

جامعة بغداد- كلية الهندسة الخوارزمي  
قسم الهندسة الكيميائية الاحيائية

دورة

تصميم التجارب

م.د. محمد يعقوب عيسى

ا.م.د. سامي داود سلمان

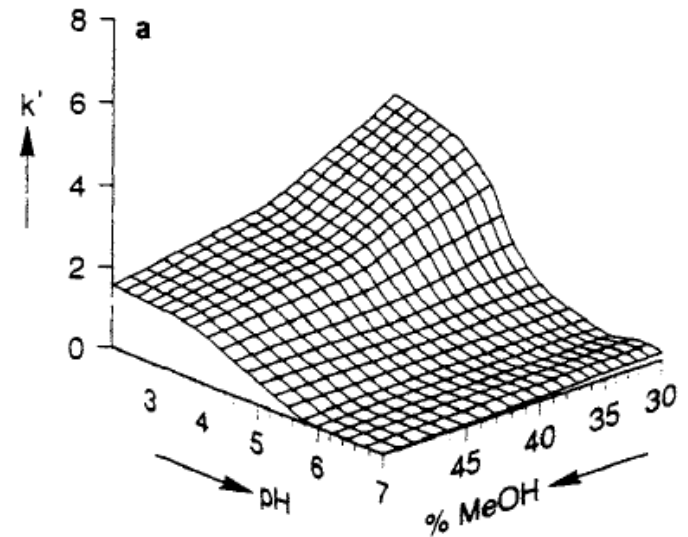
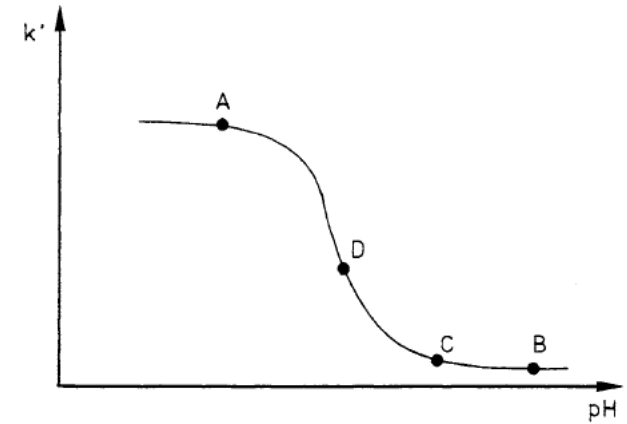
# Experimental Design

- Definition
- Variables (Factors Responses)

$$y = f(x_1, x_2, \dots, x_n)$$

$$y = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2$$

$$y = b_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{12}x_1x_2$$



# Main Steps of Experimental Design

