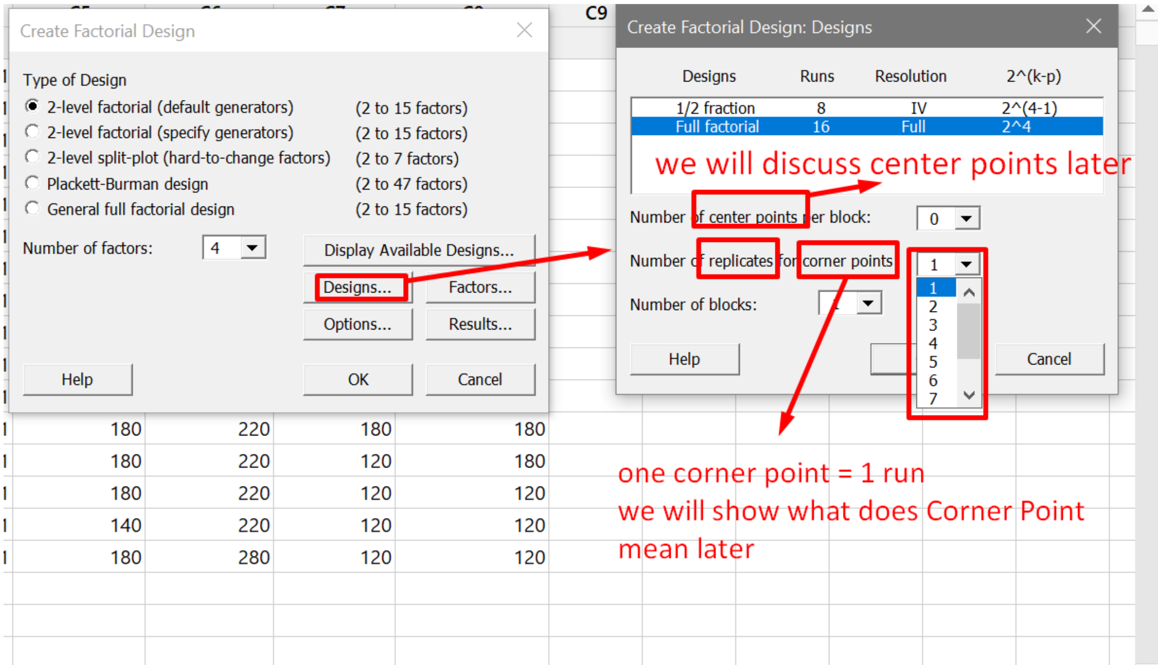
- Randomization is important to protect against uncontrolled and/or unknown influences of variables that are not part of the experiment.
- In order to minimize this risk of unknown influence, experimenters randomly assign the order of testing to improve the chances of averaging out this bias or distortion of the responses related to the factor(s) under study.
- If you are unable to randomize due to physical or cost constraints, we will need to do Blocking.

C. BLOCKING

- If you cannot randomize due to lack of resources, example, not enough raw materials to do so many runs, one may block.
- 1 Block = 1 Batch.
- Possibly, 1 Block = 1 Day. Which means, running an entire experiment in 1 day = 1 block.
- Running the experiment again the next day will be 2 blocks → Block 2.
- Blocking minimizes the risk of the nuisance-factor batches creating excessive estimates of the inherent variation.
- For example, you want to test the quality of a new printing press.
- However, press arrangement takes several hours and can only be done four times a day.
- Because the design of the experiment requires at least eight runs, you need at least two days to test the press.
- To distinguish between any block effect (incidental differences between days) and effects because of the experimental factors (temperature, humidity, and press operator), you must include the block (day) in the designed experiment. You should randomize run order within blocks.


View Help Assistant Predictive Analytics Module Additional Tools
Response Optimization: Dis...
WORKSHEET 7
Response Optimization: Distance
C1 C2 C3 C4 C5 C6 C7 C8 C9
StdOrder RunOrder CenterPt Blocks Release Angle Cup Elevation Pin Elevation Bungee Position
1 15 1 1 1 140 280 180 180
2 5 2 1 1 140 220 180 120
3 7 3 1 1 140 280 180 120
4 12 4 1 1 180 280 120 180
5 3 5 1 1 140 280 120 120
6 6 6 1 1 180 220 180 120
7 9 7 1 1 140 220 120 180
8 13 8 1 1 140 220 180 180
9 8 9 1 1 180 280 180 120
10 11 10 1 1 140 280 120 180
11 16 11 1 1 180 280 180 180
12 14 12 1 1 180 220 180 180
13 10 13 1 1 180 220 120 180
14 2 14 1 1 180 220 120 120
15 1 15 1 1 140 220 120 120
16 4 16 1 1 180 280 120 120
Create Factorial Design
Type of Design
2-level factorial (default generators) (2 to 15 factors)
2-level factorial (specify generators) (2 to 15 factors)
2-level split-plot (hard-to-change factors) (2 to 7 factors)
Plackett-Burman design (2 to 47 factors)
General full factorial design (2 to 15 factors)
Number of factors: 4
Display Available Designs...
Designs...
Factors...
Options...
Results...
Help
OK
Cancel
Create Factorial Design: Designs
Designs Runs Resolution 2^(k-p)
1/2 fraction 8 IV 2^(4-1)
Full factorial 16 Full 2^4
Number of center points per block: 0
Number of replicates for corner points: 1
Number of blocks: 1
1
2
4
8
Help
OK
Cancel
For this manuscript, we only assume 1 Block throughout (take it as just 1 Day, or 1 Batch)
Meaning, we run the entire experiment in 1 day, not more.

D. REPLICATE VS REPEAT

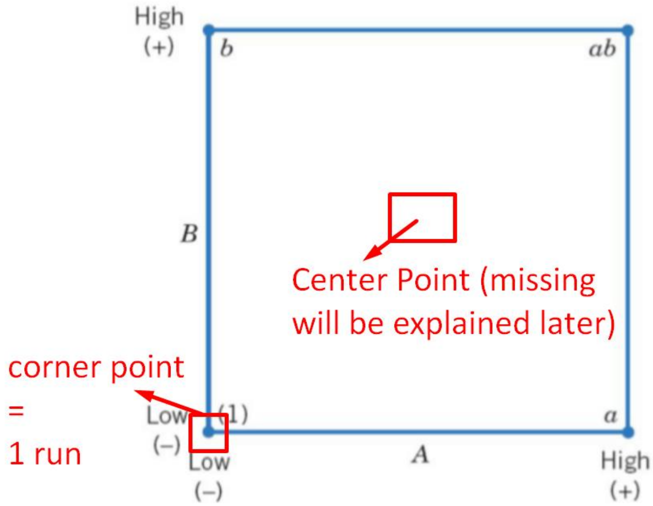


- Replication = Performing more than one trial of each run
- (Completely NEW SETUP each trial).
- A Replicate is an Independent and Random application of the run, including the setup.
- Repeat = a Repetition of a run WITHOUT going through a NEW SETUP.

E. WHAT IF MANY OF THE EFFECTS ARE SIGNIFICANT?

- Check → Was the setup for each trial really randomly replicated?
- If not, the responses are repeats, not replicates.
- Replication assumes that each trial is an independent and random performance of the process, specifically including any process setup.
- If not, the experimenter has repeats that may be neither independent nor random.
- The estimate of s (standard deviation), using repeats will be much smaller than the actual inherent variation of the process.
- This will make most effects appear significant, when in reality they have not been randomly replicated to properly estimate the inherent variation.

F. CORNER POINT / CENTER POINT



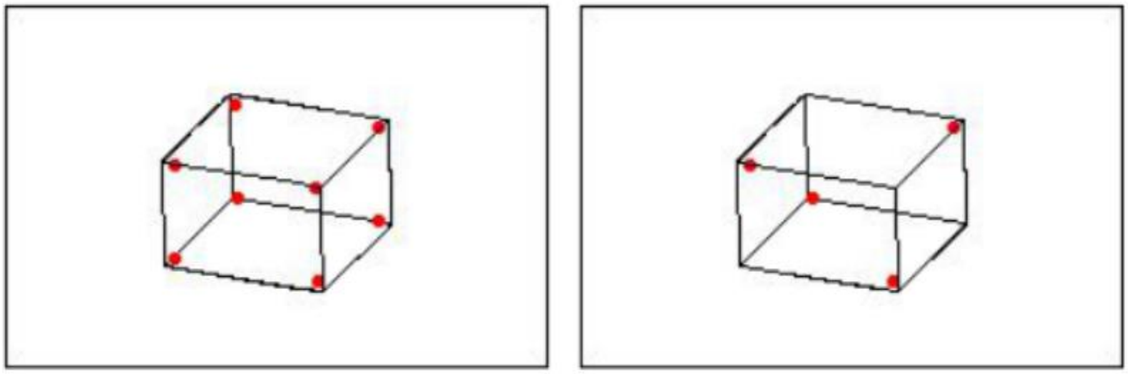
(*a*) Geometric view

	Factor		
Run	*A*	*B*	Label
1	–	–	(1)
2	+	–	*a*
3	–	+	*b*
4	+	+	*ab*

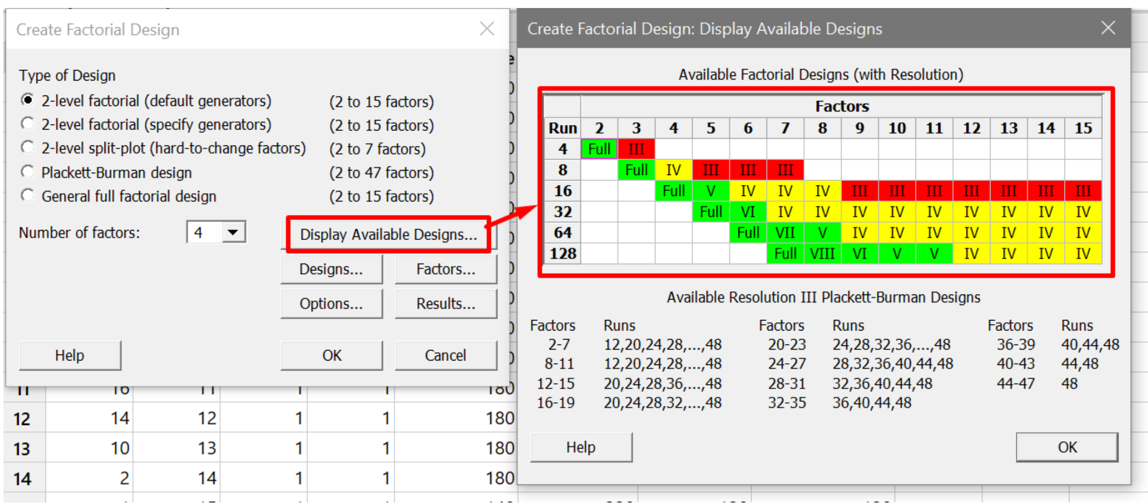
(*b*) Design or test matrix for the 2^2 factorial design

- There are 4 Corner Points:
    - (-1, -1) / (-1, 1) / (1, -1) / (1, 1) → Each is 1 Run
- The Centre Point is (0,0).
- Currently, we don't use it.
- We will explore Centre Point in the next section on Response Surface Design (RSM): Central Composite Design (CCD).

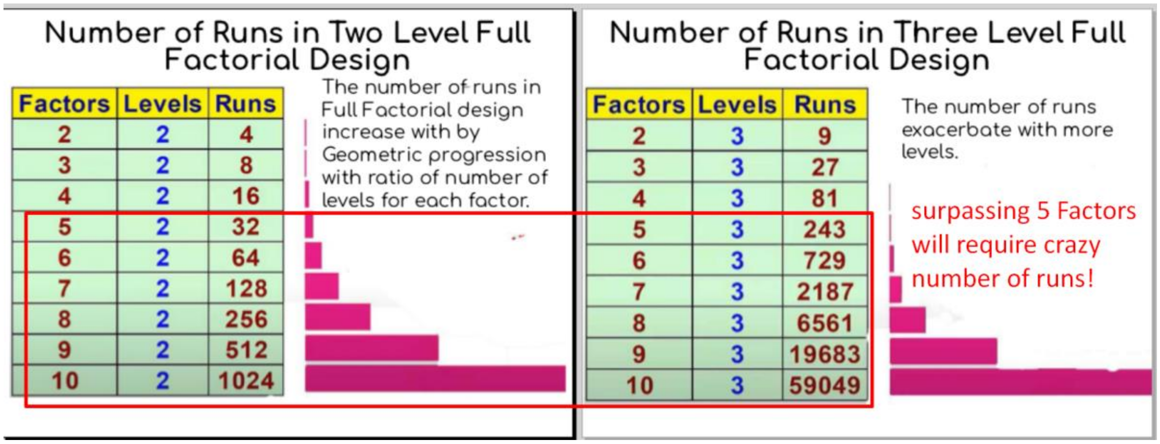
G. FULL VS FRACTIONAL FACTORIALS



Full factorial design ½ Fraction factorial design



- Full Factorial means All Runs
- For example, 2^3 → 2 Levels 3 Factors = Total 8 Runs
- But if you lack resources, are you able to do it in just 4 Runs?
- Yes, but its labelled as Resolution III Design (see picture above, in Red → 4 Run, 3 Factors).



Number of Runs in Two Level Full Factorial Design

Factors	Levels	Runs
2	2	4
3	2	8
4	2	16
5	2	32
6	2	64
7	2	128
8	2	256
9	2	512
10	2	1024

The number of runs in Full Factorial design increase with by Geometric progression with ratio of number of levels for each factor.

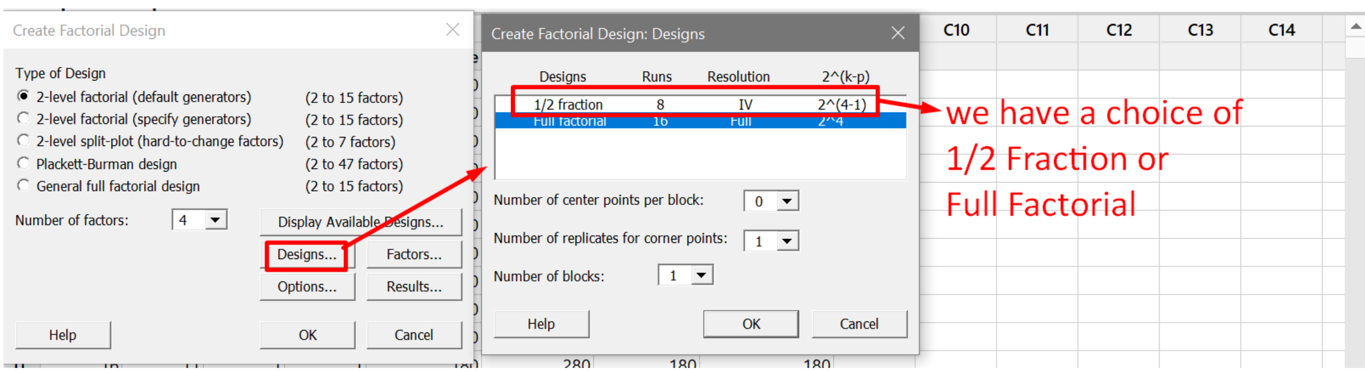
Number of Runs in Three Level Full Factorial Design

Factors	Levels	Runs
2	3	9
3	3	27
4	3	81
5	3	243
6	3	729
7	3	2187
8	3	6561
9	3	19683
10	3	59049

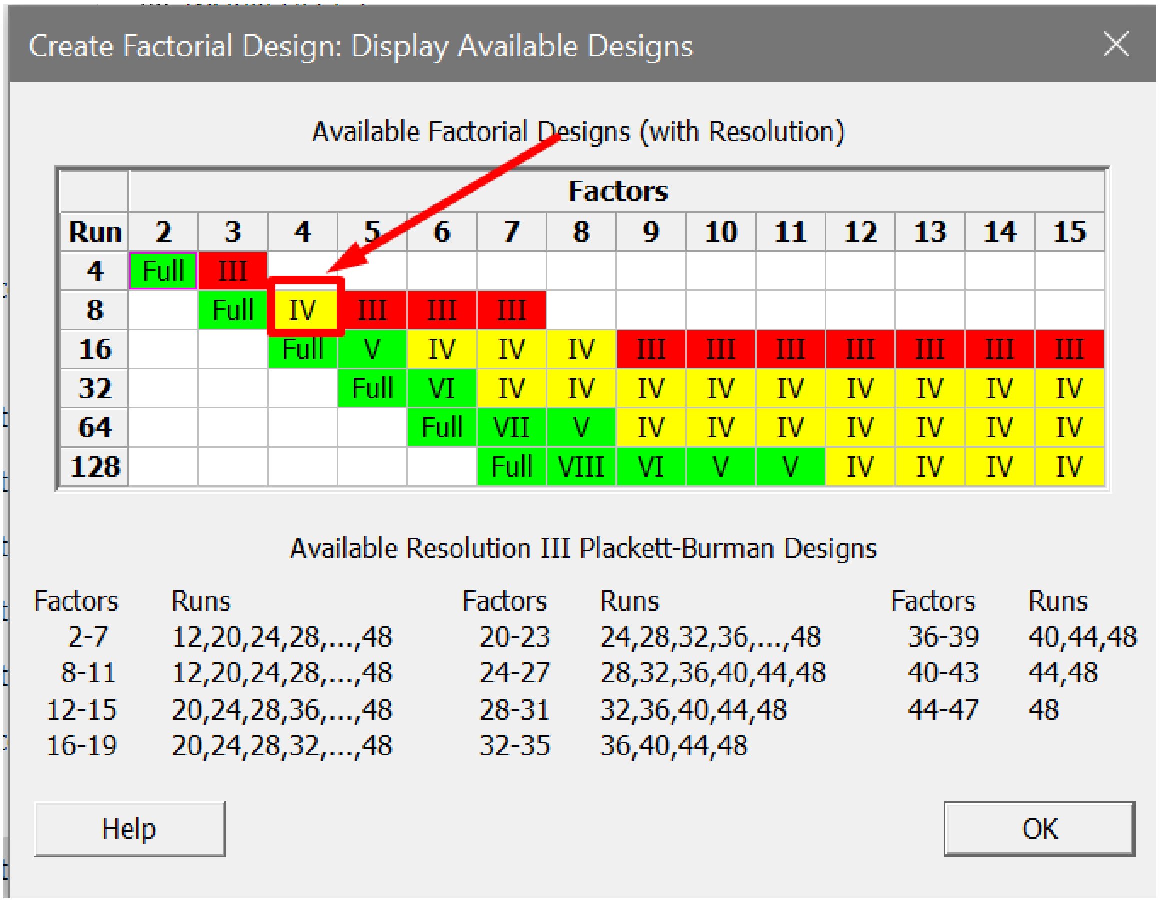
The number of runs exacerbate with more levels.

surpassing 5 Factors will require crazy number of runs!

- You can see that the number of Runs increase dramatically as number of Factors increase!
- Thus we need Fractional Factorial to cut down the number of Runs (we can do Screening to Screen out the unimportant Runs as shown later).



- Similarly, in the previous experiment (Create Factorial Designs) we did a 2^4 (2 Levels 4 Factors) which we have the option of running the Full Experiment (=16 runs… in which we did…), or we could just do 8 runs.



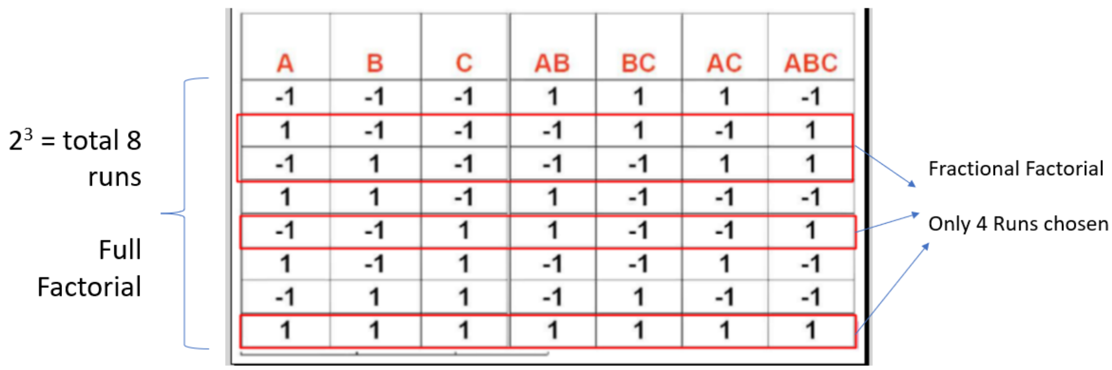
Run	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

- If we had chosen 8 Runs, this would be a resolution IV (see picture above, in Yellow)

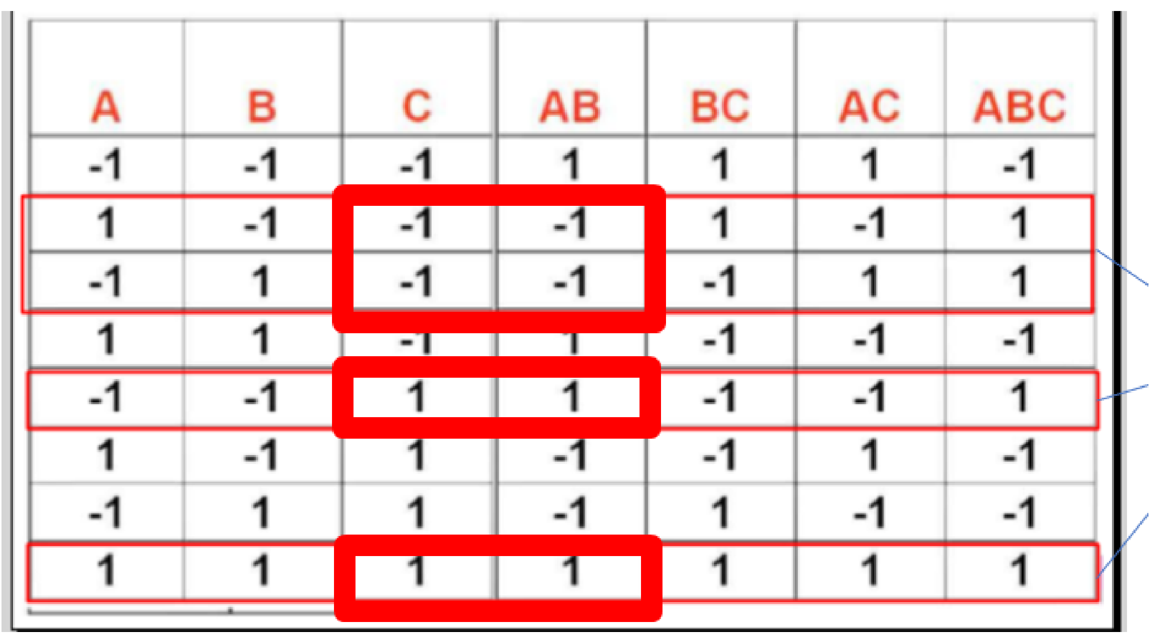
H. RESOLUTION AND CONFOUNDING

- So long as you do not Run Full Factorials (which means, Run all possible combinations i.e. perform ALL experiments), you will experience Confounding.



A	B	C	AB	BC	AC	ABC
-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

- Presume we have the above: 8 runs cut down to 4 runs….



A	B	C	AB	BC	AC	ABC
-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

- Notice that C and AB have the same effects! They are Confounded!

A	B	C	AB	BC	AC	ABC
-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

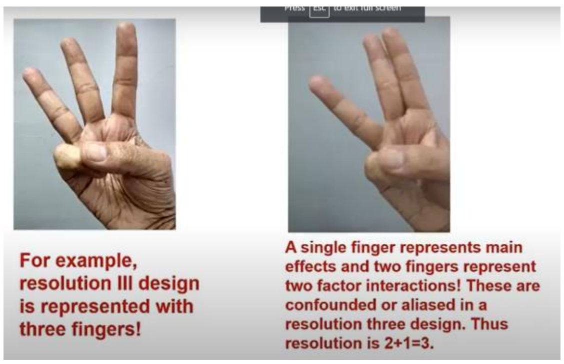
- Notice that B and AC have the same effects! They are Confounded!

A	B	C	AB	BC	AC	ABC
-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

- Notice that A and BC have the same effects! They are Confounded!

- Since they have the same effects, Confounding means that you cannot tell whether the Response is due to
    - A or BC?
    - B or AC?
    - C or AB?

1. RESOLUTION III



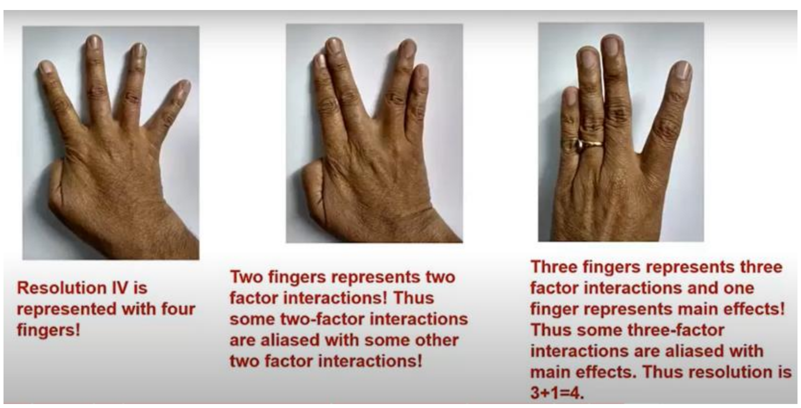
A + BC

B + AC

C + AB

Resolution III

2. RESOLUTION IV



A + BCD

B + ACD

C + ABD

D + ABC

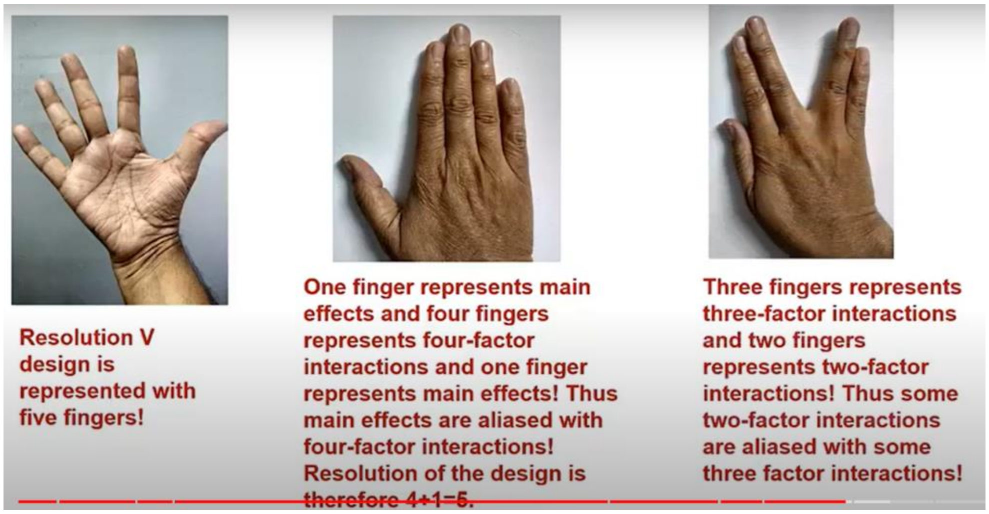
AB + CD

AC + BD

AD + BC

Resolution IV

3. RESOLUTION V



A + BCDE	AE + BCD
B + ACDE	BC + ADE
C + ABDE	BD + ACE
D + ABCE	BE + ACD
E + ABCD	CD + ABE
AB + CDE	CE + ABD
AC + BDE	DE + ABC
AD + BCE	Resolution V

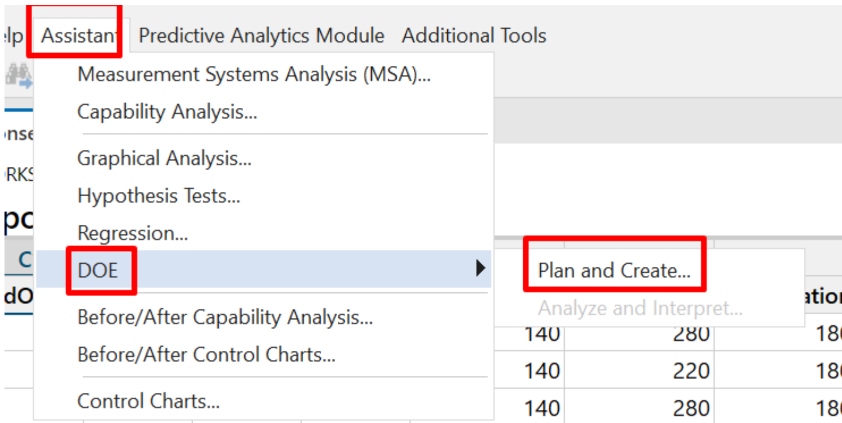
- Confounding should be Avoided because we cannot differentiate which Factor is affecting the Response.
- However, due to limitations of Resources, we need to Screen out the unimportant Runs.

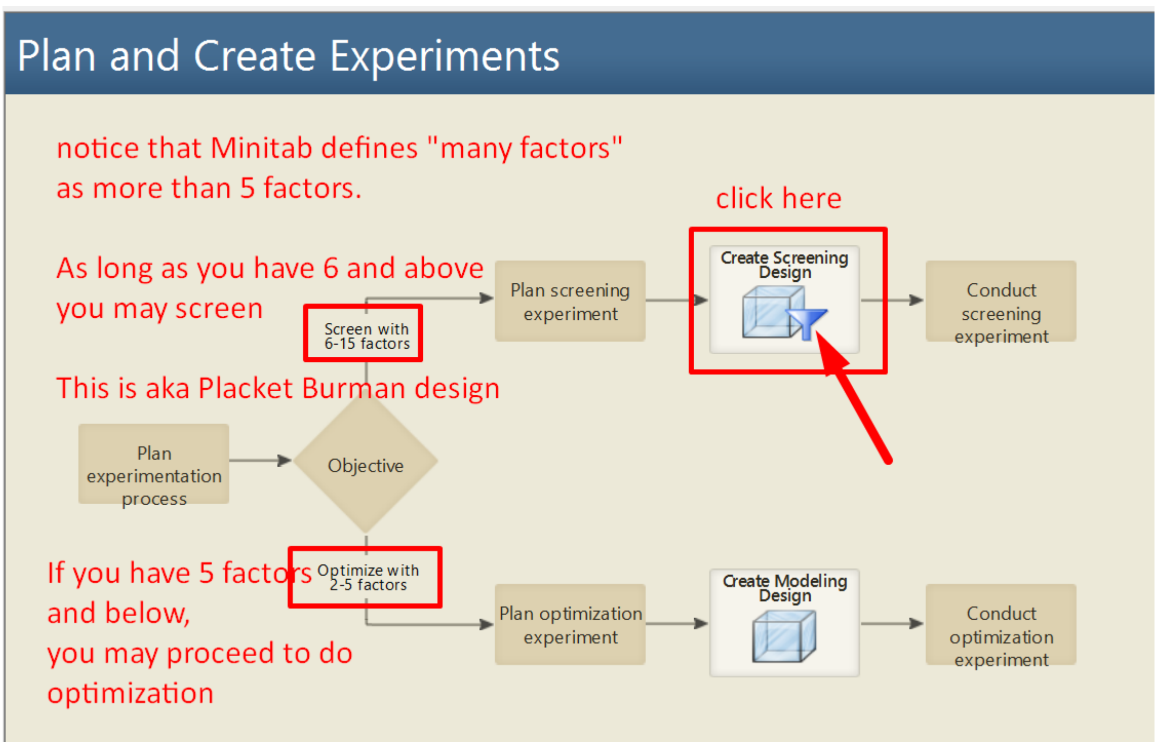
I. SCREENING (PLACKETT BURMAN DESIGN)

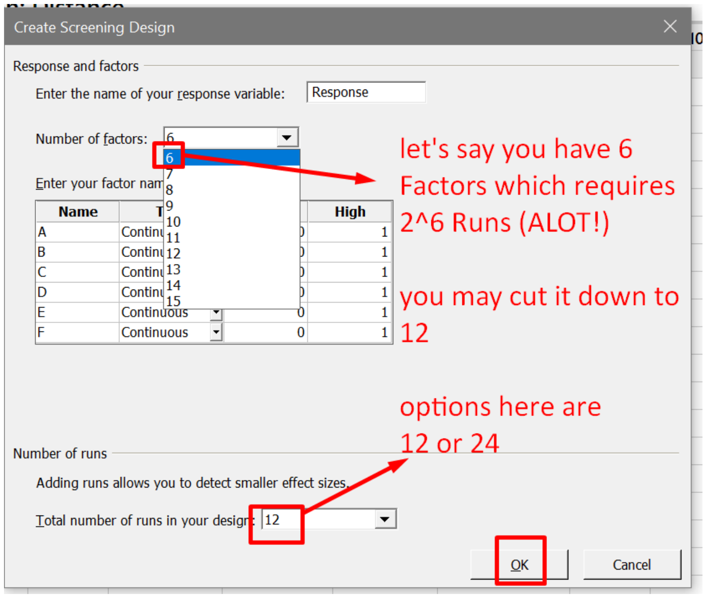
- We already know (from Section: Full vs Fractional Factorials) that that the number of Runs increase dramatically as number of Factors increase (>5 Factors)!
- Thus we need Fractional Factorial to cut down the number of Runs
- Screening helps to Screen out unimportant Runs and cut it down to a Fractional Factorial.
- In this manuscript, we consider 2 ways of Screening:
  - Using Assistant
  - Screening while Creating the Factorial Design
- Note that in this Manuscript we only consider Plackett Burman Screening Design.
- And if we use Assistant option in Minitab, we are actually doing Plackett Burman Screening.
- Plackett Burman designs are only Resolution III experiments AND 6 or more factors.
- It only identifies Main effects and ignore Interaction effects
- In other words, Minitab only performs Screening when we have >6 Factors.
- Else, Minitab will auto-generate the Fractional Factorial Options for us to choose from (while we create the Factorial Design).

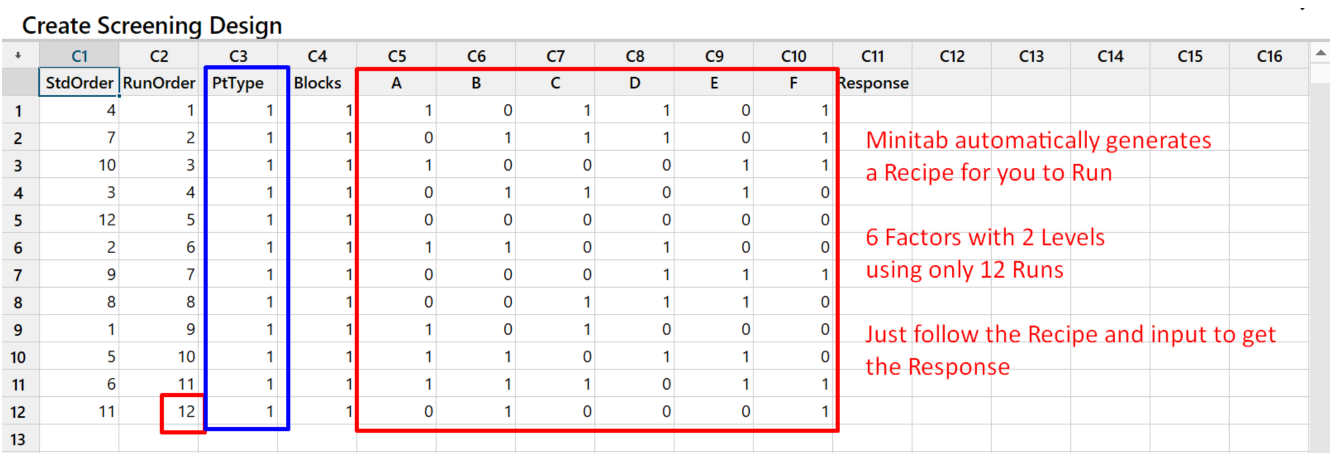
1. USING ASSISTANT

Note that Assistant Screening = Plackett Burman Screening





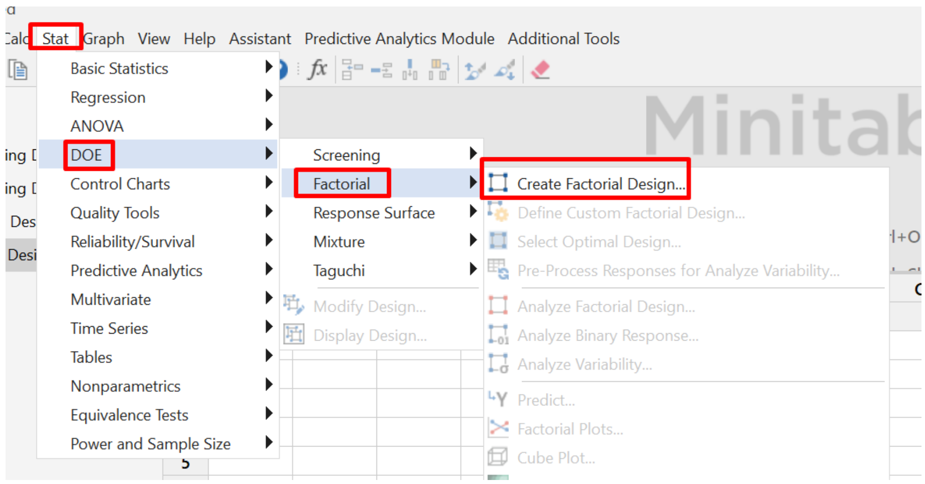


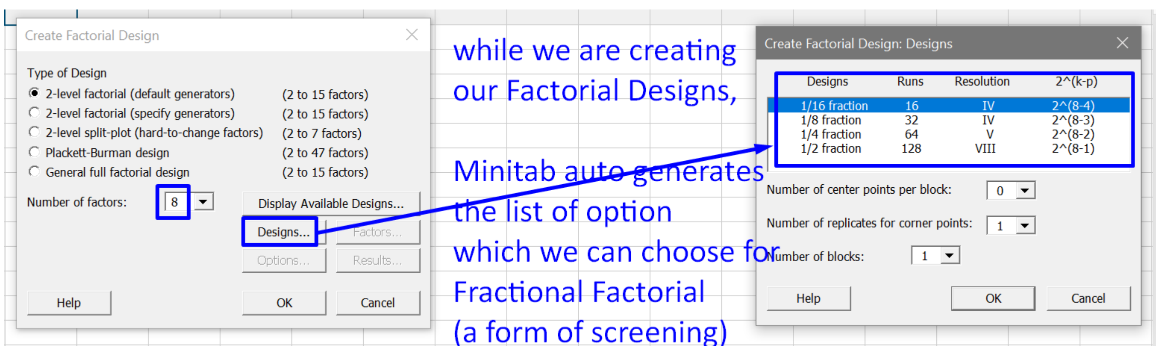


	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	StdOrder	RunOrder	PtType	Blocks	A	B	C	D	E	F	Response
1	4	1	1	1	1	0	1	1	0	1	
2	7	2	1	1	0	1	1	1	0	1	
3	10	3	1	1	1	0	0	0	1	1	
4	3	4	1	1	0	1	1	0	1	0	
5	12	5	1	1	0	0	0	0	0	0	
6	2	6	1	1	1	1	0	1	0	0	
7	9	7	1	1	0	0	0	1	1	1	
8	8	8	1	1	0	0	1	1	1	0	
9	1	9	1	1	1	0	1	0	0	0	
10	5	10	1	1	1	1	0	1	1	0	
11	6	11	1	1	1	1	1	0	1	1	
12	11	12	1	1	0	1	0	0	0	1	
13											

- C3 (CenterPt or PtType) stores the point type.
- If you create a 2-level design, Minitab names this column CenterPt.
- If you create a Plackett-Burman or general full factorial design, Minitab names this column PtType.
- The codes are: 0 is a Center Point run and 1 is a Corner Point. (we will explain Centre Point and Corner Point later in RSM – CCD, next section).

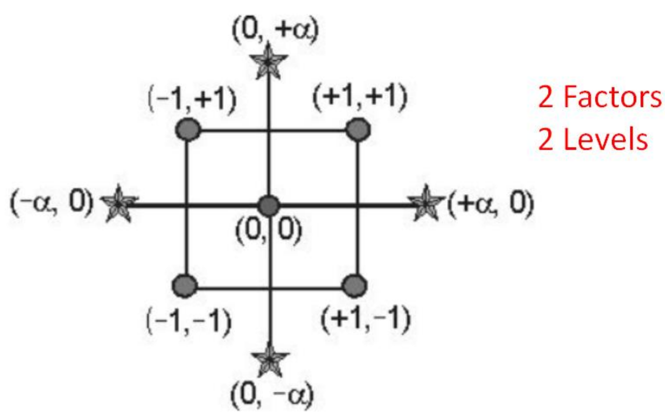
2. SCREENING WHILE CREATING FACTORIAL DESIGN

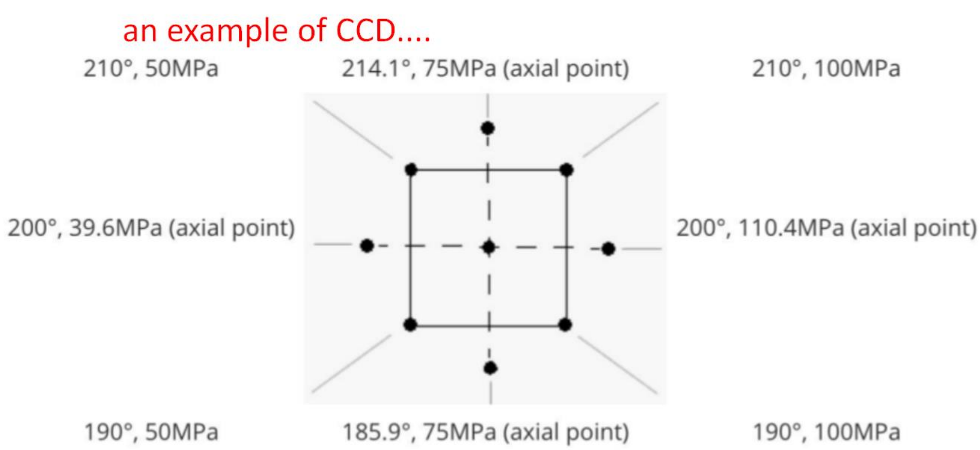




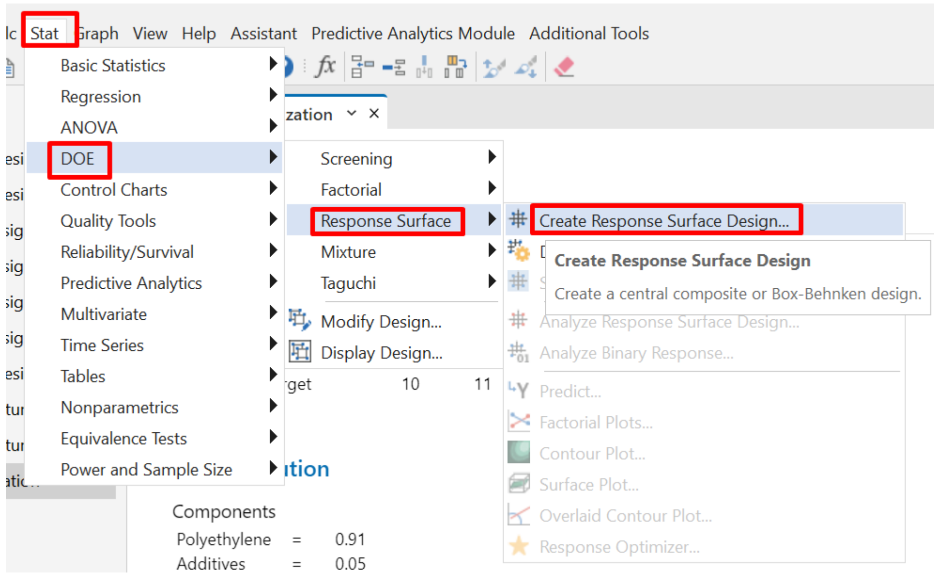
- There are two types of Response Surface Methods (RSM)
    - Central Composite Design (CCD)
    - Box-Behnken

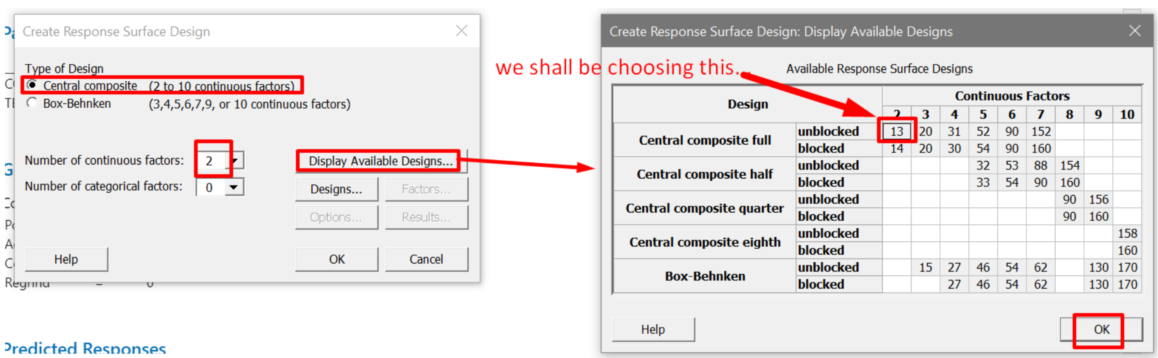
A. CENTRAL COMPOSITE DESIGN (CCD)

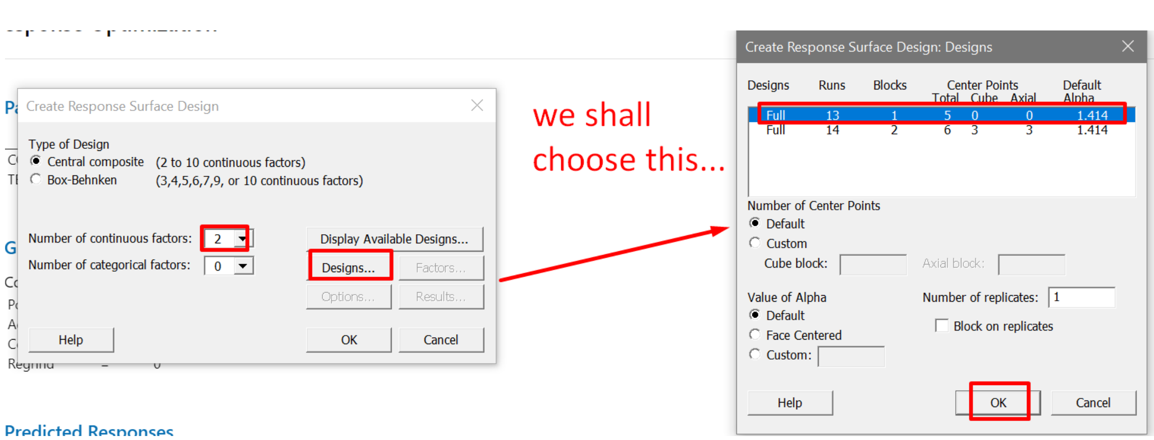


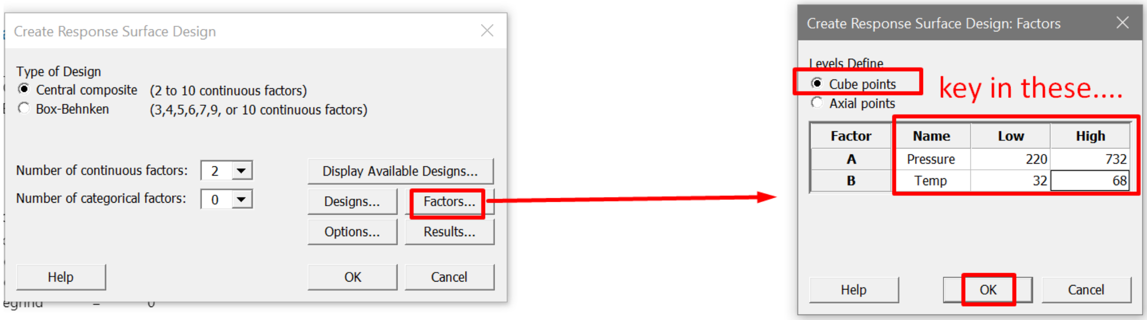


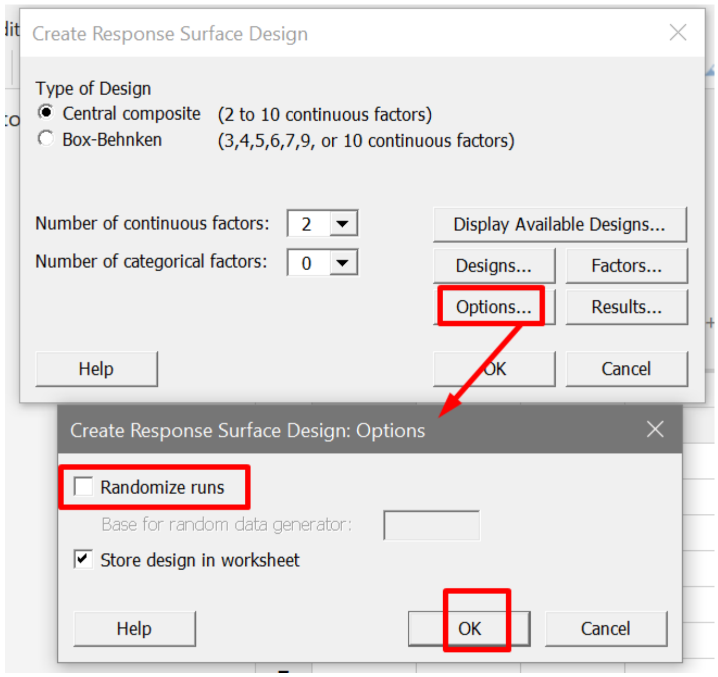
1. CREATING THE EXPERIMENT







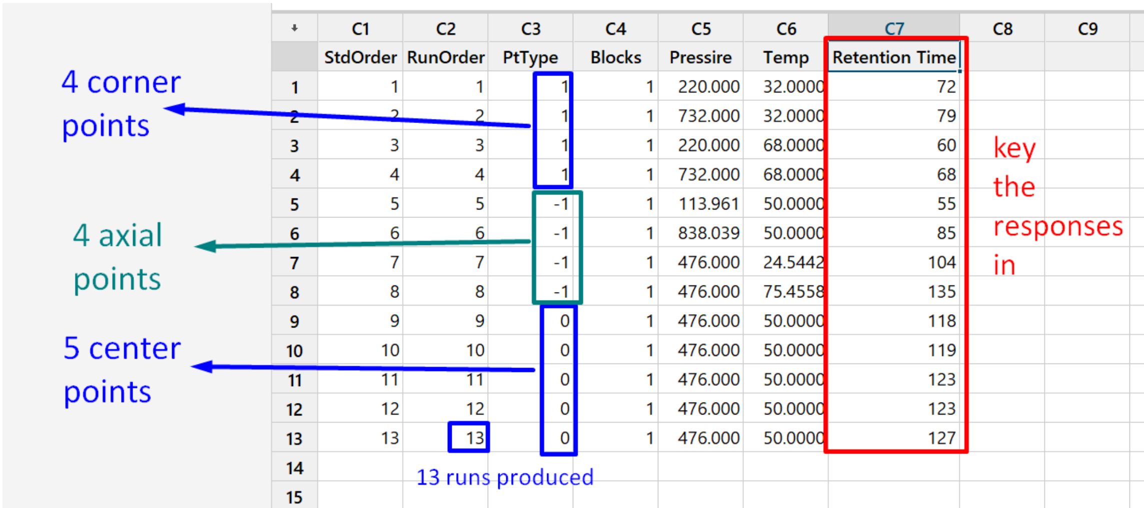




As you can see frrom the above, we have many CCDs….

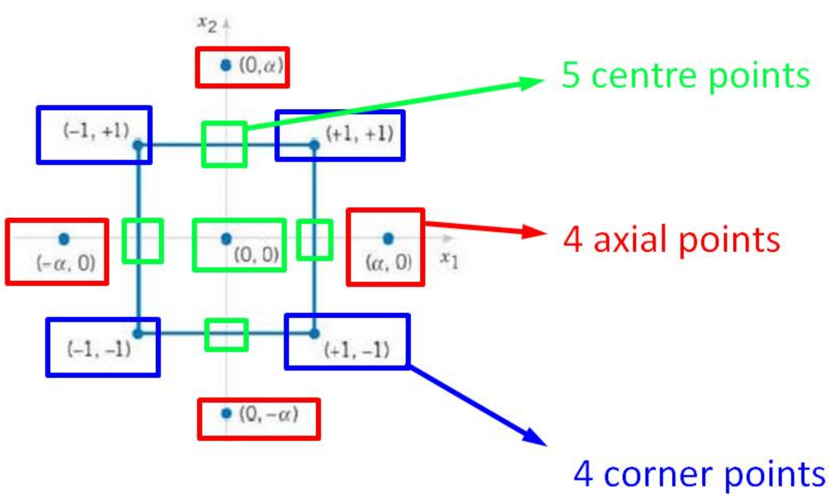
- Full / Half / Quarter / Eighth….
- We will not go through them
- More explanation here: https://support.minitab.com/en-us/minitab/21/help-and-how-to/statistical-modeling/doe/supporting-topics/response-surface-designs/summary-of-central-composite-designs/

2. EXPLAINING THE PT TYPE



↓	C1	C2	C3	C4	C5	C6	C7	C8	C9
	StdOrder	RunOrder	PtType	Blocks	Pressire	Temp	Retention Time		
1	1	1	1	1	220.000	32.0000	72		
2	2	2	1	1	732.000	32.0000	79		
3	3	3	1	1	220.000	68.0000	60		
4	4	4	1	1	732.000	68.0000	68		
5	5	5	-1	1	113.961	50.0000	55		
6	6	6	-1	1	838.039	50.0000	85		
7	7	7	-1	1	476.000	24.5442	104		
8	8	8	-1	1	476.000	75.4558	135		
9	9	9	0	1	476.000	50.0000	118		
10	10	10	0	1	476.000	50.0000	119		
11	11	11	0	1	476.000	50.0000	123		
12	12	12	0	1	476.000	50.0000	123		
13	13	13	0	1	476.000	50.0000	127		
14									
15									

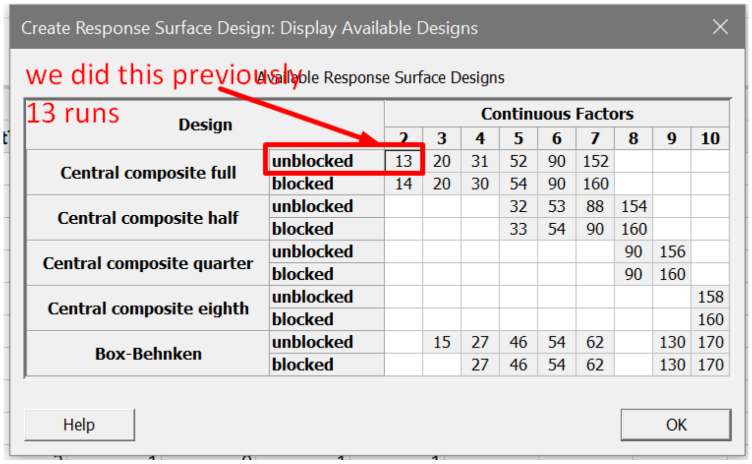
How did we manage to achieve 13 runs?



- 5 Centre Points + 4 Axial Points + 4 Corner Points = 13 Runs in total

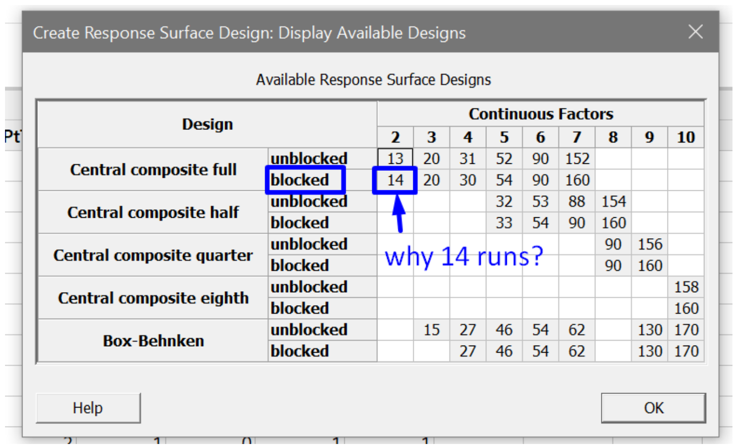
a) Blocking within CCD

- Previously, we saw that 5 Centre Points + 4 Axial Points + 4 Corner Points = 13 Runs in total
- But they were all run in 1 Block. (unblocked)



Design		Continuous Factors 2	3	4	5	6	7	8	9	10
Central composite full	unblocked	13	20	31	52	90	152			
	blocked	14	20	30	54	90	160			
Central composite half	unblocked				32	53	88	154		
	blocked				33	54	90	160		
Central composite quarter	unblocked							90	156	
	blocked							90	160	
Central composite eighth	unblocked									158
	blocked									160
Box-Behnken	unblocked		15	27	46	54	62		130	170
	blocked			27	46	54	62		130	170

- Presume now there was Blocking (we wanted to Run the experiment in 2 days or 2 blocks).



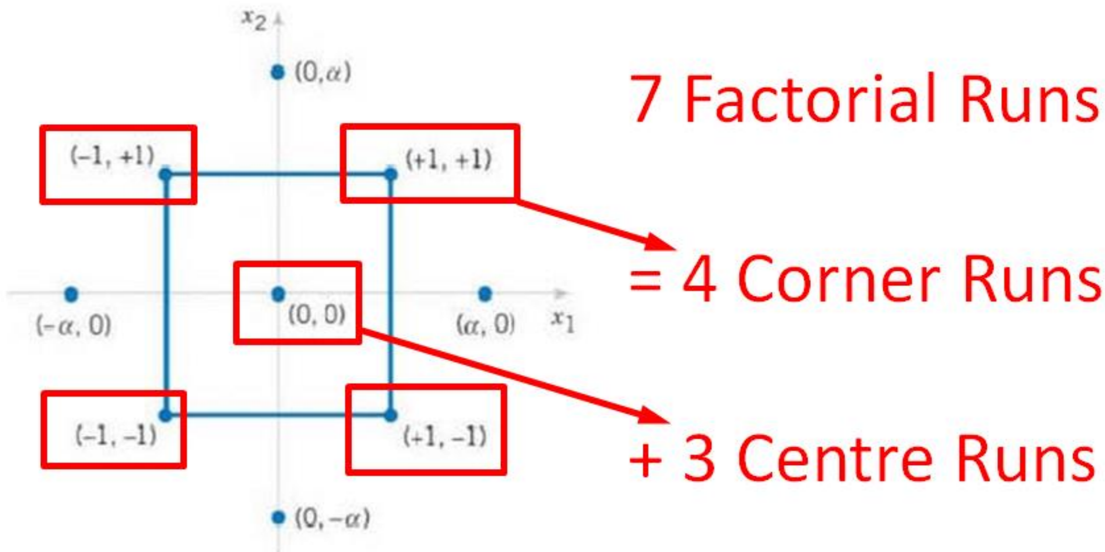
Design		Continuous Factors 2	3	4	5	6	7	8	9	10
Central composite full	unblocked	13	20	31	52	90	152			
	blocked	14	20	30	54	90	160			
Central composite half	unblocked				32	53	88	154		
	blocked				33	54	90	160		
Central composite quarter	unblocked							90	156	
	blocked							90	160	
Central composite eighth	unblocked									158
	blocked									160
Box-Behnken	unblocked		15	27	46	54	62		130	170
	blocked			27	46	54	62		130	170

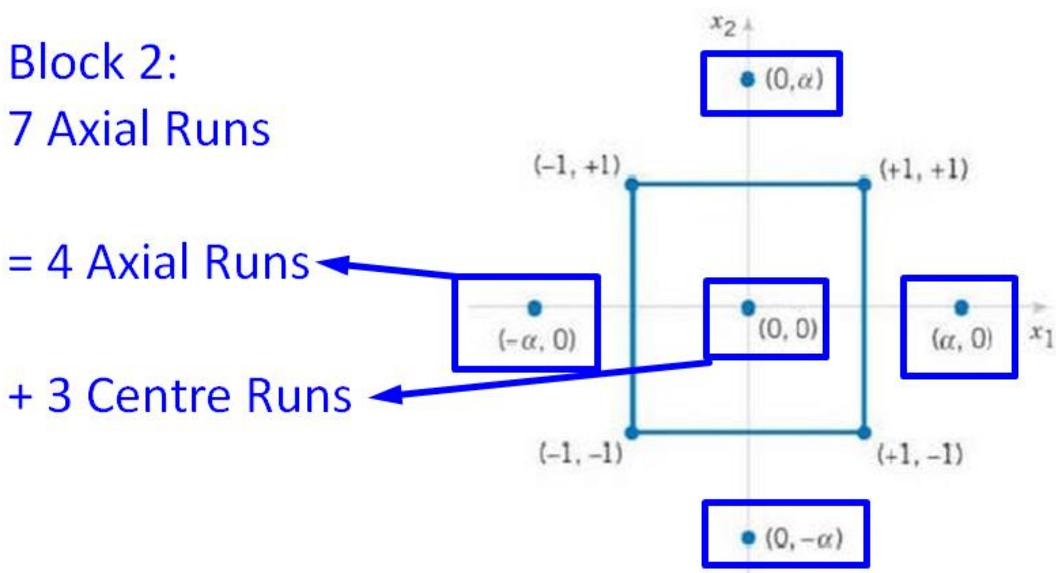
- Why do we need 14 runs?

Pattern	Block	X_1	X_2	Comment
--	1	-1	-1	Full Factorial
-+	1	-1	+1	Full Factorial
+-	1	+1	-1	Full Factorial
++	1	+1	+1	Full Factorial
00	1	0	0	Center-Full Factorial
00	1	0	0	Center-Full Factorial
00	1	0	0	Center-Full Factorial
-0	2	-1.414214	0	Axial
+0	2	+1.414214	0	Axial
0-	2	0	-1.414214	Axial
0+	2	0	+1.414214	Axial
00	2	0	0	Center-Axial
00	2	0	0	Center-Axial
00	2	0	0	Center-Axial

(this picture shows 14 runs = 7 Corner (Factorial) Runs and 7 Axial Runs)

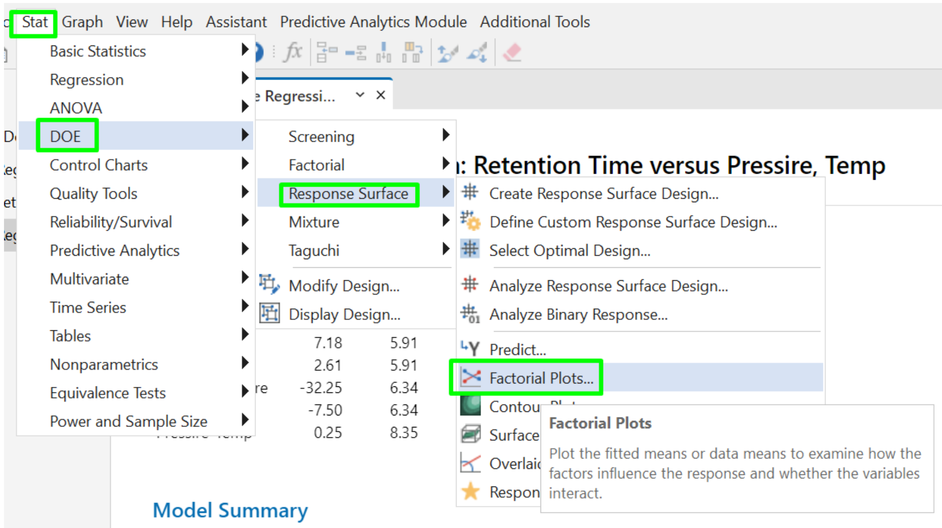
- 14 Runs is because, when two blocks are required there should be a
    - Factorial Block (Block 1 = 7 Factorial Runs) and
    - An Axial Block (Block 2 = 7 Axial Runs).

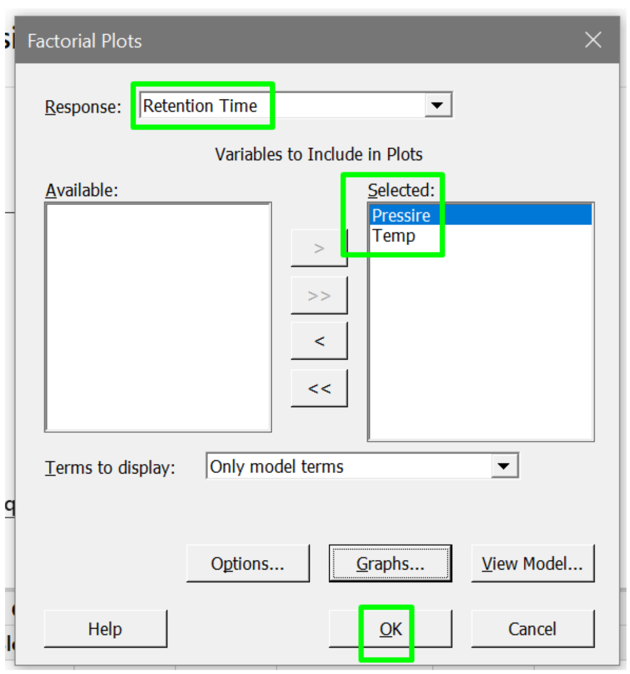

x_2
(0,α)
(−1, +1)
(+1, +1)
(−α, 0)
(0, 0)
(α, 0)
x_1
(−1, −1)
(+1, −1)
(0, −α)
7 Factorial Runs
= 4 Corner Runs
+ 3 Centre Runs

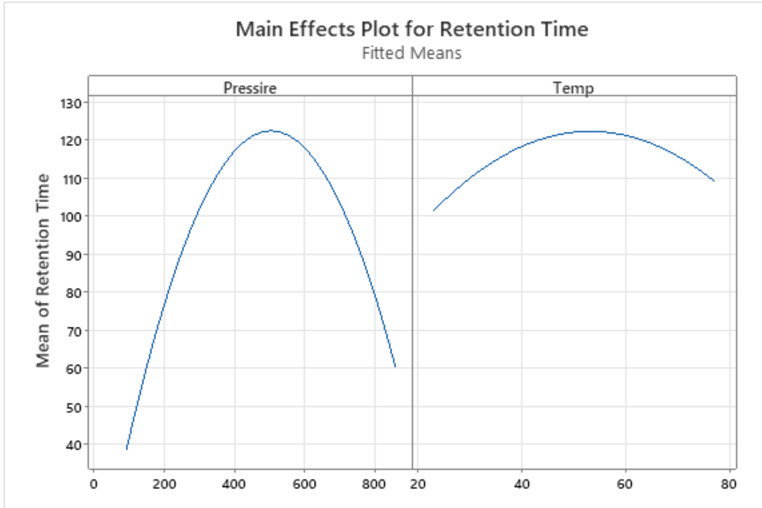

Block 2:
7 Axial Runs
= 4 Axial Runs
+ 3 Centre Runs
x_2
(0,α)
(−1, +1)
(+1, +1)
(−α, 0)
(0, 0)
(α, 0)
x_1
(−1, −1)
(+1, −1)
(0, −α)

3. ANALYZING THE CCD EXPERIMENT

a) Factorial Plot





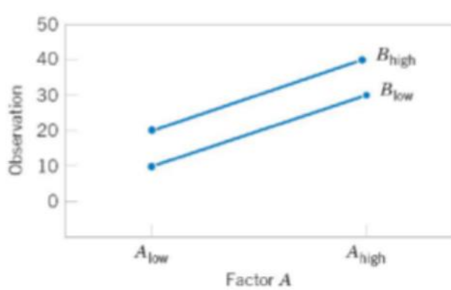


- Notice the difference between the chart above vs the one in Section: Factorial Plot (ctrl click the link).

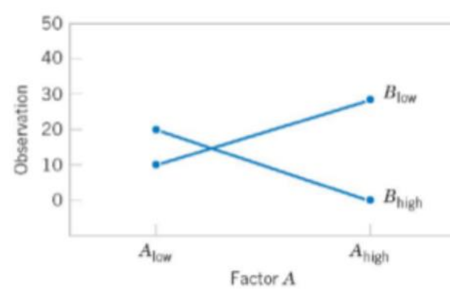
- The Factorial Plot of a CCD is curved because Minitab generated many points to test per Factor. E.g. Pressure = 220 / 732 / 114 / 838 / 476…

- If you compare this to a Factorial Plot of a Simple 2 points experiment (shown below)…. You see that its impossible to generate a curve with just 2 points….(high and low)

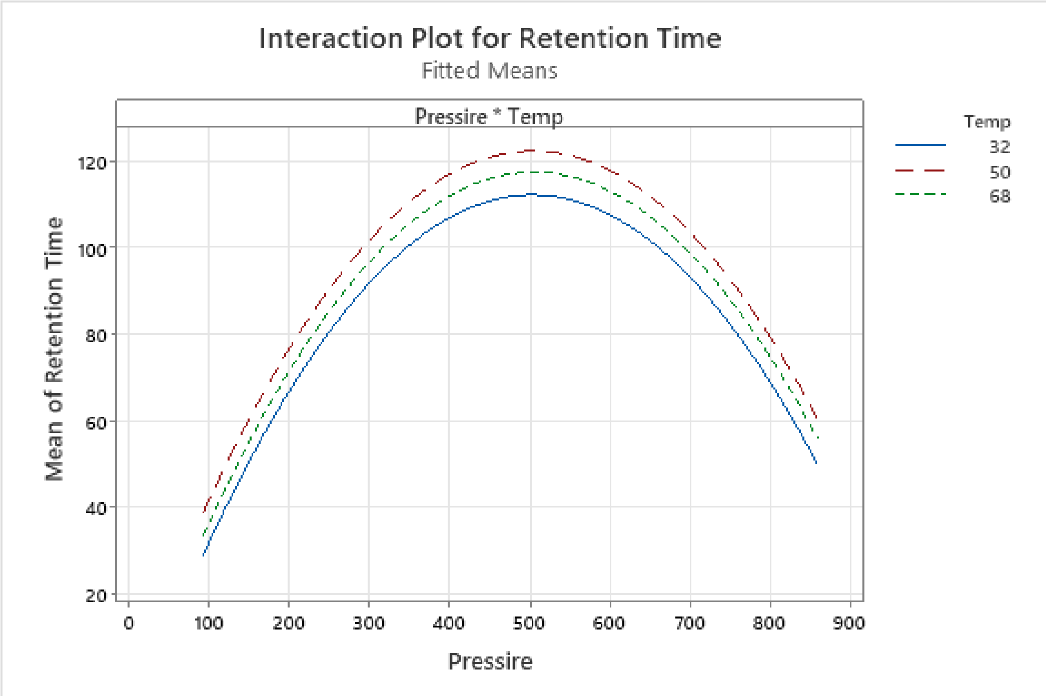
- Thus, CCD (RSM) is better than a Simple Factorial Experiment because it can detect curvature (Non-Linear)



No Interaction

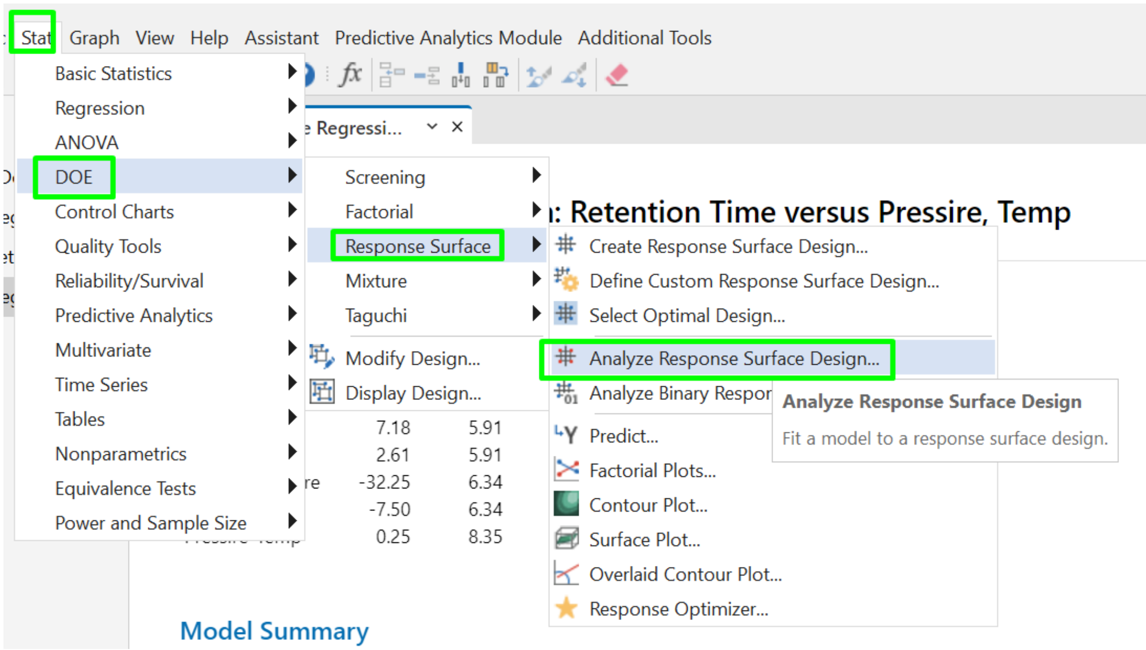


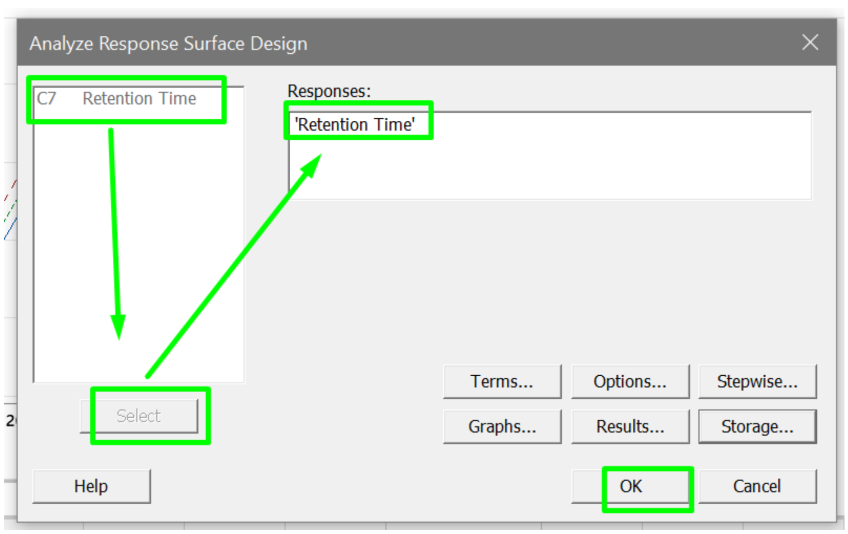
With Interaction



We note that there is a maximum Retention Time when the Pressure is arouund 500 and the Temperature around 50.

b) Pareto Chart and Model Equation





Regression Equation in Uncoded Units

Retention Time = -66.7 + 0.494 Pressire + 2.43 Temp - 0.000492 Pressire*Pressire - 0.0231 Temp*Temp + 0.00005 Pressire*Temp

An equation to model the relationship is created....
Note that its non-linear...

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	7778.75	1555.75	5.57	0.022
Linear	2	466.52	233.26	0.84	0.473
Pressire	1	412.22	412.22	1.48	0.264
Temp	1	54.29	54.29	0.19	0.673
Square	2	7311.98	3655.99	13.09	0.004
Pressire*Pressire	1	7235.22	7235.22	25.91	0.001
Temp*Temp	1	391.30	391.30	1.40	0.275
2-Way Interaction	1	0.25	0.25	0.00	0.977
Pressire*Temp	1	0.25	0.25	0.00	0.977
Error	7	1954.48	279.21		
Lack-of-Fit	3	1902.48	634.16	48.78	0.001
Pure Error	4	52.00	13.00		
Total	12	9733.23			

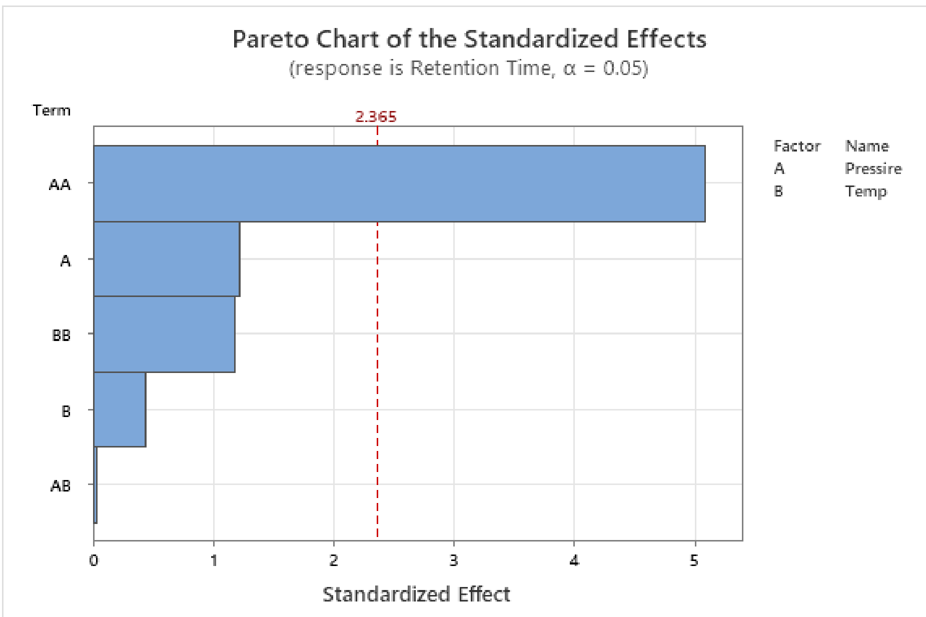
we ignore the linear model since curvature is significant

0.001 < 0.05 means that Pressure is significant

0.275 > 0.05 means that Temperature is insignificant

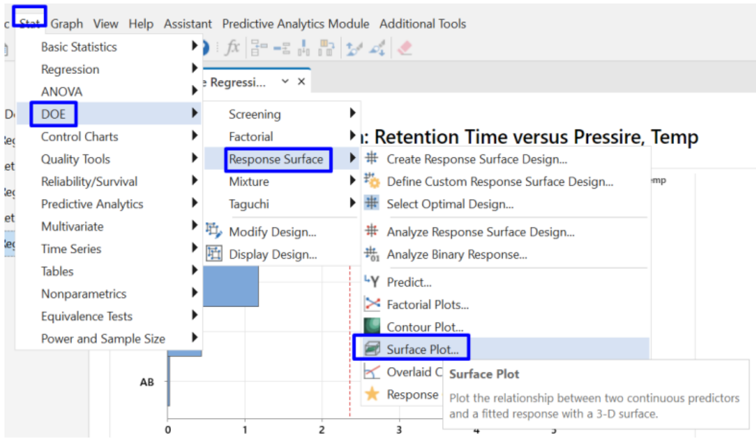
the interatction between Press and Temp is insignificant

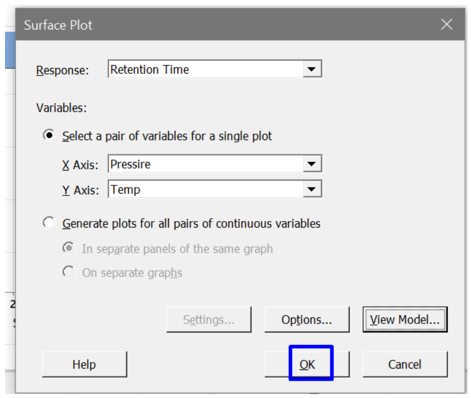
0.001 < 0.05 means that the curvature is significant

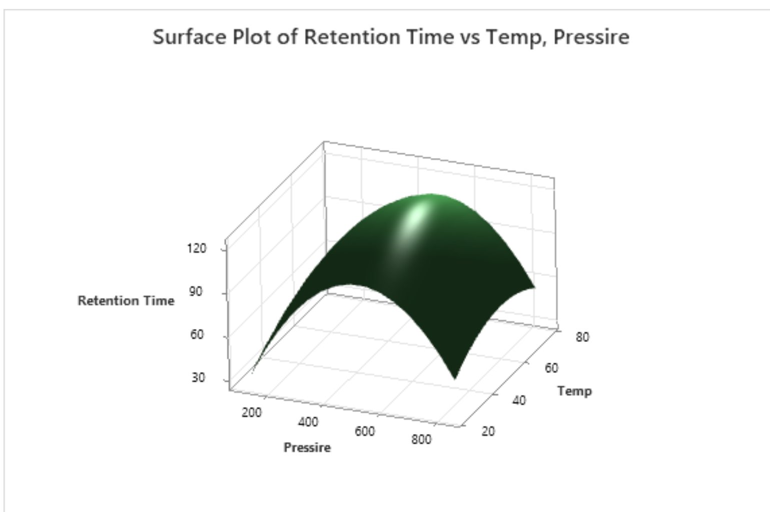


- We note that Pressure is the Key Factor affecting Response Time.
- Temperature is insignificant.

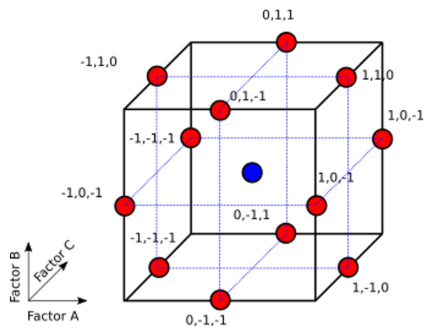
c) Surface Plot



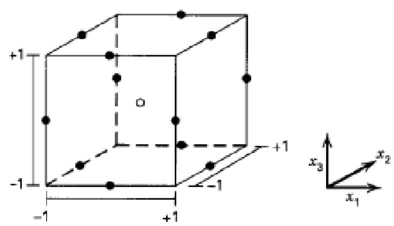


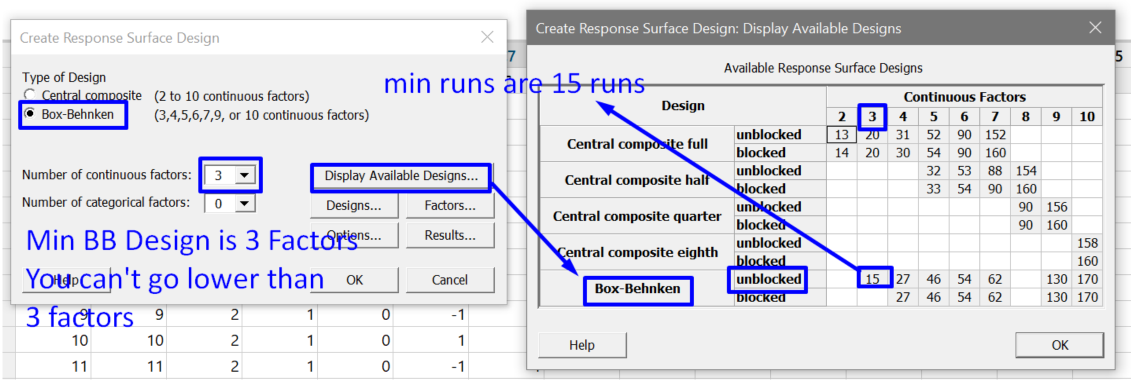


B. BOX-BEHNKEN DESIGN



Run	x_1	x_2	x_3
1	−1	−1	0
2	−1	1	0
3	1	−1	0
4	1	1	0
5	−1	0	−1
6	−1	0	1
7	1	0	−1
8	1	0	1
9	0	−1	−1
10	0	−1	1
11	0	1	−1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0



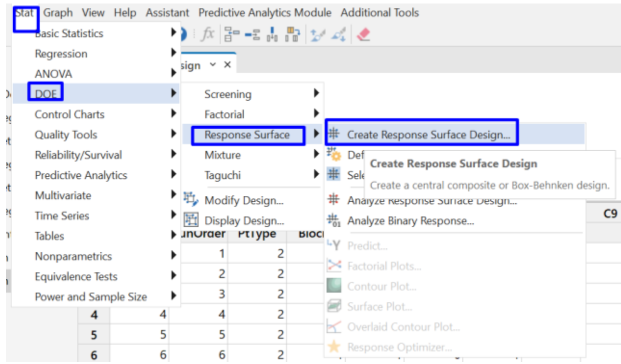


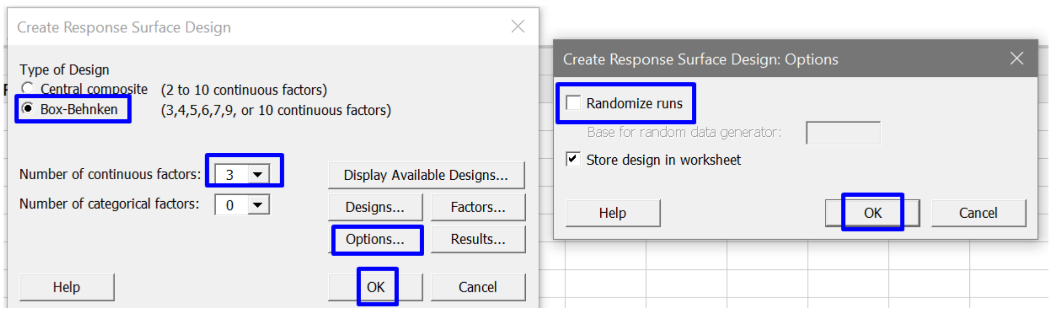
- Note that a 3 Factor 2 Level BB Design minimum is 15 Runs

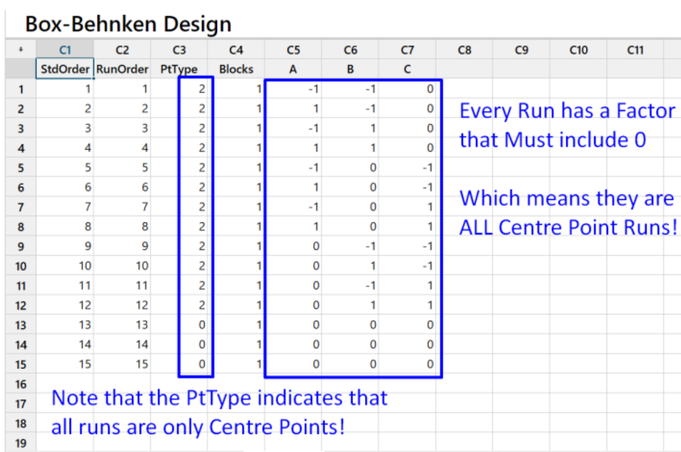
- Note that BB Design are ALL Centre Point Runs!!!

- In other words, BB is a special subset of the CCD (you can imagine it to be a Fractional Factorial of a Full Factorial Design).

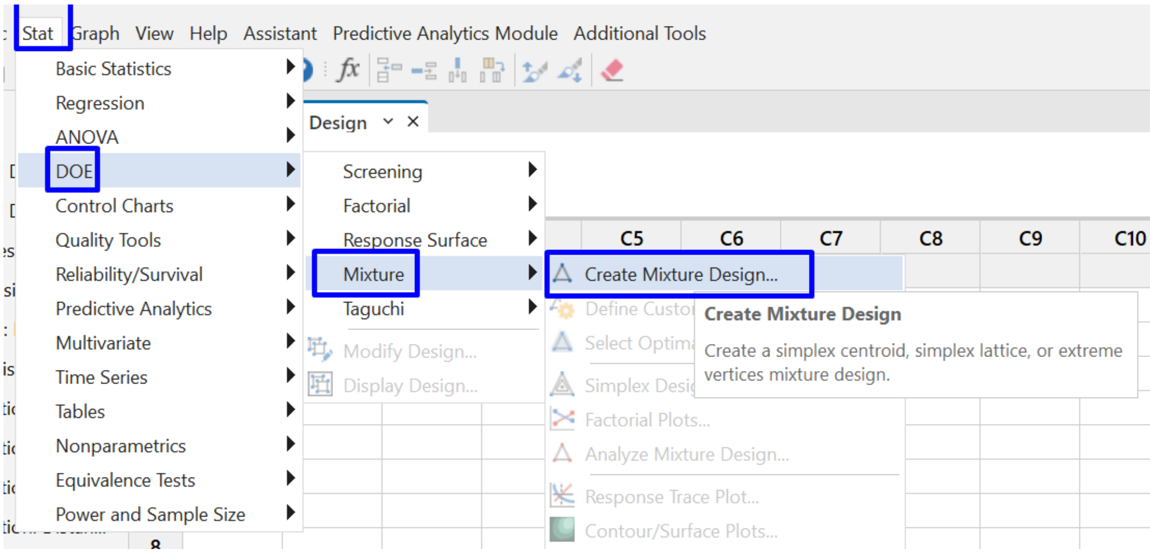
1. CREATING THE BB EXPERIMENT

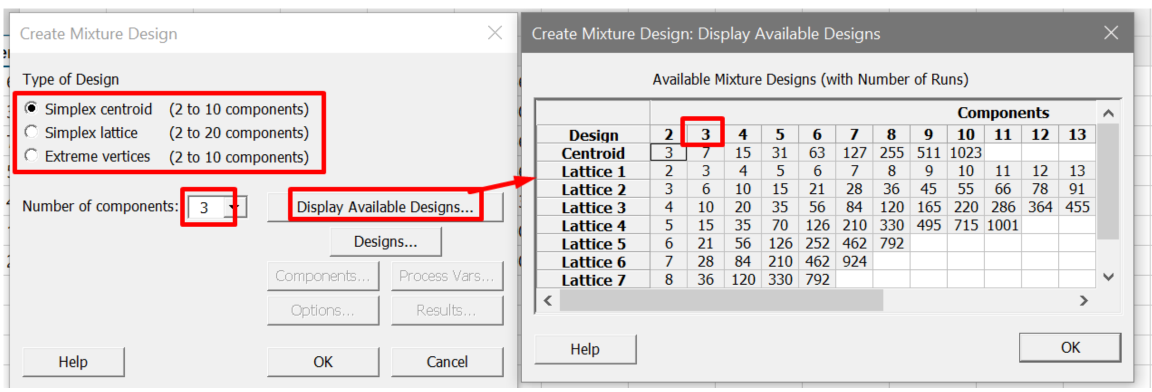






- We shall not carry on with further experiments.
- We shall stop here at only creating the BB experimental design.
- This is because the rest of the steps are similar and can be repeated as above (see section: CCD: Creating the Experiment (ctrl click the link))

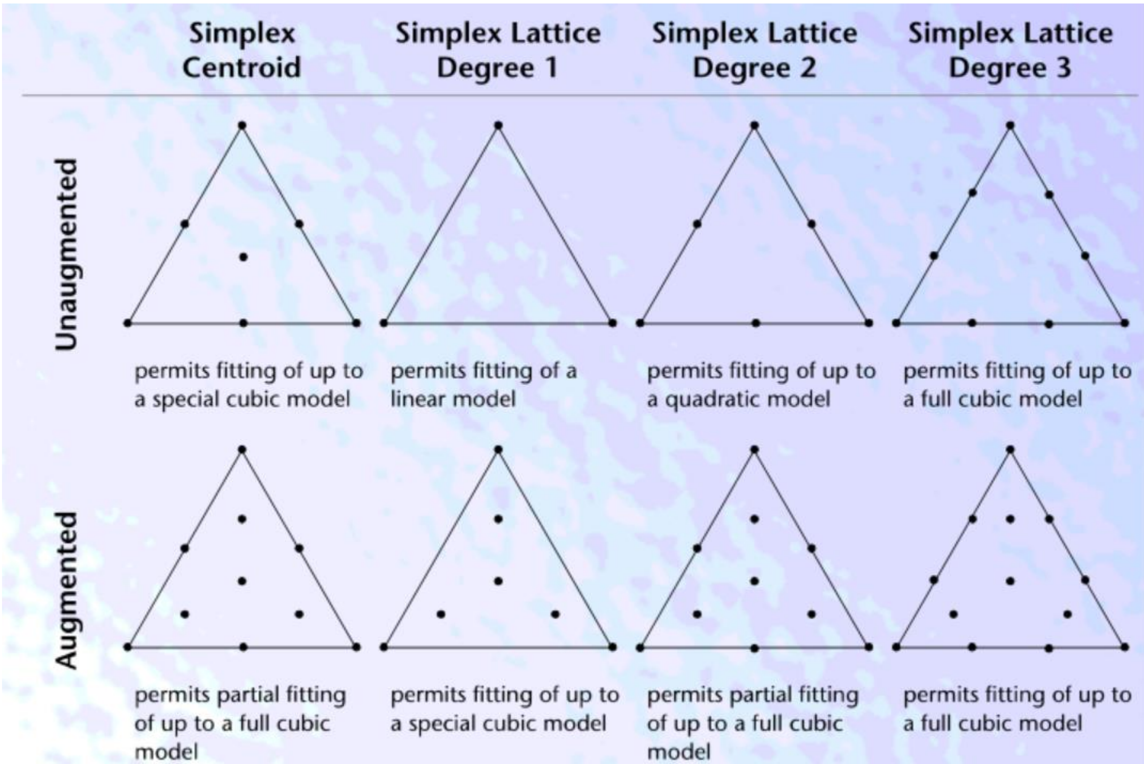




There are 3 types of Mixture Designs:

- Simplex Centroid
- Simplex Lattice
- Extreme Vertices

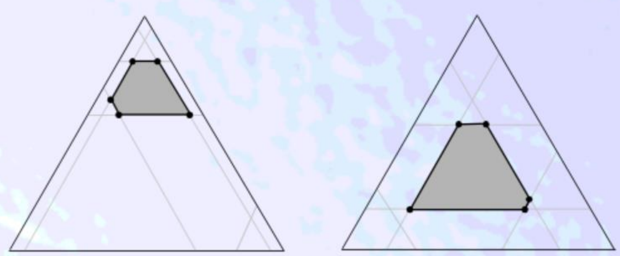
A. WHAT IS A MIXTURE DESIGN



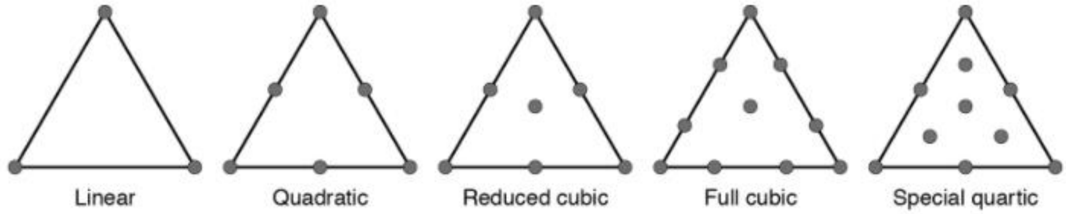
Extreme vertices designs

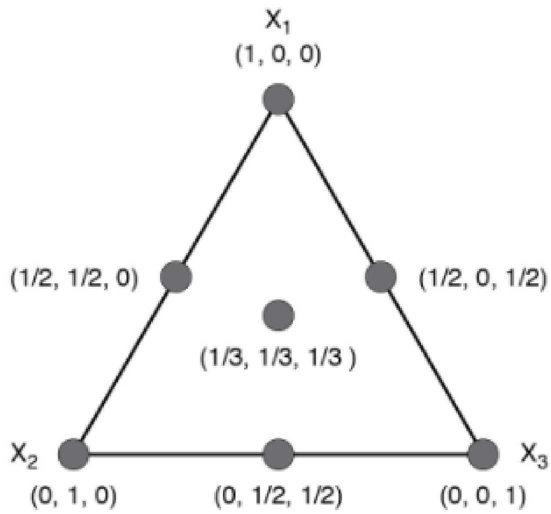
Very Complex
We will not dwell further into this....

In extreme vertices designs, MINITAB employs an algorithm that generates extreme vertices and their blends up to the specified degree. These designs must be used when your chosen design space is not an L-simplex. The presence of both lower and upper bound constraints on the components often create this condition. The goal of an extreme vertices design is to choose design points that adequately cover the design space. The illustration below shows the extreme vertices for two three-component designs with both upper and lower constraints:



The light gray lines represent the lower and upper bound constraints on the components. The dark gray area represents the design space. The points are placed at the extreme vertices of design space.

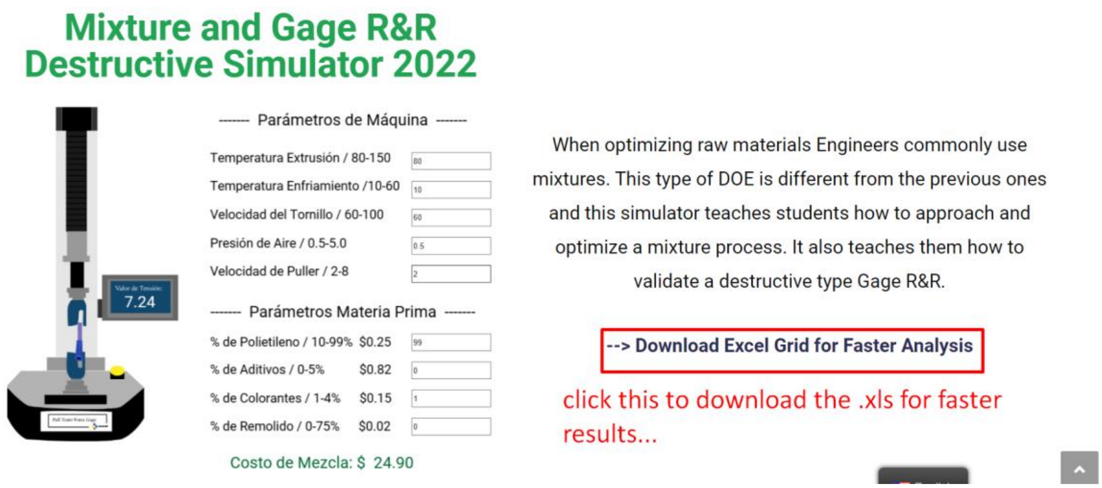


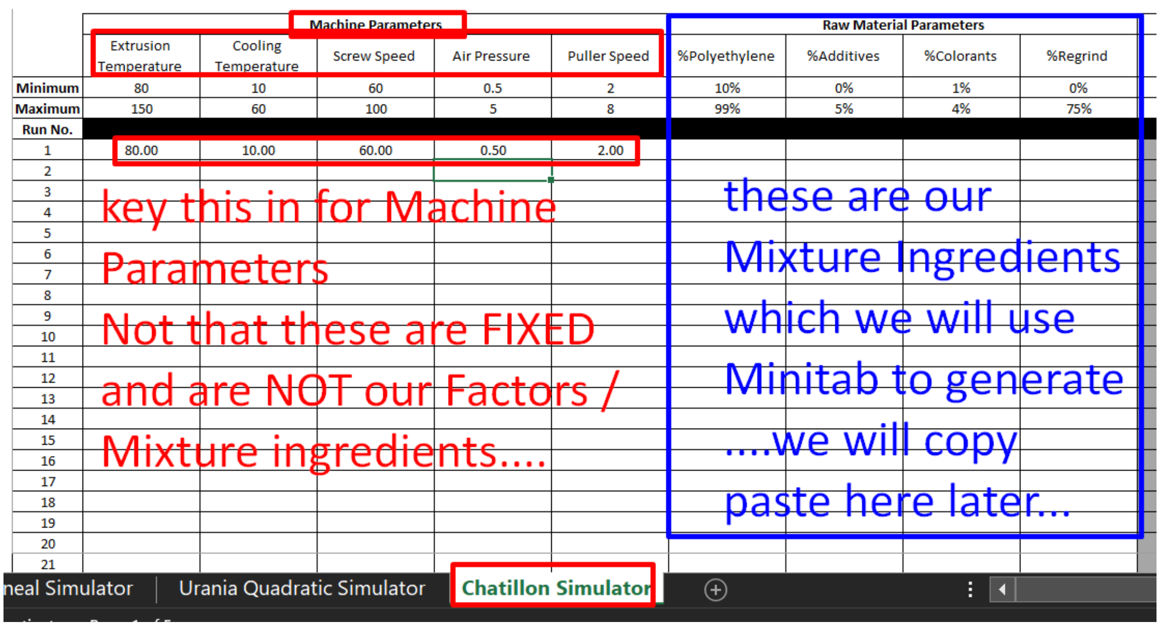


- Picture above shows a Simplex Centroid (Unaugmented) with 7 Points (7 Runs)
- There are 3 Components / Factors (X1 / X2 / X3)
- X1 + X2 + X3 Must == 100% → They are ingredients (mixture) which make up a total percentage of 100%.

B. MIXTURE EXPERIMENT EXAMPLE

- Go https://cusum.mx/en/simuladores/





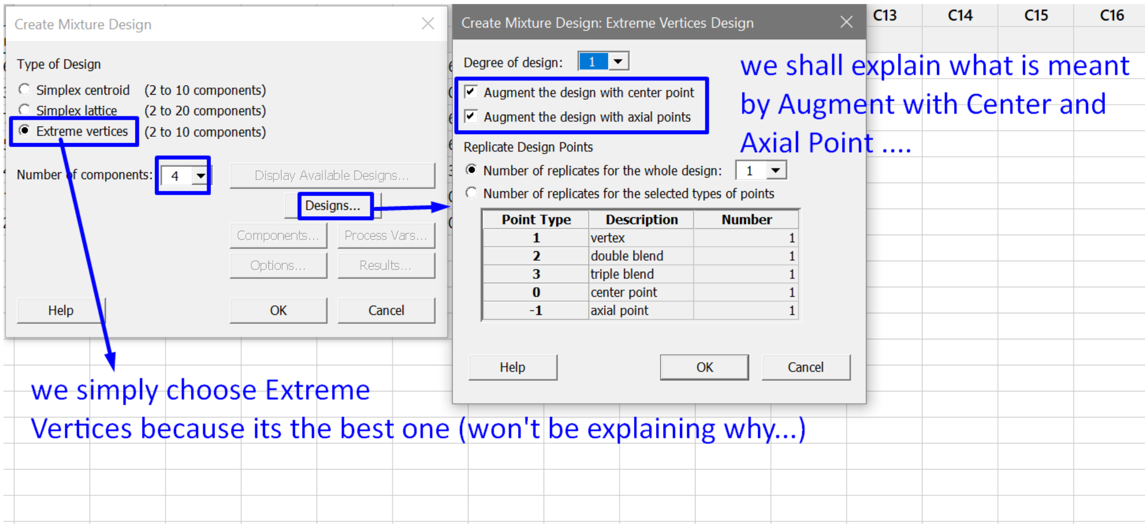
The Machine Parameters (Fixed Constants) are:

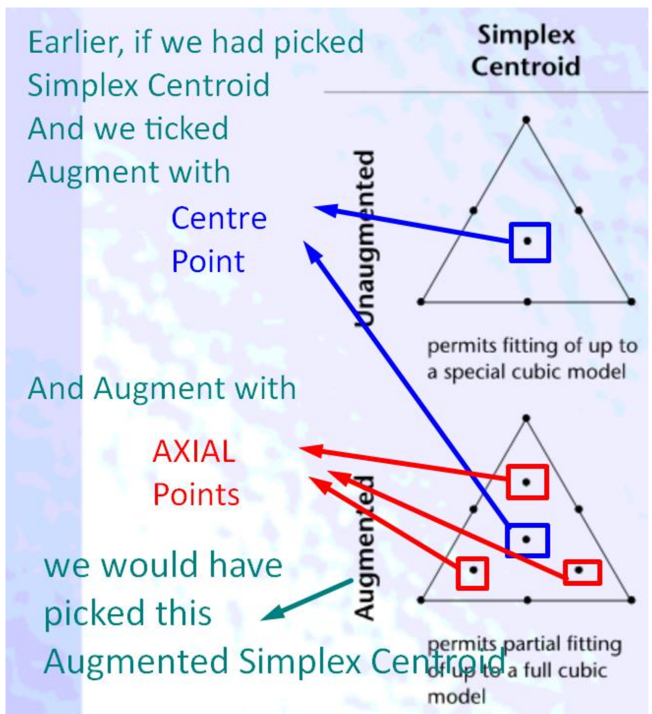
- Extrusion: 80
- Cooling: 10
- Screw: 60
- Air: 0.5
- Puller: 2

The Raw Material Parameters (Mixture Ingredients) are:

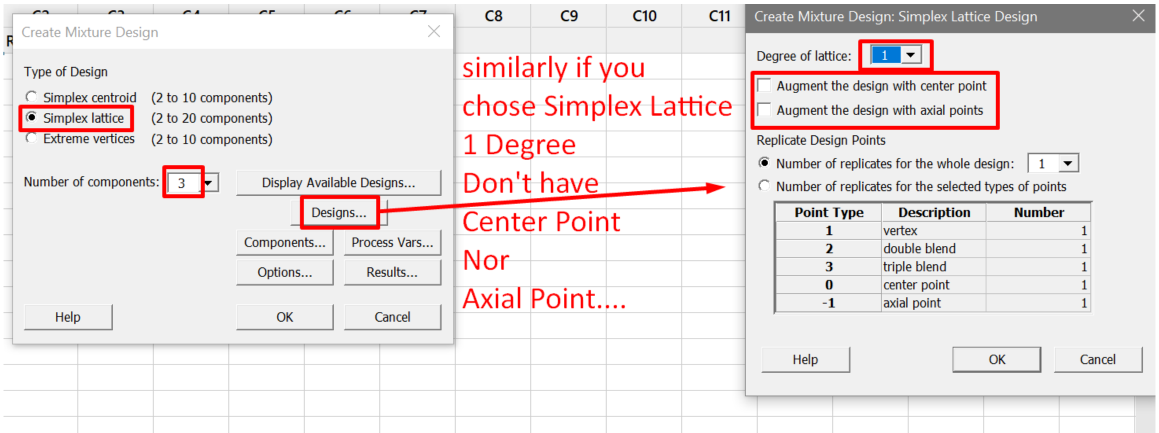
- Polyethylene: 10 ~ 99%
- Additives: 0 ~5%
- Colorants: 1 ~ 4%
- Regrind: 0~75%

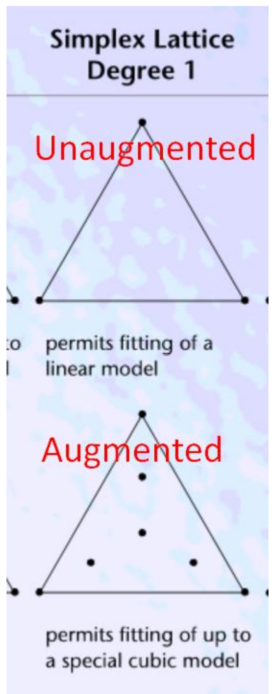
1. CREATING THE MIXTURE EXPERIMENT





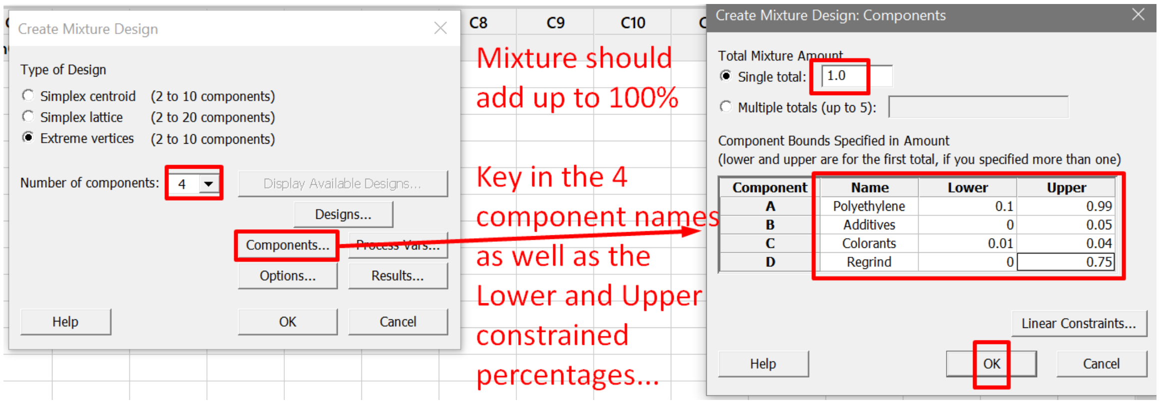
An Augmented Simplex Centroid has 10 Points (see above picture).. thus it will produce a table of 10 runs…

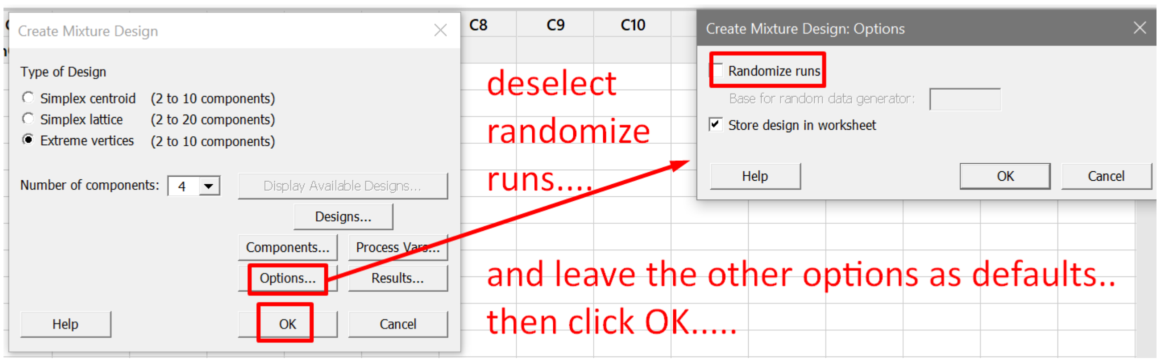




	C1	C2	C3	C4	C5	C6	C7
	StdOrder	RunOrder	PtType	Blocks	A	B	C
1	2	1	1	1	0	1	0
2	1	2	1	1	1	0	0
3	3	3	1	1	0	0	1
4							
5							

this creates a 3 run
3 component table
because it has 3 points
on the triangle....





Extreme Vertices Design this new table has been created....

	C1 StdOrder	C2 RunOrder	C3 PtType	C4 Blocks	C5 Polyethylene	C6 Additives	C7 Colorants	C8 Regrind
1	1	1	1	1	0.9900	0.0000	0.0100	0.0000
2	2	2	1	1	0.2400	0.0000	0.0100	0.7500
3	3	3	1	1	0.2100	0.0000	0.0400	0.7500
4	4	4	1	1	0.1900	0.0500	0.0100	0.7500
5	5	5	1	1	0.1600	0.0500	0.0400	0.7500
6	6	6	1	1	0.9600	0.0000	0.0400	0.0000
7	7	7	1	1	0.9400	0.0500	0.0100	0.0000
8	8	8	1	1	0.9100	0.0500	0.0400	0.0000
9	9	9	0	1	0.5750	0.0250	0.0250	0.3750
10	10	10	-1	1	0.7825	0.0125	0.0175	0.1875
11	11	11	-1	1	0.4075	0.0125	0.0175	0.5625
12	12	12	-1	1	0.3925	0.0125	0.0325	0.5625
13	13	13	-1	1	0.3825	0.0375	0.0175	0.5625
14	14	14	-1	1	0.3675	0.0375	0.0325	0.5625
15	15	15	-1	1	0.7675	0.0125	0.0325	0.1875
16	16	16	-1	1	0.7575	0.0375	0.0175	0.1875
17	17	17	-1	1	0.7425	0.0375	0.0325	0.1875

copy and paste these 4 columns back into the Excel spreadsheet

to generate
- Results
- Costs

as the Response....

- Recall: PtType stores the point type.
- The codes are:
    - 0 is a Centre Point run and
    - 1 is a Corner Point.
    - I think -1 is an Axial Point

	Machine Parameters					Raw Material Parameters					Results	
	Extrusion Temperature	Cooling Temperature	Screw Speed	Air Pressure	Puller Speed	%Polyethylene	%Additives	%Colorants	%Regrind	Multiplier	Mixture Cost	Tension Results Lbs/f
Minimum	80	10	60	0.5	2	10%	0%	1%	0%	N/A	N/A	10
Maximum	150	60	100	5	8	99%	5%	4%	75%	N/A	N/A	12
Run No.												
1	80.00	10.00	60.00	0.50	2.00	0.99	0	0.01	0	0.993	$ 24.90	7.411
2	80.00	10.00	60.00	0.50	2.00	0.24	0	0.01	0.75	0.183	$ 7.65	1.354
3	80.00	10.00	60.00	0.50	2.00	0.21	0	0.04	0.75	0.162	$ 7.35	1.201
4	80.00	10.00	60.00	0.50	2.00	0.19	0.05	0.01	0.75	0.633	$ 10.50	4.648
5	80.00	10.00	60.00	0.50	2.00	0.16	0.05	0.04	0.75	0.612	$ 10.20	4.449
6	80.00	10.00	60.00	0.50	2.00	0.96	0	0.04	0	0.972	$ 24.60	7.294
7	80.00	10.00	60.00	0.50	2.00	0.94	0.05	0.01	0	1.443	$ 27.75	10.670
8	80.00	10.00	60.00	0.50	2.00	0.91	0.05	0.04	0	1.422	$ 27.45	10.591
9	80.00	10.00	60.00	0.50	2.00	0.575	0.025	0.025	0.375	0.8025	$ 17.55	5.992
10	80.00	10.00	60.00	0.50	2.00	0.7825	0.0125	0.0175	0.1875	0.89775	$ 21.23	6.695
11	80.00	10.00	60.00	0.50	2.00	0.4075	0.0125	0.0175	0.5625	0.49275	$ 12.60	3.588
12	80.00	10.00	60.00	0.50	2.00	0.3925	0.0125	0.0325	0.5625	0.48225	$ 12.45	3.618
13	80.00	10.00	60.00	0.50	2.00	0.3825	0.0375	0.0175	0.5625	0.71775	$ 14.03	5.267
14	80.00	10.00	60.00	0.50	2.00	0.3675	0.0375	0.0325	0.5625	0.70725	$ 13.88	5.155
15	80.00	10.00	60.00	0.50	2.00	0.7675	0.0125	0.0325	0.1875	0.88725	$ 21.08	6.626
16	80.00	10.00	60.00	0.50	2.00	0.7575	0.0375	0.0175	0.1875	1.12275	$ 22.65	8.326
17	80.00	10.00	60.00	0.50	2.00	0.7425	0.0375	0.0325	0.1875	1.11225	$ 22.50	8.085
18											$	
19											$ -	
20											$ -	
21											$ -	
22											$ -	
23											$ -	
24											$ -	
25											$ -	
26											$ -	
27											$ -	
28											$ -	
29											$ -	
30											$ -	

these are the machine parameters
that are left constant.....

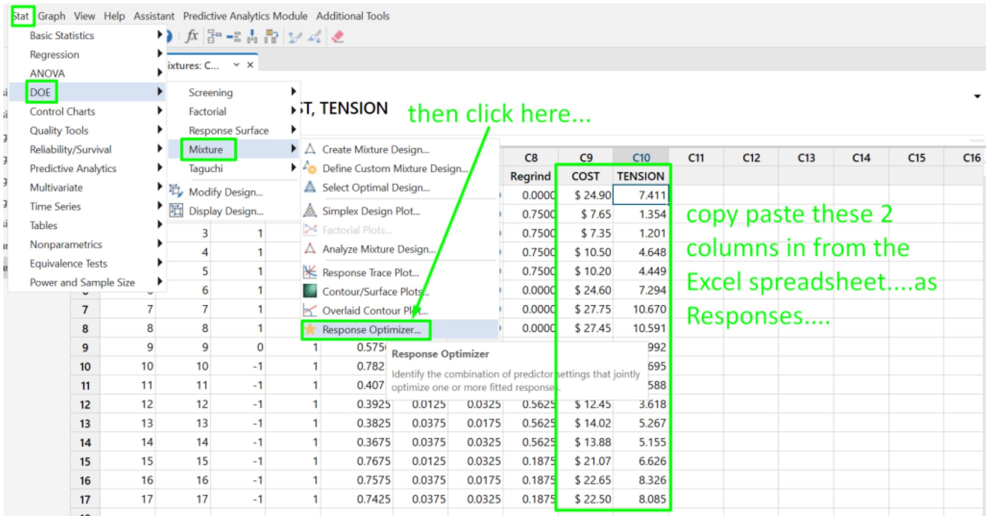
these are my Mixture Ingredients
which should add up to 100%
per row....

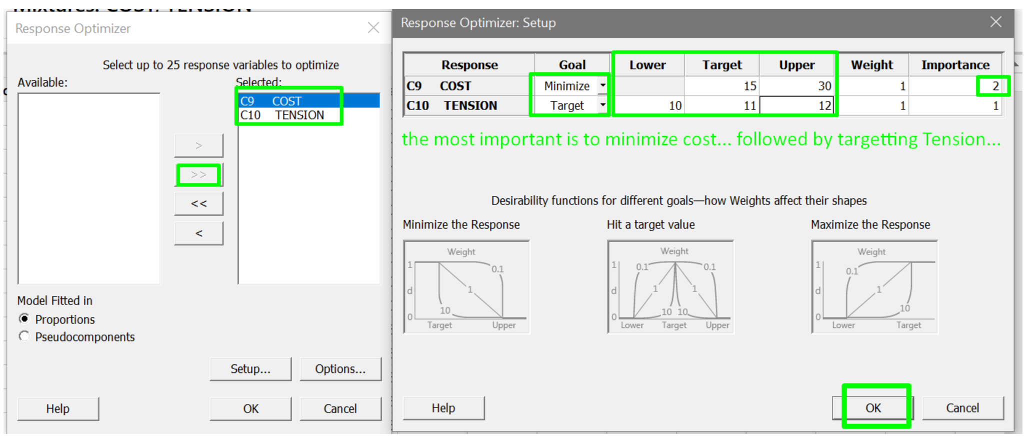
which i copied pasted from
Minitab....

these are my 2
responses which
i will copy paste
into Minitab....

neal Simulator | Urania Quadratic Simulator | Chatillon Simulator

2. PREDICTING THE MIXTURE EXPERIMENT





Response Optimization

Parameters

	Goal	Lower	Target	Upper	Weight	Import
COST	Minimum	15	15	30	1	2
TENSION	Target	10	11	12	1	1

in order to achieve a minimum COST of $15 and targetted TENSION of 11....

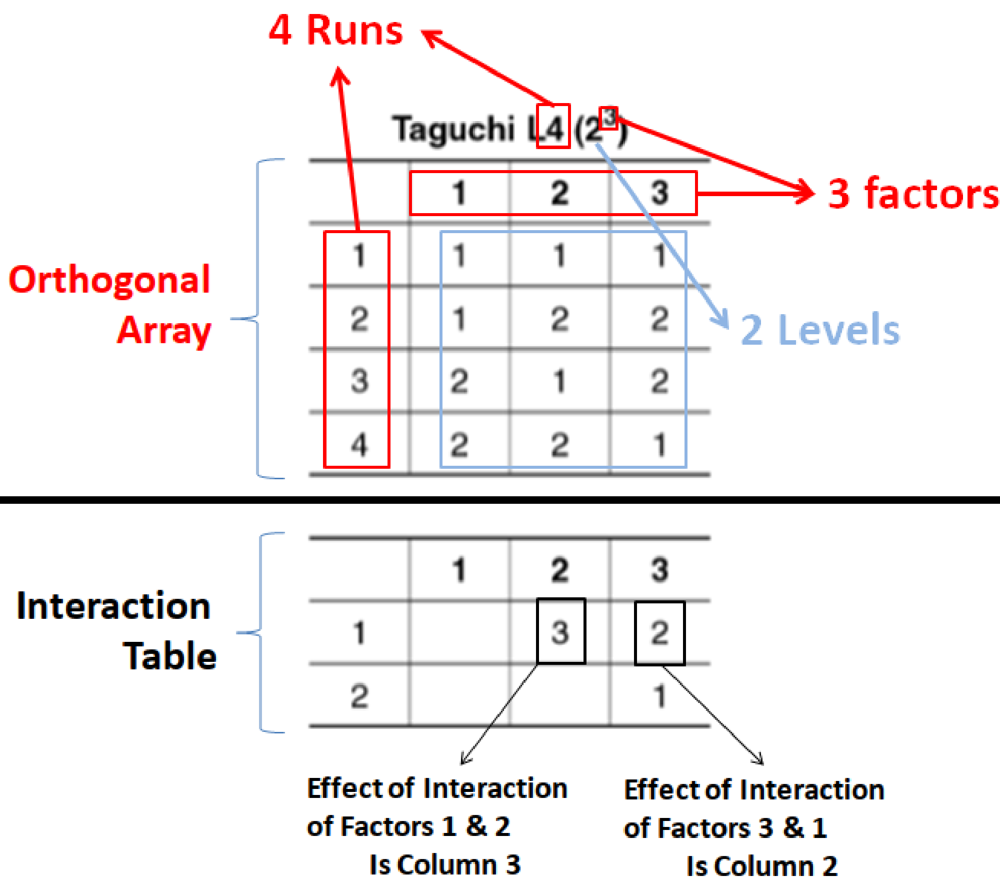
Global Solution

Components

Polyethylene	=	0.91
Additives	=	0.05
Colorants	=	0.04
Regrind	=	0

we should use these Mixture %

A. CONCEPT

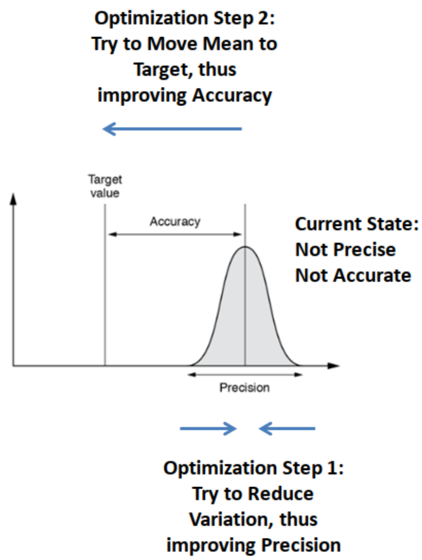


- By right, a Full Factorial for a 3 factor 2 level (2^3) = 8 runs required.
- Taguchi can reduce the number of runs to only 4.
- This is possible because Taguchi assumes the 3rd column (3rd factor) to be the interaction effect of factors 1 and 2, thus it can be ignored.

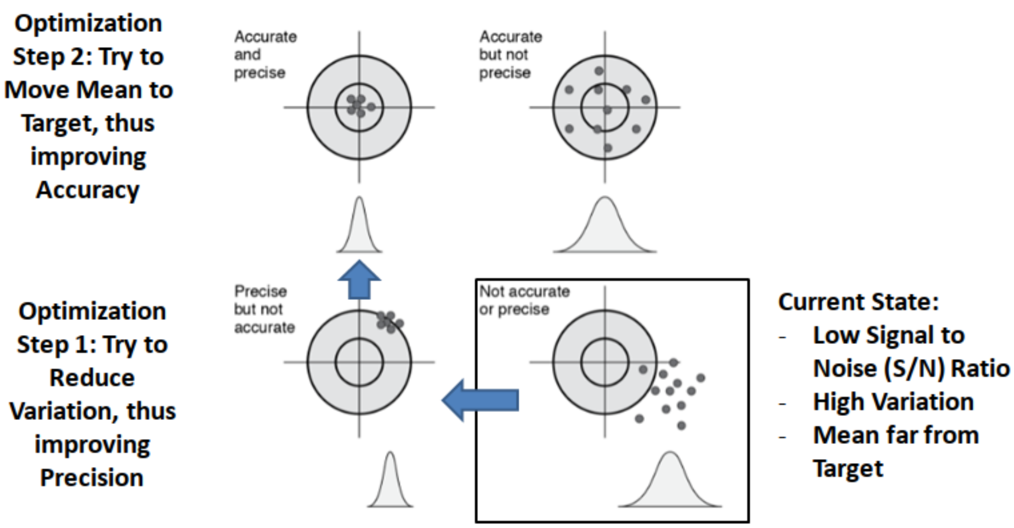
	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

- Taguchi regards Factor Interaction Effects as Noise (thus they are insignificant and ignored).
- Taguchi only regards Main Factor Effects.

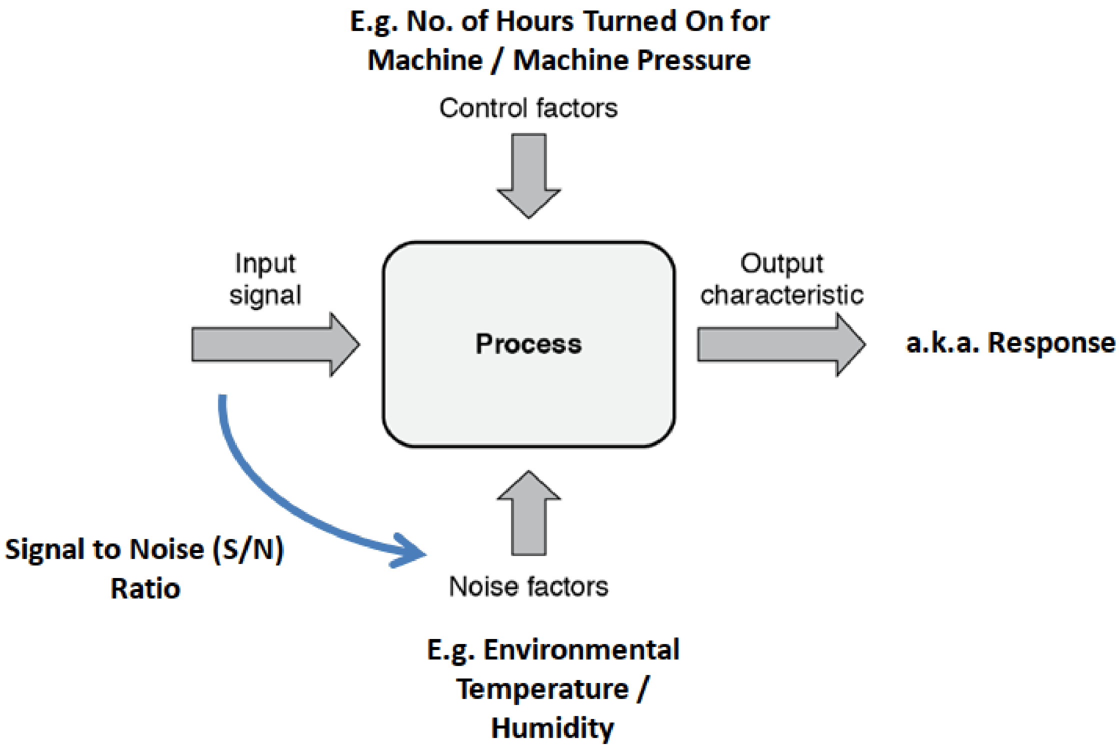
B. TAGUCHI'S OPTIMIZATION



- Precision relates to the Standard Deviation (SD)
    - Target Value relates to the Mean



C. MEANING OF SIGNAL TO NOISE RATIO (S/N)

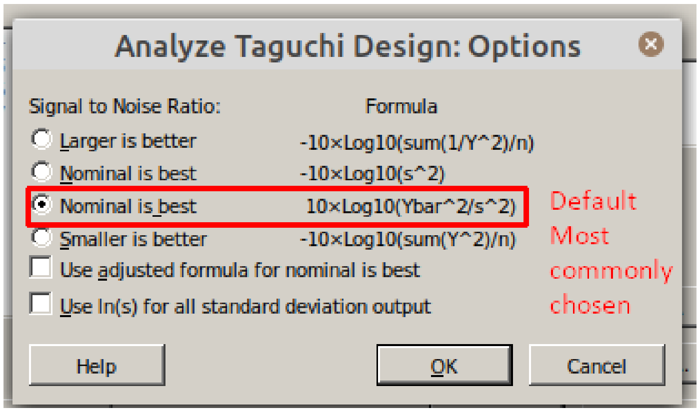


- S/N ratio combines the effect of the Mean and Standard Deviation **into one value** used to gage the process output.[1]
- In other words, the larger the S/N ratio, the more robust the process is to Noise.
- As mentioned above,
    - Precision relates to the Standard Deviation (Step 1 for Optimization). We use the S/N ratio to identify those Control Factors that reduce variability.

[1] https://www.amazon.com/Practical-Design-Experiments-DOE-Optimizing/dp/0873899245

- Accuracy relates to the Target Value (Mean) (Step 2 for Optimization). We identify Control Factors that move the mean to target and have no effect on the S/N ratio.

- There are 4 types of S/N ratio in Minitab: (note that for all types, our objective is to Maximize the S/N ratio → increase Signal, lower Noise)



1. LARGER IS BETTER

- Objective is to Maximize the Response.
- Example: Identify the Factors that Increase the hardness of the steel alloy.

2. NOMINAL IS BEST

- Objective is to try to hit the Target Response using S/N ratio based on Standard Deviations.

3. NOMINAL IS BEST (DEFAULT)

- Objective is to try to hit the Target Response using S/N ratio based on Means and Standard Deviations.
- Example: Identify the Factors that allow the manufacture to find the nominal specification.

4. SMALLER IS BETTER

- Objective is to Minimize the Response.
- Example: Identify the Factors that Reduce the force necessary to open the sealed packaging.

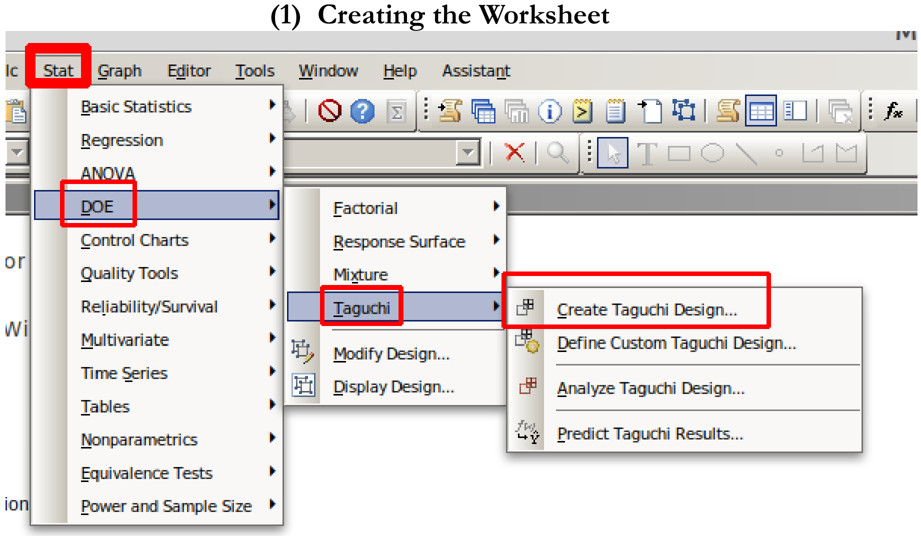
D. EXAMPLE: MINIMIZING THE RESPONSE (SMALLER IS BETTER)

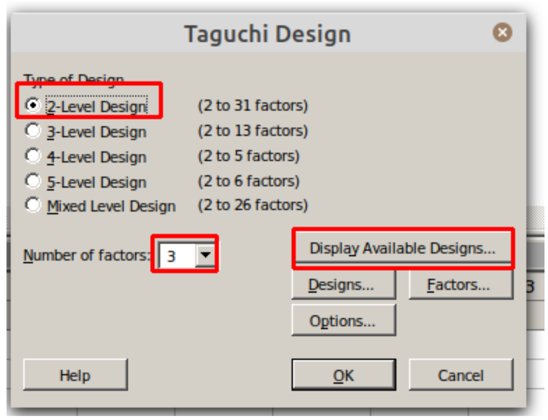
Time	Temp	Pressure	With Noise 1	With Noise 2	With Noise 3
1.25	250	80	2.9	3	2.8
1.25	260	90	2.4	2.2	2.3
2.5	250	90	3.5	3.6	3.7
2.5	260	80	2.6	2.5	2.7

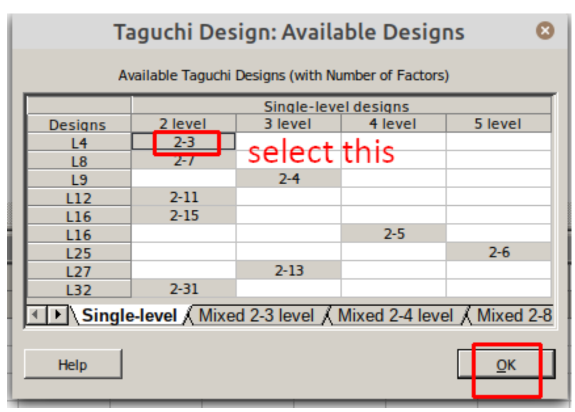
- This example is taken from (Durivage, 2016)
- A sealing process requires large force to open the packaging.
- 3 Factors, 2 Levels
  - Time: 1.25 and 2.5 seconds
  - Temperature: 250 and 260 Degree Celsius
  - Pressure: 80 and 90 PSI
- By right, a 2^3 will take total 8 runs, but we will do a L4 (only 4 runs)
- Responses (Three outputs collected under three different noise conditions)
  - With Noise 1
  - With Noise 2
  - With Noise 3
- Objective:
  - What are the Factors that help to reduce the Force required to open the package?
  - Noise is irremovable, we can only try to Maximize the S/N ratio

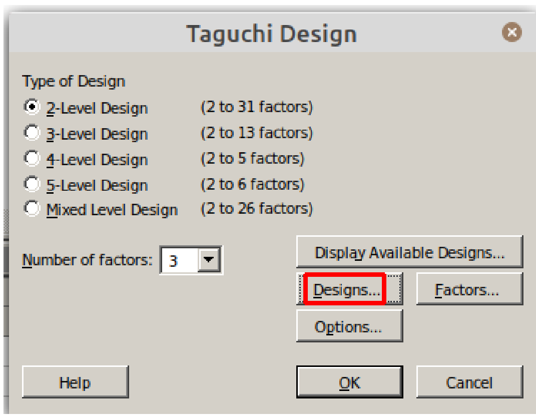
a) Minitab Solution

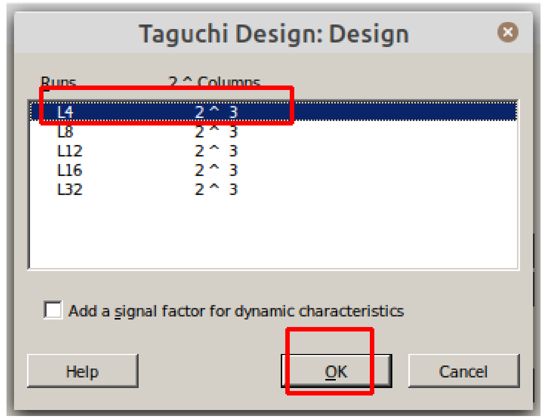
(1) Creating the Worksheet

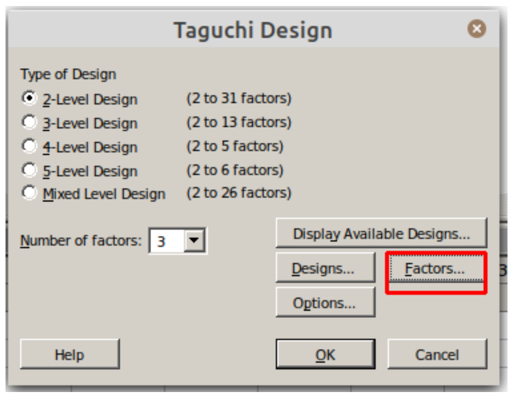


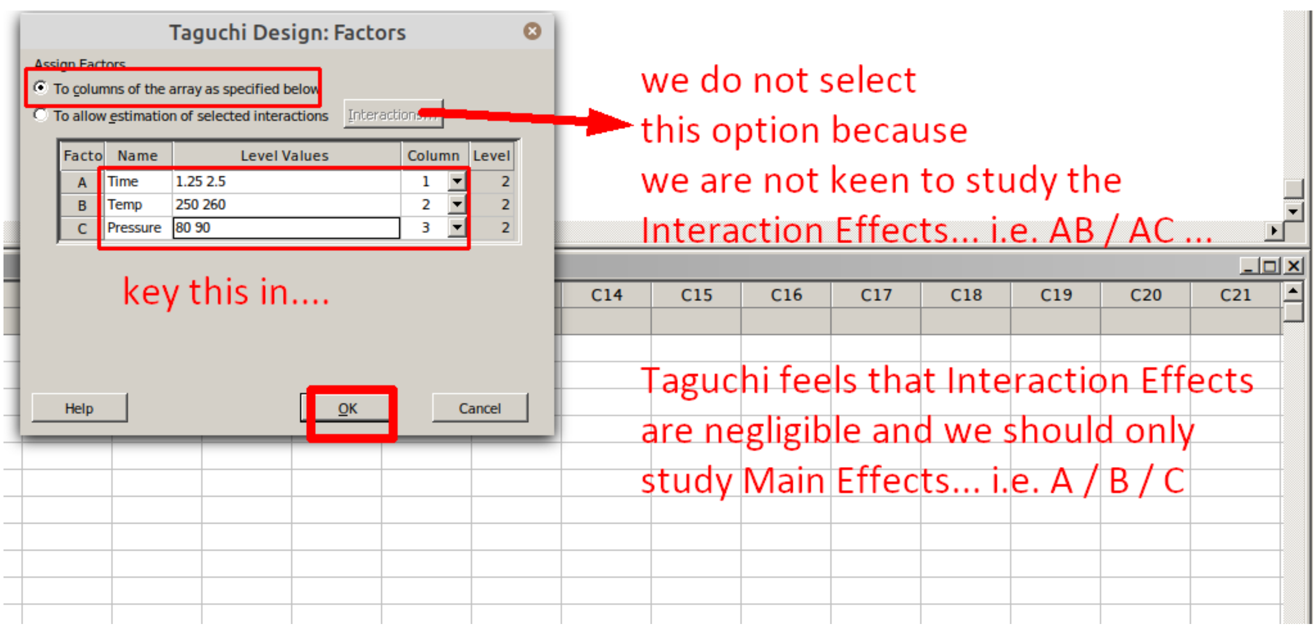


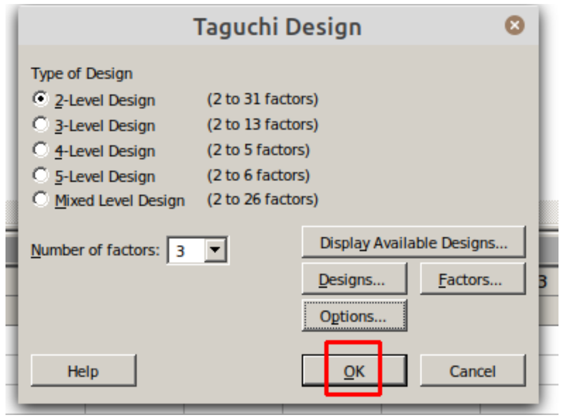


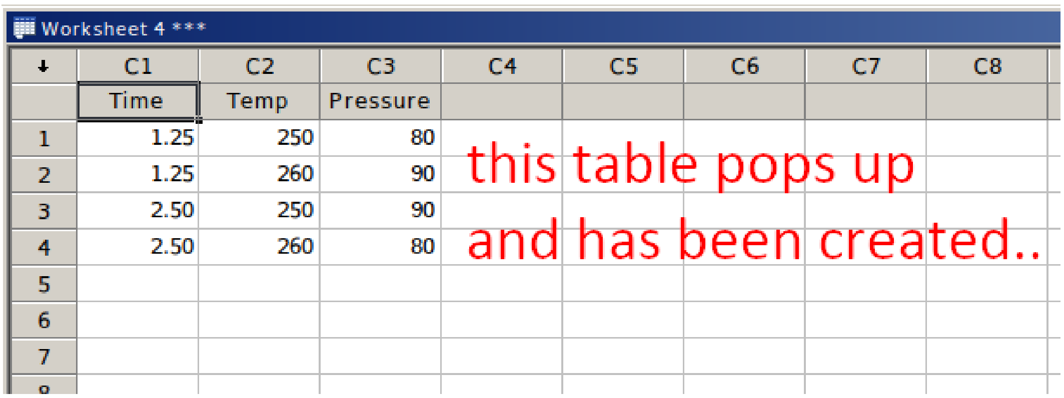

Taguchi Design
Type of Design
2-Level Design (2 to 31 factors)
3-Level Design (2 to 13 factors)
4-Level Design (2 to 5 factors)
5-Level Design (2 to 6 factors)
Mixed Level Design (2 to 26 factors)
Number of factors: 3
Display Available Designs...
Designs...
Factors...
Options...
Help
OK
Cancel


Taguchi Design: Design
Runs
2 ^ Columns
L4 2 ^ 3
L8 2 ^ 3
L12 2 ^ 3
L16 2 ^ 3
L32 2 ^ 3
Add a signal factor for dynamic characteristics
Help
OK
Cancel

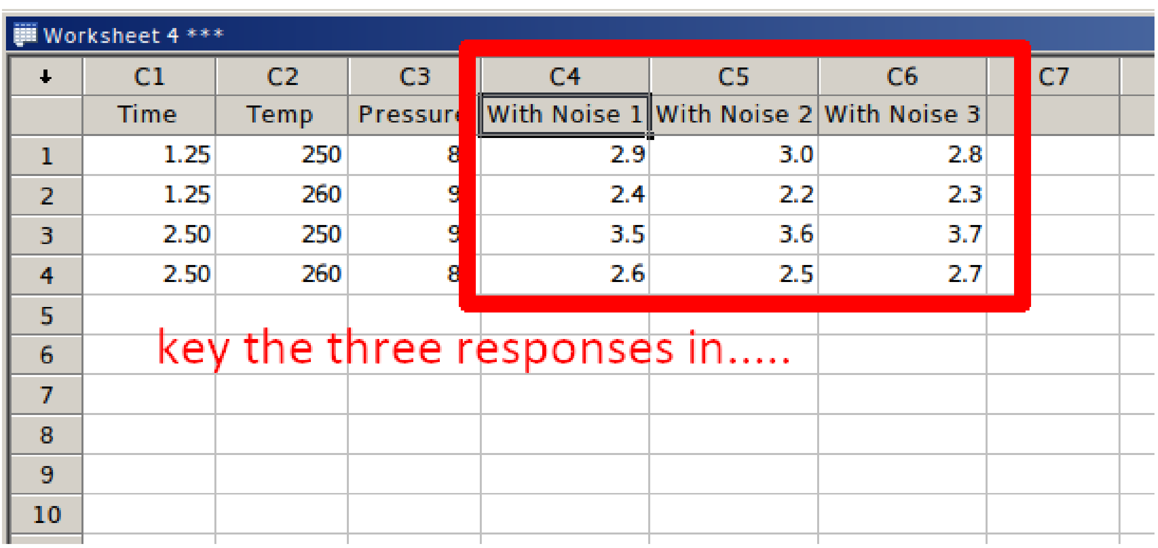

Taguchi Design
Type of Design
2-Level Design (2 to 31 factors)
3-Level Design (2 to 13 factors)
4-Level Design (2 to 5 factors)
5-Level Design (2 to 6 factors)
Mixed Level Design (2 to 26 factors)
Number of factors: 3
Display Available Designs...
Designs...
Factors...
Options...
Help
OK
Cancel


Taguchi Design: Factors
Assign Factors
To columns of the array as specified below
To allow estimation of selected interactions
Interactions...
Facto Name Level Values Column Level
A Time 1.25 2.5 1 2
B Temp 250 260 2 2
C Pressure 80 90 3 2
key this in....
Help
OK
Cancel
we do not select
this option because
we are not keen to study the
Interaction Effects... i.e. AB / AC ...
C14 C15 C16 C17 C18 C19 C20 C21
Taguchi feels that Interaction Effects
are negligible and we should only
study Main Effects... i.e. A / B / C



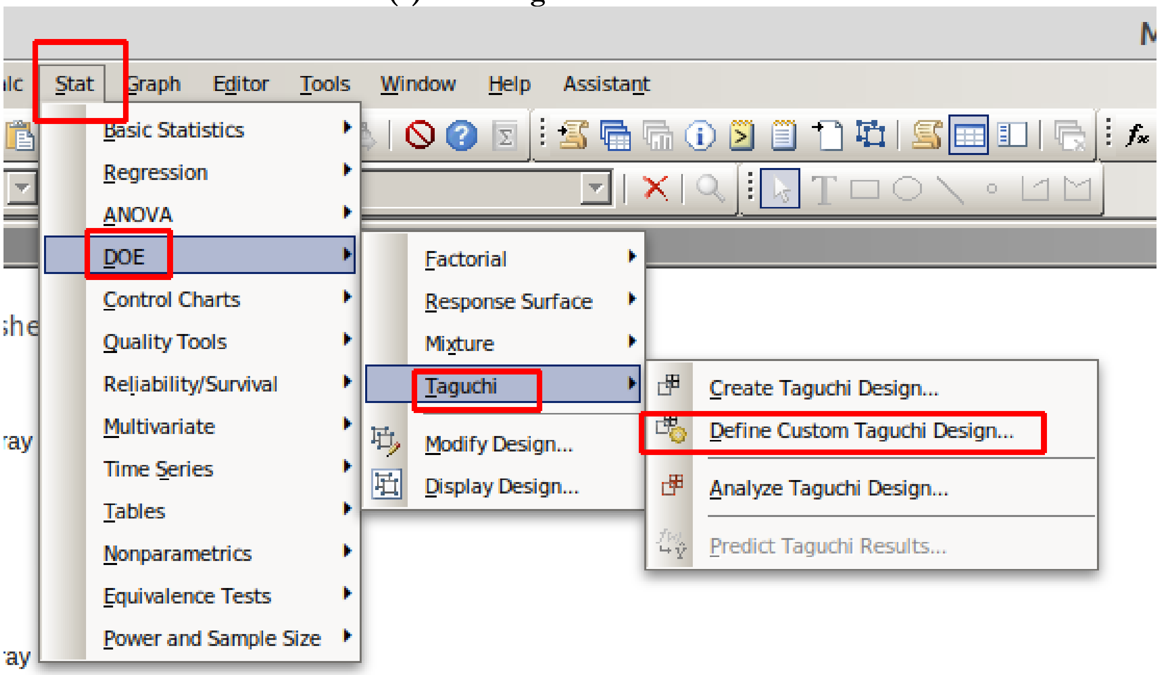


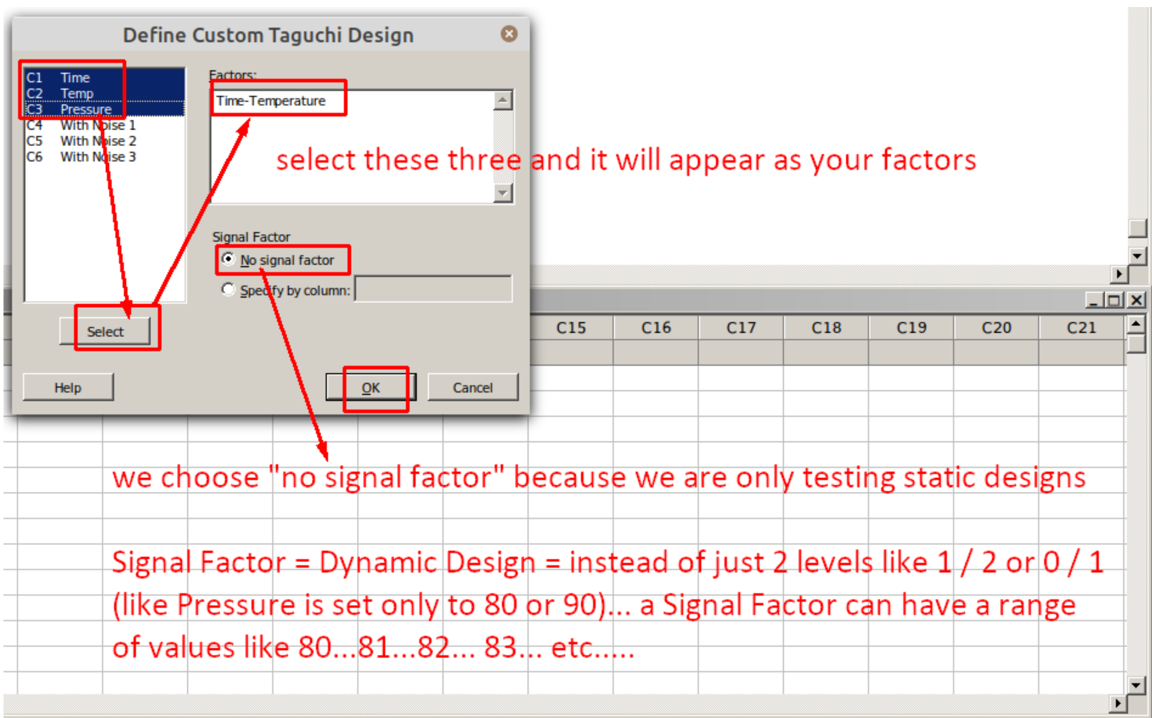
↓	C1	C2	C3	C4	C5	C6	C7	C8
	Time	Temp	Pressure					
1	1.25	250	80					
2	1.25	260	90					
3	2.50	250	90					
4	2.50	260	80					
5								
6								
7								



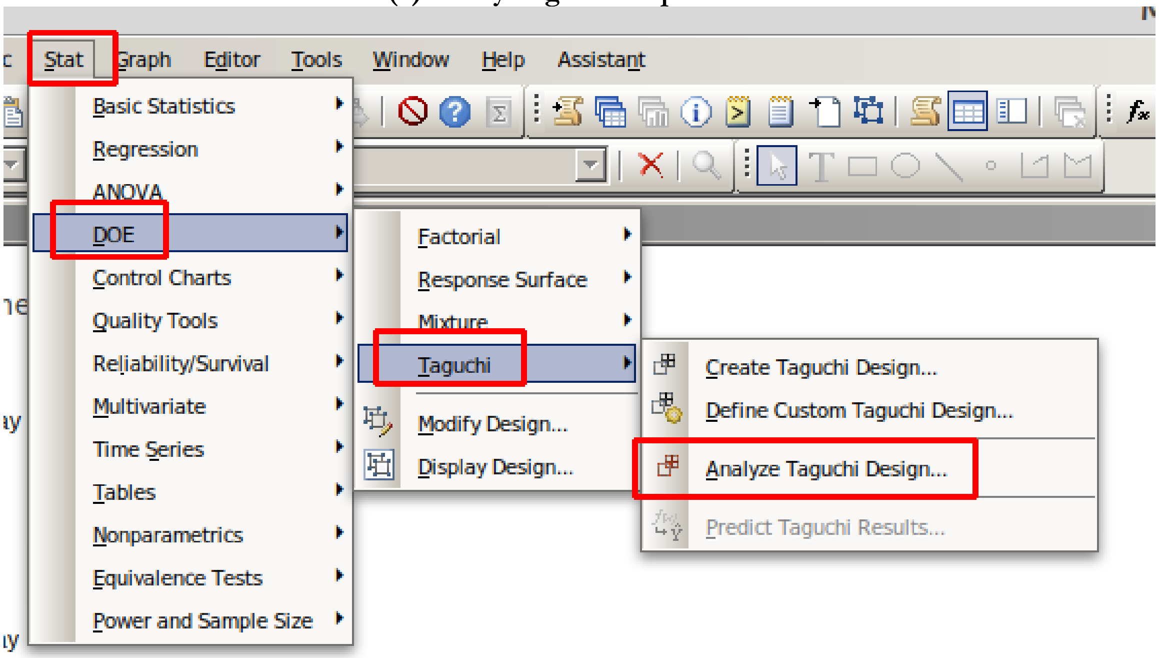
↓	C1	C2	C3	C4	C5	C6	C7
	Time	Temp	Pressure	With Noise 1	With Noise 2	With Noise 3	
1	1.25	250	8	2.9	3.0	2.8	
2	1.25	260	9	2.4	2.2	2.3	
3	2.50	250	9	3.5	3.6	3.7	
4	2.50	260	8	2.6	2.5	2.7	
5							
6							
7							
8							
9							
10							

(2) Defining the Factors

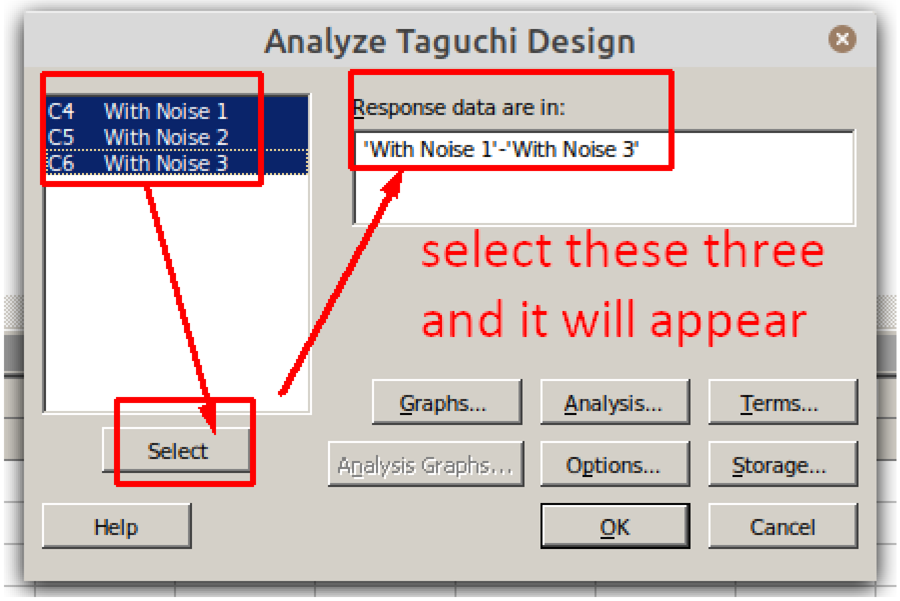




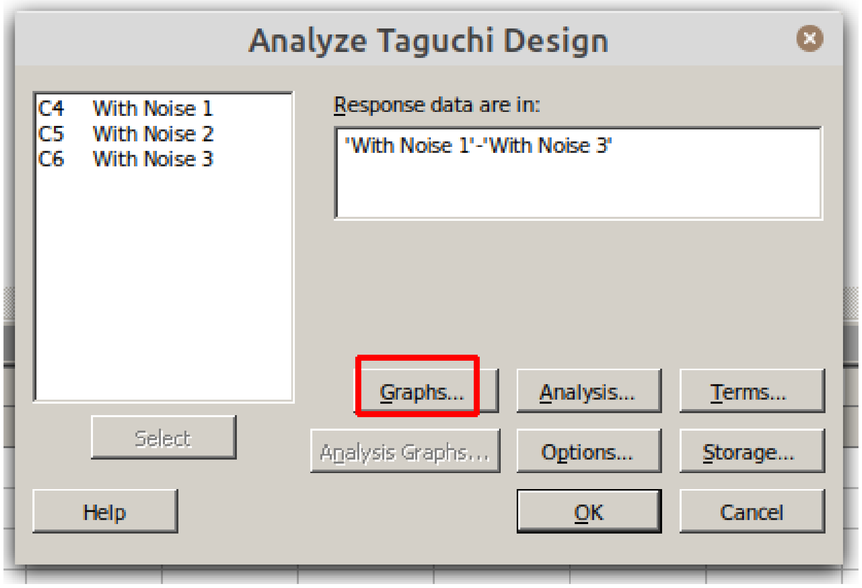
(3) Analyzing the Responses

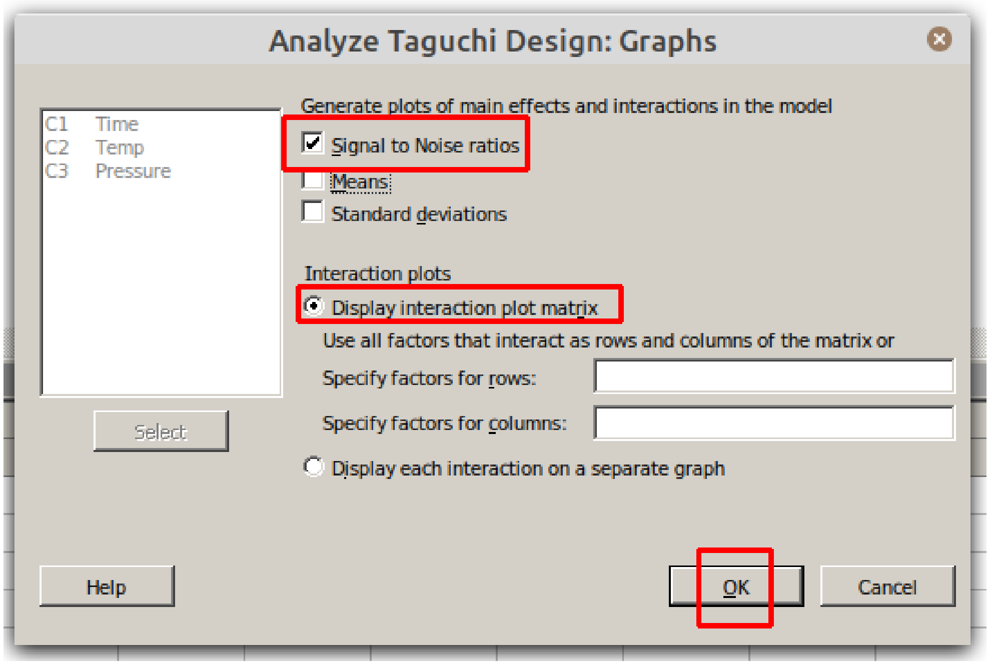


(a) Defining the Responses

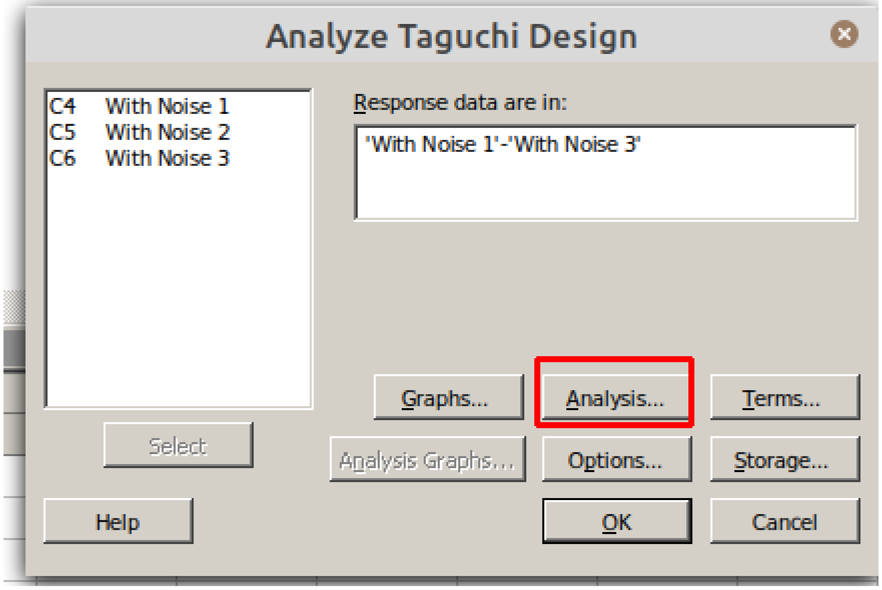


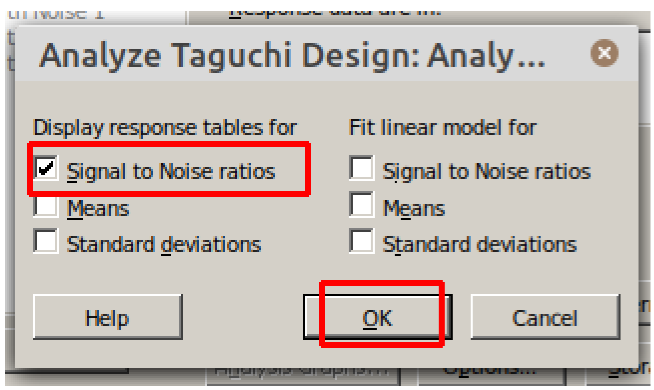
(b) Graphs


Analyze Taguchi Design
C4 With Noise 1
C5 With Noise 2
C6 With Noise 3
Response data are in:
'With Noise 1'-'With Noise 3'
Select
Graphs...
Analysis...
Terms...
Analysis Graphs...
Options...
Storage...
Help
OK
Cancel

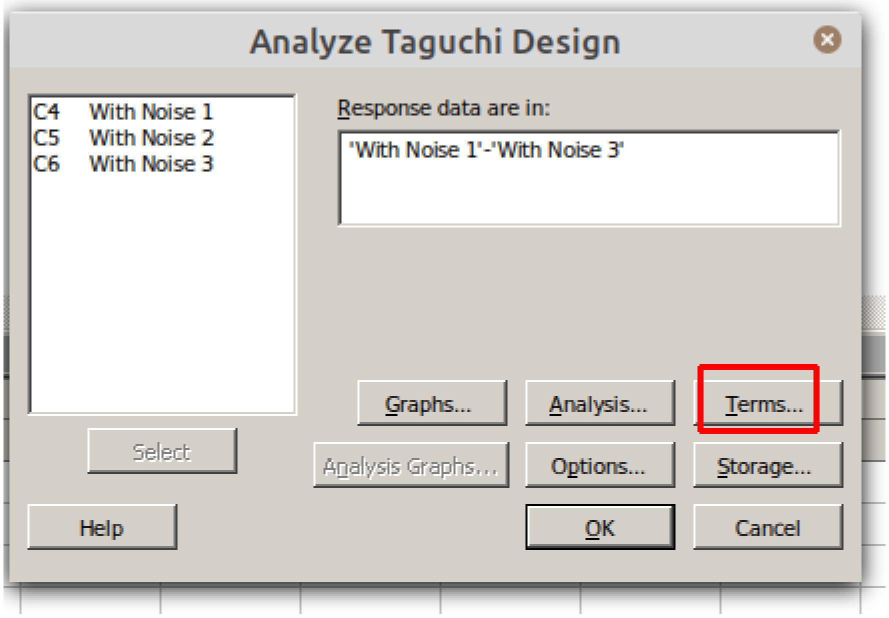

Analyze Taguchi Design: Graphs
C1 Time
C2 Temp
C3 Pressure
Select
Generate plots of main effects and interactions in the model
Signal to Noise ratios
Means
Standard deviations
Interaction plots
Display interaction plot matrix
Use all factors that interact as rows and columns of the matrix or
Specify factors for rows:
Specify factors for columns:
Display each interaction on a separate graph
Help
OK
Cancel

(c) Analyses

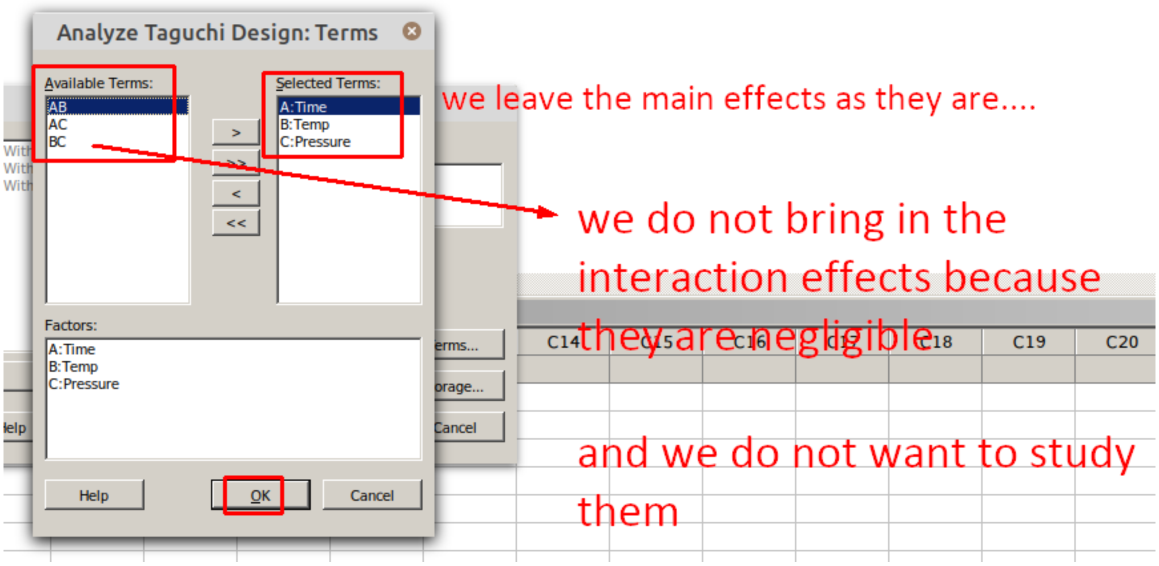

Analyze Taguchi Design
C4 With Noise 1
C5 With Noise 2
C6 With Noise 3
Response data are in:
'With Noise 1'-'With Noise 3'
Select
Graphs...
Analysis...
Terms...
Analysis Graphs...
Options...
Storage...
Help
OK
Cancel


Analyze Taguchi Design: Analy...
Display response tables for
Signal to Noise ratios
Means
Standard deviations
Fit linear model for
Signal to Noise ratios
Means
Standard deviations
Help
OK
Cancel

(d) Terms

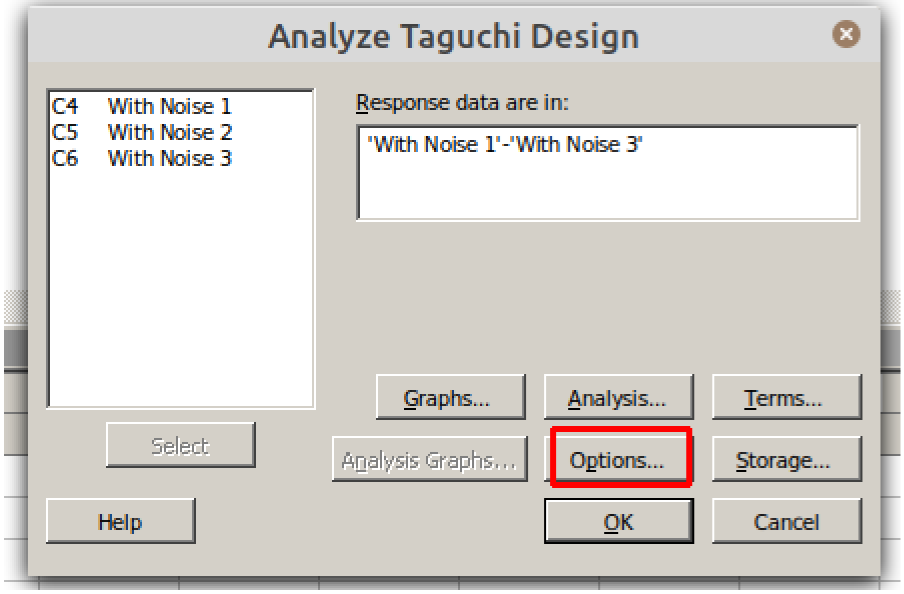


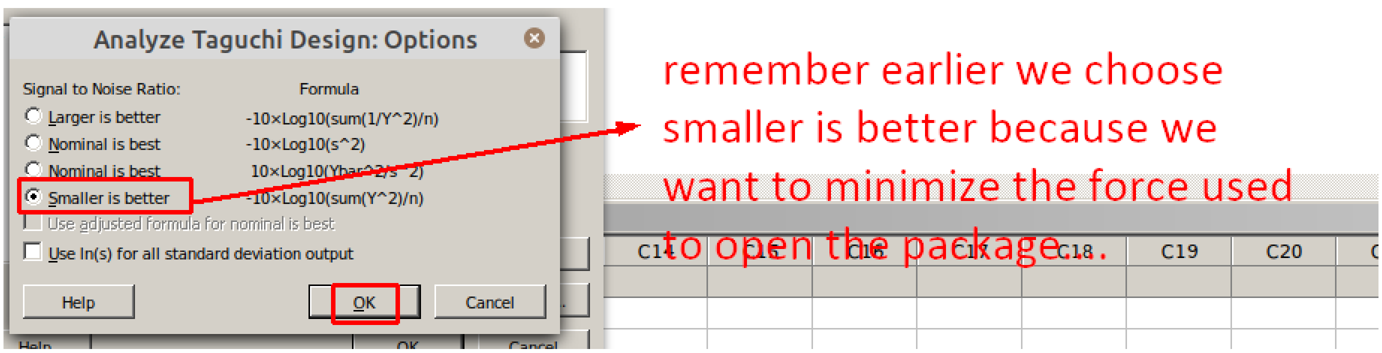
Analyze Taguchi Design
C4 With Noise 1
C5 With Noise 2
C6 With Noise 3
Response data are in:
'With Noise 1'-'With Noise 3'
Graphs...
Analysis...
Terms...
Select
Analysis Graphs...
Options...
Storage...
Help
OK
Cancel



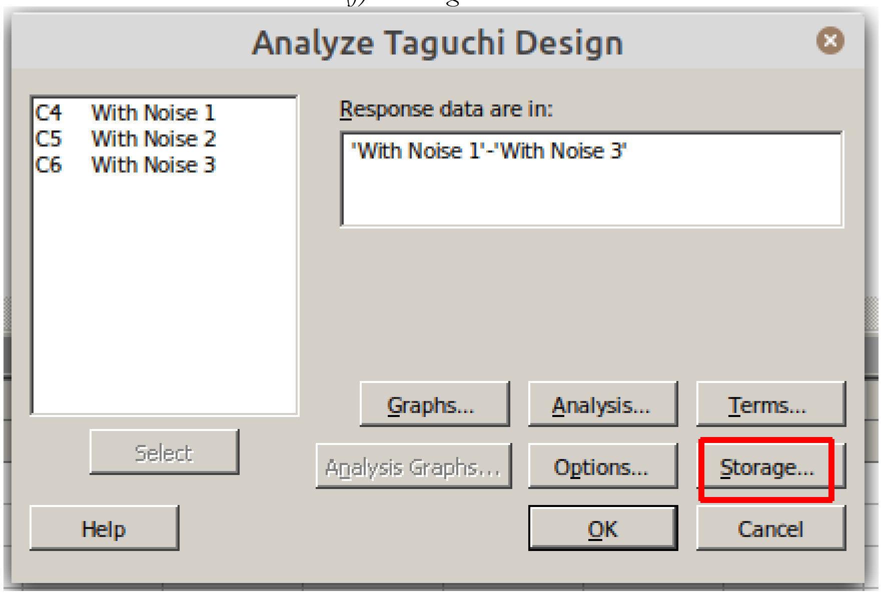
Analyze Taguchi Design: Terms
Available Terms:
AB
AC
BC
Selected Terms:
A:Time
B:Temp
C:Pressure
Factors:
A:Time
B:Temp
C:Pressure
Help
OK
Cancel
we leave the main effects as they are....
we do not bring in the interaction effects because they are negligible
and we do not want to study them

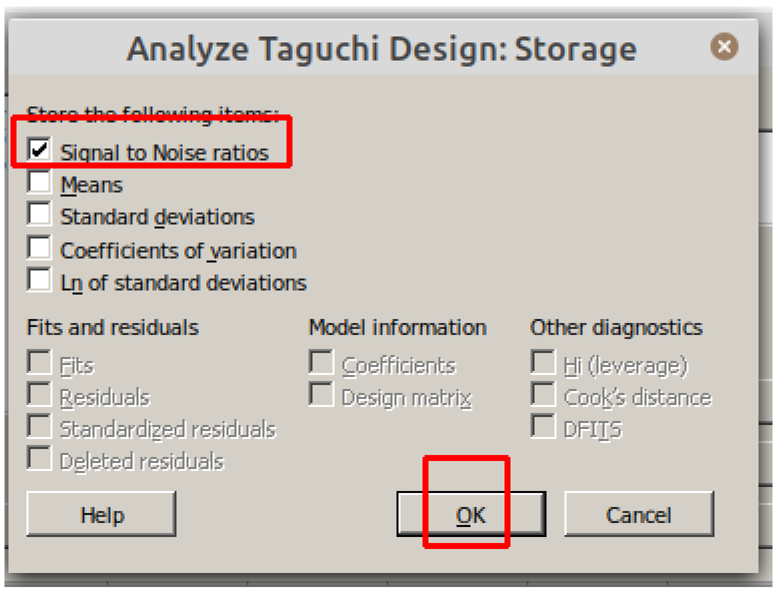
(e) Options


Analyze Taguchi Design
C4 With Noise 1
C5 With Noise 2
C6 With Noise 3
Response data are in:
'With Noise 1'-'With Noise 3'
Graphs...
Analysis...
Terms...
Select
Analysis Graphs...
Options...
Storage...
Help
OK
Cancel

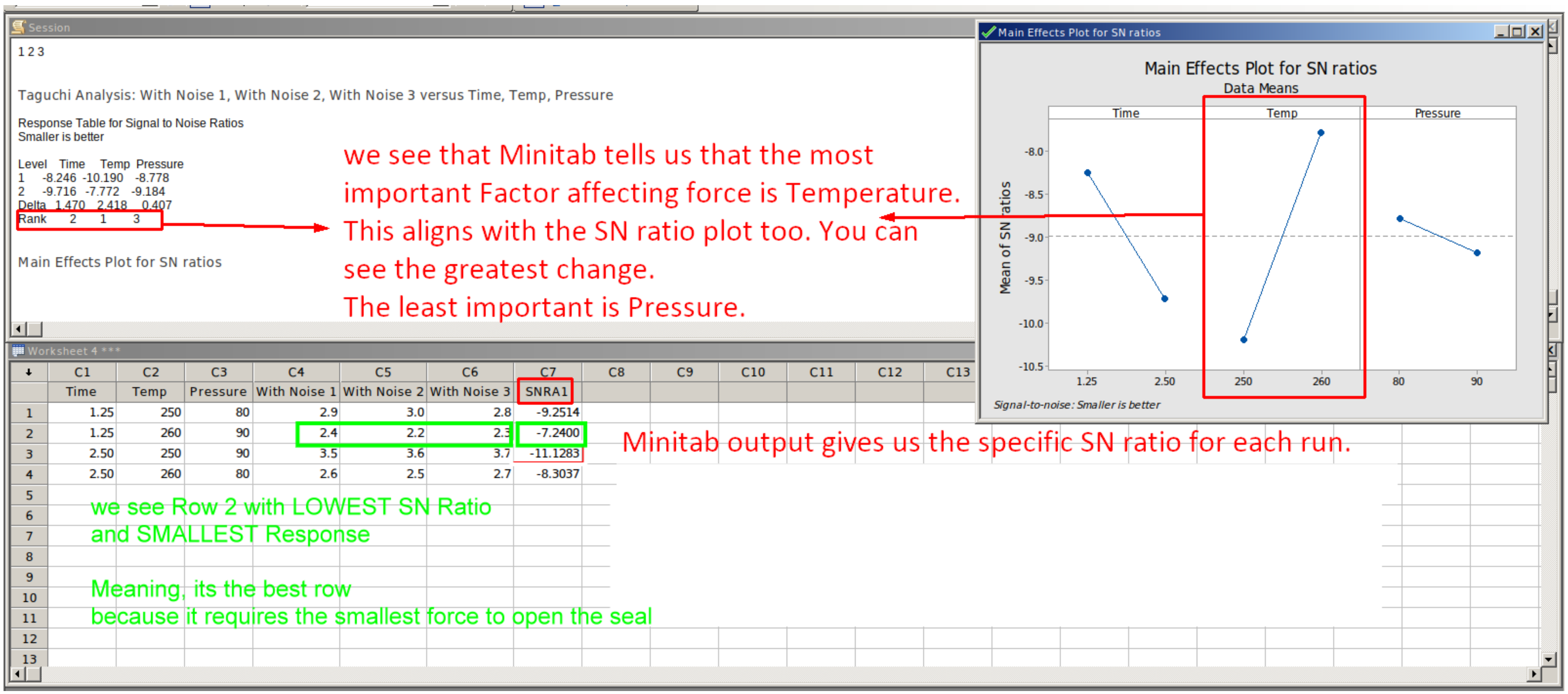

Analyze Taguchi Design: Options
Signal to Noise Ratio:
Formula
Larger is better
-10×Log10(sum(1/Y^2)/n)
Nominal is best
-10×Log10(s^2)
Nominal is best
Smaller is better
-10×Log10(sum(Y^2)/n)
Use adjusted formula for nominal is best
Use ln(s) for all standard deviation output
Help
OK
Cancel
remember earlier we choose smaller is better because we want to minimize the force used to open the package.
C19
C20

(f) Storage

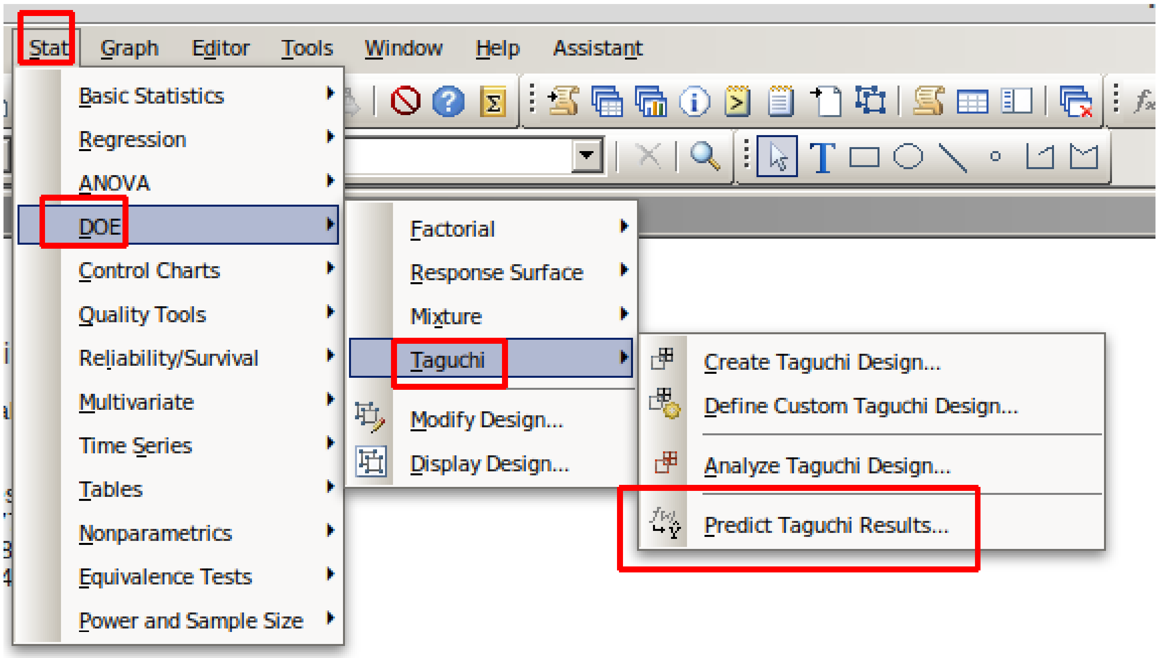

Analyze Taguchi Design
C4 With Noise 1
C5 With Noise 2
C6 With Noise 3
Response data are in:
'With Noise 1'-'With Noise 3'
Graphs...
Analysis...
Terms...
Select
Analysis Graphs...
Options...
Storage...
Help
OK
Cancel

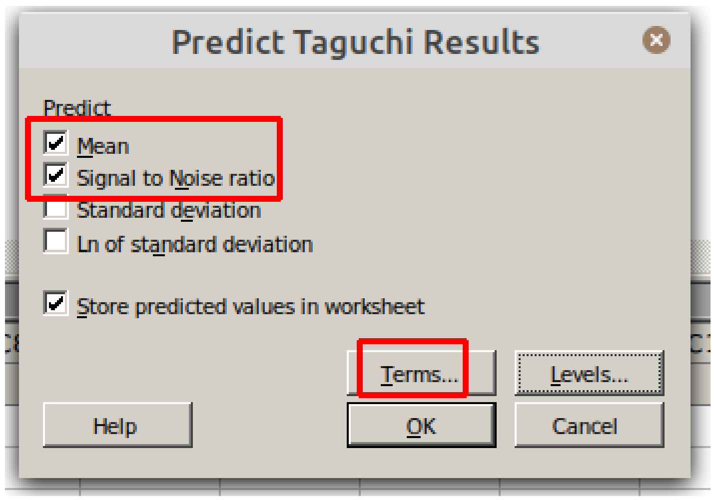

Analyze Taguchi Design: Storage
Store the following items:
Signal to Noise ratios
Means
Standard deviations
Coefficients of variation
Ln of standard deviations
Fits and residuals
Fits
Residuals
Standardized residuals
Deleted residuals
Model information
Coefficients
Design matrix
Other diagnostics
Hi (leverage)
Cook's distance
DFITS
Help
OK
Cancel

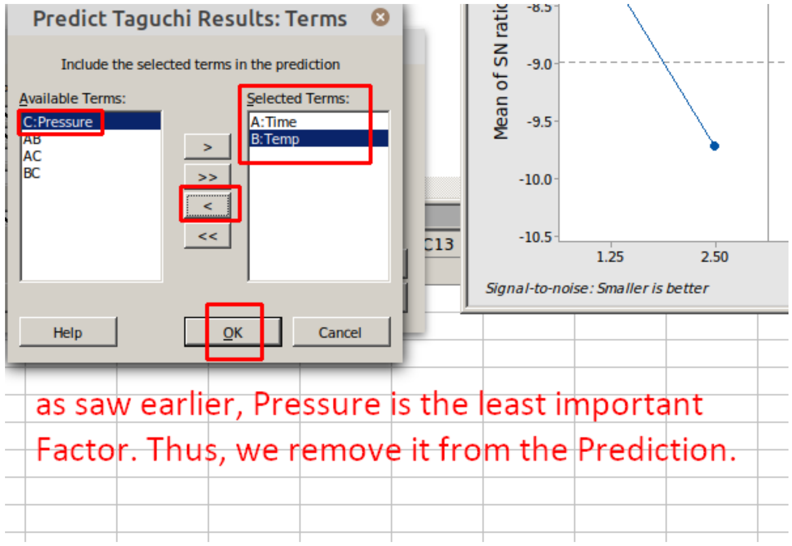
b) Minitab Output

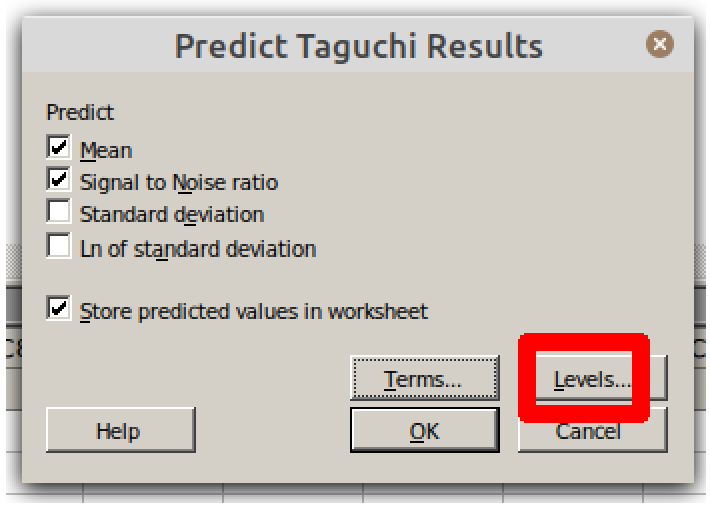


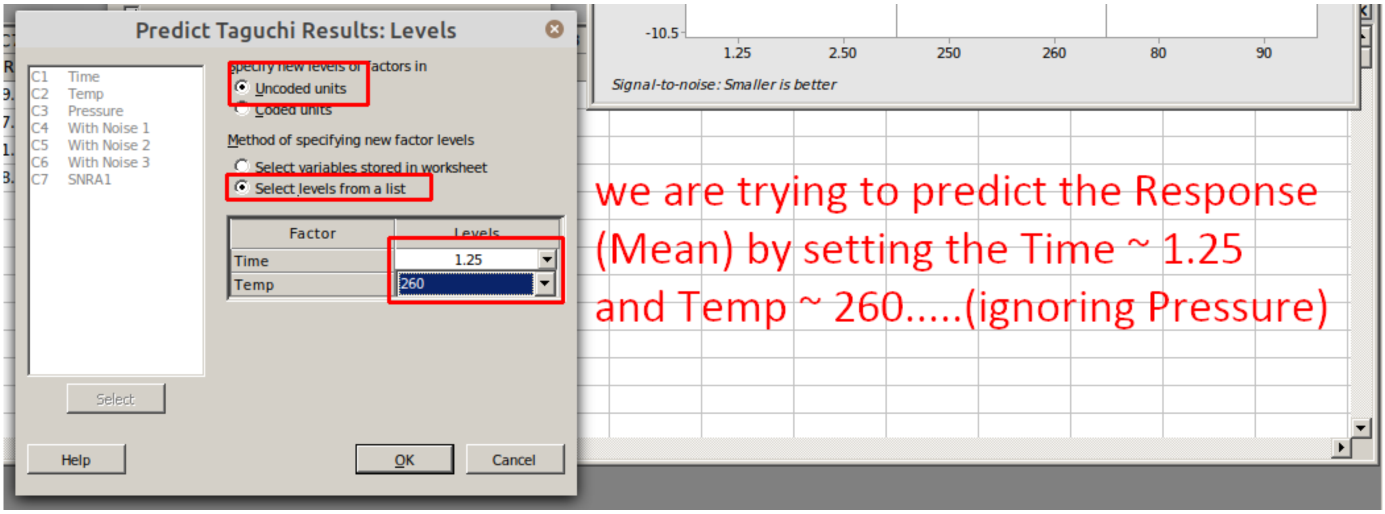
c) Predicting Taguchi Results

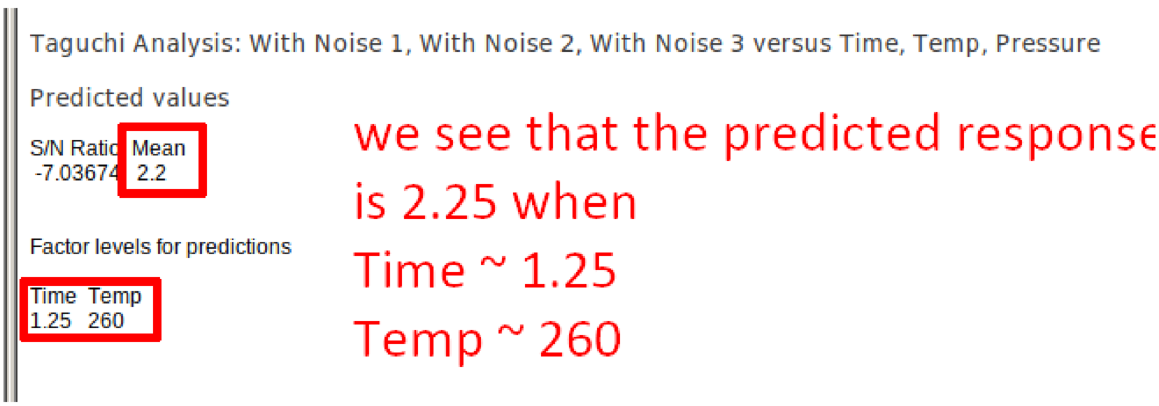





Predict Taguchi Results: Terms
Include the selected terms in the prediction
Available Terms:
C:Pressure
AB
AC
BC
Selected Terms:
A:Time
B:Temp
Help
OK
Cancel
Mean of SN ratio
-9.0
-9.5
-10.0
-10.5
1.25
2.50
Signal-to-noise: Smaller is better
C13
as saw earlier, Pressure is the least important
Factor. Thus, we remove it from the Prediction.


Predict Taguchi Results
Predict
Mean
Signal to Noise ratio
Standard deviation
Ln of standard deviation
Store predicted values in worksheet
Terms...
Levels...
Help
OK
Cancel


Predict Taguchi Results: Levels
C1 Time
C2 Temp
C3 Pressure
C4 With Noise 1
C5 With Noise 2
C6 With Noise 3
C7 SNRA1
Uncoded units
Coded units
Method of specifying new factor levels
Select variables stored in worksheet
Select levels from a list
Factor
Levels
Time
1.25
Temp
260
Select
Help
OK
Cancel
-10.5
1.25
2.50
250
260
80
90
Signal-to-noise: Smaller is better
we are trying to predict the Response (Mean) by setting the Time ~ 1.25 and Temp ~ 260.....(ignoring Pressure)


Taguchi Analysis: With Noise 1, With Noise 2, With Noise 3 versus Time, Temp, Pressure
Predicted values
Mean
2.2
-7.03674
Factor levels for predictions
Time Temp
1.25 260
we see that the predicted response is 2.25 when
Time ~ 1.25
Temp ~ 260

E. SUMMARY OF TAGUCHI'S EXAMPLE

With reference to Example: Minimizing the Response (Smaller is Better), we can repeat this example for:

1. NOMINAL RESPONSE (NOMINAL IS BEST)

	Temp	*Time*	*Pressure*	*Polymer*
Level 1 – 1 Lo	125	80	2	0.5
Level 2 –2Mid	150	85	4	1
Level 3 – 3 Hi	200	90	6	1.5

- We want to nominalize the product specifications
- Choose a L9 (4 Factor 3 Levels) Taguchi Experiment

Run	1 Temp	2 Time	3 Pressure	4 Polymer	Y_1	Y_2	Y_3	S/N
1	1	1	1	1	88.2	82.4	70.3	18.88
2	1	2	2	2	74.7	69.2	64.1	22.33
3	1	3	3	3	56.4	53.7	44.9	18.69
4	2	1	2	3	80.2	78.9	63.2	17.88
5	2	2	3	1	77.4	76.2	53.9	14.37
6	2	3	1	2	88.9	88.1	82.9	28.48
7	3	1	3	2	64.3	61.9	56.1	23.17
8	3	2	1	3	98.6	92.6	88.8	25.53
9	3	3	2	1	75.9	73.4	62.8	20.11

- Produce the table above (where Y1, Y2 and Y3 are the Responses with Noise).

2. LARGEST RESPONSE (LARGER IS BETTER)

	Preheat	*Equalize*	*Austenize*	*Temper*	*Quench*
Level 1 – Low	1250	1350	1725	750	150
Level 2 – Hi	1450	1450	1775	950	200

- We want to increase the hardness of steel alloy.
- Choose a L8 (5 Factor 2 Levels) Taguchi Experiment

Run	1 Preheat	2 Equalize	3 Austenize	4 Temper	5 Quench	Y_1	Y_2	Y_3	S/N
1	1	1	1	1	1	38.0	36.3	38.3	31.48
2	1	1	1	2	2	39.9	56.2	35.1	32.32
3	1	2	2	1	1	45.1	65.7	32.1	32.48
4	1	2	2	2	2	41.5	46.8	29.7	31.40
5	2	1	2	1	2	62.1	53.9	61.3	35.38
6	2	1	2	2	1	23.4	19.8	42.9	27.85
7	2	2	1	1	2	33.7	43.0	61.8	32.51
8	2	2	1	2	1	31.4	47.7	31.2	30.82

- Produce the following table above (where Y1, Y2 and Y3 are the Responses with Noise).
- The S/N ration should be the same as above.

VII. DOE FAQS

A. WHAT IF MANY / ALL FACTORS BECOME SIGNIFICANT?

- There could be outliers or special causes that distort each run.
- Check if there are any unusual values.
- Outliers should be removed or replaced.

B. WHAT IF THERE'S MISSING DATA?

- Replace missing data with average.

C. MUST WE USE ALL FACTORS?

- Yes, try to. it is to your advantage.
- If you don't use them, the unused factors will be called "dummy" factors.

D. WHAT IF I CAN'T REPLICATE ALL RUNS?

- Randomly select runs to be replicated

E. MUST I RANDOMIZE ALL TRIALS?

- No, but it would be best.
- Sometimes it's not possible to re-setup e.g., setting up a furnace temperature is only done once.
- You can't randomize and must carry things out in certain order at one go.
- This may lead to confounding the temperature with another unknown factor. (Due to no randomization).

VIII. SUCCESSFUL STEPS TO IMPLEMENT DOE

1. Define objectives
2. Assemble a small knowledge team
3. Review all pertinent relevant data
4. Brainstorm to generate potential factors.
    a. Be creative and do not accept existing theories without data.
5. Segregate (from the list) those factors that can be controlled vs uncontrollable.
6. Separate the expensive factors vs cheap factors.
    a. Always include factors that are cheap, quick and easy to study.
7. For every factor, set levels boldly but NOT carelessly.
    a. You need levels to be as wide as possible to force effects out of them.
    b. But you must avoid dangerous or unfeasible conditions.
8. Design your study.
    a. Narrow down the factors + review the total cost + complexity and control of the experiment + need for replications.
9. Randomize but if you can't, be aware of drawing false conclusions due to unknown external influence affecting the DOE.
10. Run the DOE + ensure correct levels + ensure materials are correct and keep good records.
11. Use Graphs to communicate findings.
    a. Report conclusions in simple language for the audience, not statistical terminologies.

IX. OBSTACLES TO DOE

A. RESISTANCE INERTIA

- "We have always used OFAT and no time to learn new approach!"
- Answer: You will always get what you have always gotten if you keep doing what you keep doing!

B. EXPENSIVE COST

- Nothing is free.
- DOE is an investment with a payback.
- Normally, the main cost is not Material Cost nor Processing Cost.
- Its the cost of using People's time.
- Use it carefully.

C. LACK OF MANAGEMENT SUPPORT

- Management must be involved.
- They must be educated and understanding what the objectives are, what the costs will be, what is expected, and believe the power of DOE.

D. LACK OF TRAINING

- You need educated people who knows DOE techniques to carry it out.

E. WRONG THINKING THAT DOE IS ONLY USED FOR MANUFACTURING

- DOE can be used for any area that can define factors for study.
- Including strategy and sales.

A. SELECTED FACTORIAL DESIGNS

1. 2^2 FULL FACTORIAL

2^2 Full Factorial

	A	B
1	–	–
2	+	–
3	–	+
4	+	+

All terms are free from aliasing.

Full Resolution

2. 2^3 FULL FACTORIAL

2^3 Full Factorial

	A	B	C
1	–1	–1	–
2	1	–1	–
3	–1	1	–
4	1	1	–
5	–1	–1	+
6	1	–1	+
7	–1	1	+
8	1	1	+

All terms are free from aliasing.

Full Resolution

3. 2^3 HALF FRACTIONAL FACTORIAL

2^3 Half Fractional Factorial

	A	B	C
1	–	–	+
2	+	–	–
3	–	+	–
4	+	+	+

I + ABC

A + BC

B + AC

C + AB

Resolution III

F. SELECTED PLACKET BURMAN DESIGNS

Eight-Run 2^7 Plackett-Burman

	A	B	C	D	E	F	G
1	+	−	−	+	−	+	+
2	+	+	−	−	+	−	+
3	+	+	+	−	−	+	−
4	−	+	+	+	−	−	+
5	+	−	+	+	+	−	−
6	−	+	−	+	+	+	−
7	−	−	+	−	+	+	+
8	−	−	−	−	−	−	−

12-Run 2^{11} Plackett-Burman

	A	B	C	D	E	F	G	H	I	J	K
1	+	−	+	−	−	−	+	+	+	−	+
2	+	+	−	+	−	−	−	+	+	+	−
3	−	+	+	−	+	−	−	−	+	+	+
4	+	−	+	+	−	+	−	−	−	+	+
5	+	+	−	+	+	−	+	−	−	−	+
6	+	+	+	−	+	+	−	+	−	−	−
7	−	+	+	+	−	+	+	−	+	−	−
8	−	−	+	+	+	−	+	+	−	+	−
9	−	−	−	+	+	+	−	+	+	−	+
10	+	−	−	−	+	+	+	−	+	+	−
11	−	+	−	−	−	+	+	+	−	+	+
12	−	−	−	−	−	−	−	−	−	−	−

16-Run 2^{15} Plackett-Burman

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	+	−	−	−	+	−	−	+	+	−	+	−	+	+	+
2	+	+	−	−	−	+	−	−	+	+	−	+	−	+	+
3	+	+	+	−	−	−	+	−	−	+	+	−	+	−	+
4	+	+	+	+	−	−	−	+	−	−	+	+	−	+	−
5	−	+	+	+	+	−	−	−	+	−	−	+	+	−	+
6	+	−	+	+	+	+	−	−	−	+	−	−	+	+	−
7	−	+	−	+	+	+	+	−	−	−	+	−	−	+	+
8	+	−	+	−	+	+	+	+	−	−	−	+	−	−	+
9	+	+	−	+	−	+	+	+	+	−	−	−	+	−	−
10	−	+	+	−	+	−	+	+	+	+	−	−	−	+	−
11	−	−	+	+	−	+	−	+	+	+	+	−	−	−	+
12	+	−	−	+	+	−	+	−	+	+	+	+	−	−	−
13	−	+	−	−	+	+	−	+	−	+	+	+	+	−	−
14	−	−	+	−	−	+	+	−	+	−	+	+	+	+	−

G. SELECTED TAGUCHI DESIGNS

Taguchi L4 (2^3)

	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

	1	2	3
1		3	2
2			1

Taguchi L8 (2^7)

	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

	1	2	3	4	5	6	7
1		3	2	5	4	7	6
2			1	6	7	4	5
3				7	6	5	4
4					1	2	3
5						3	2
6							1

Taguchi L8 (1^4 with up to 2^4)

	1	2	3	4	5
1	1	1	1	1	1
2	1	2	2	2	2
3	2	1	1	2	2
4	2	2	2	1	1
5	3	1	2	1	2
6	3	2	1	2	1
7	4	1	2	2	1
8	4	2	1	1	2

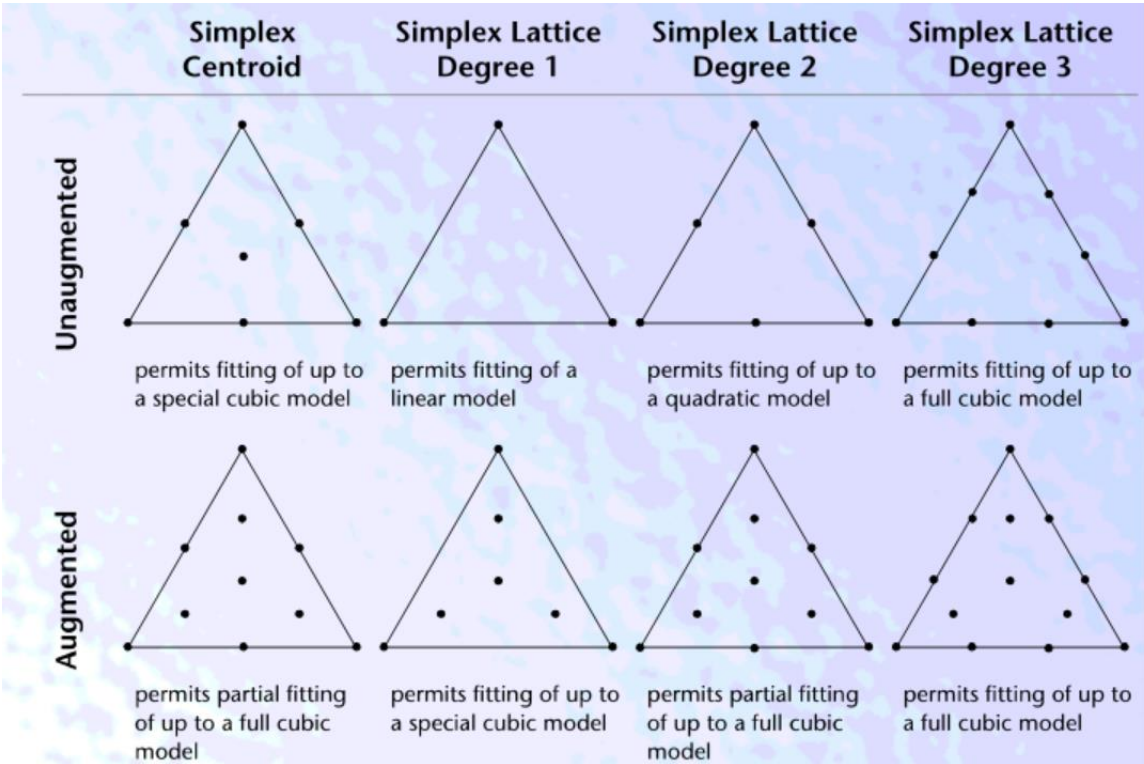
The L8 (1^4 with up to 2^4) array does not have an interaction table.

Taguchi L9 (3^4)

	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The L9 (3^4) array does not have an interaction table.

H. SELECTED MIXTURE DESIGNS



Three-Factor Simplex Centroid Design

Run	A	B	C
1	1	0	0
2	0	1	0
3	0	0	1
4	0.5	0.5	0
5	0.5	0	0.5
6	0	0.5	0.5
7	0.333	0.333	0.333

Three-Factor Simplex Lattice Design

Run	A	B	C
1	1	0	0
2	0	1	0
3	0	0	1
4	0.333	0.333	0.333
5	0.667	0.167	0.167
6	0.167	0.667	0.167
7	0.167	0.167	0.667

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ABOUT DR. ALVIN ANG

Dr. Alvin Ang earned his Ph.D., Masters and Bachelor degrees from NTU, Singapore. He is a scientist, entrepreneur, as well as a personal/business advisor. More about him at www.AlvinAng.sg.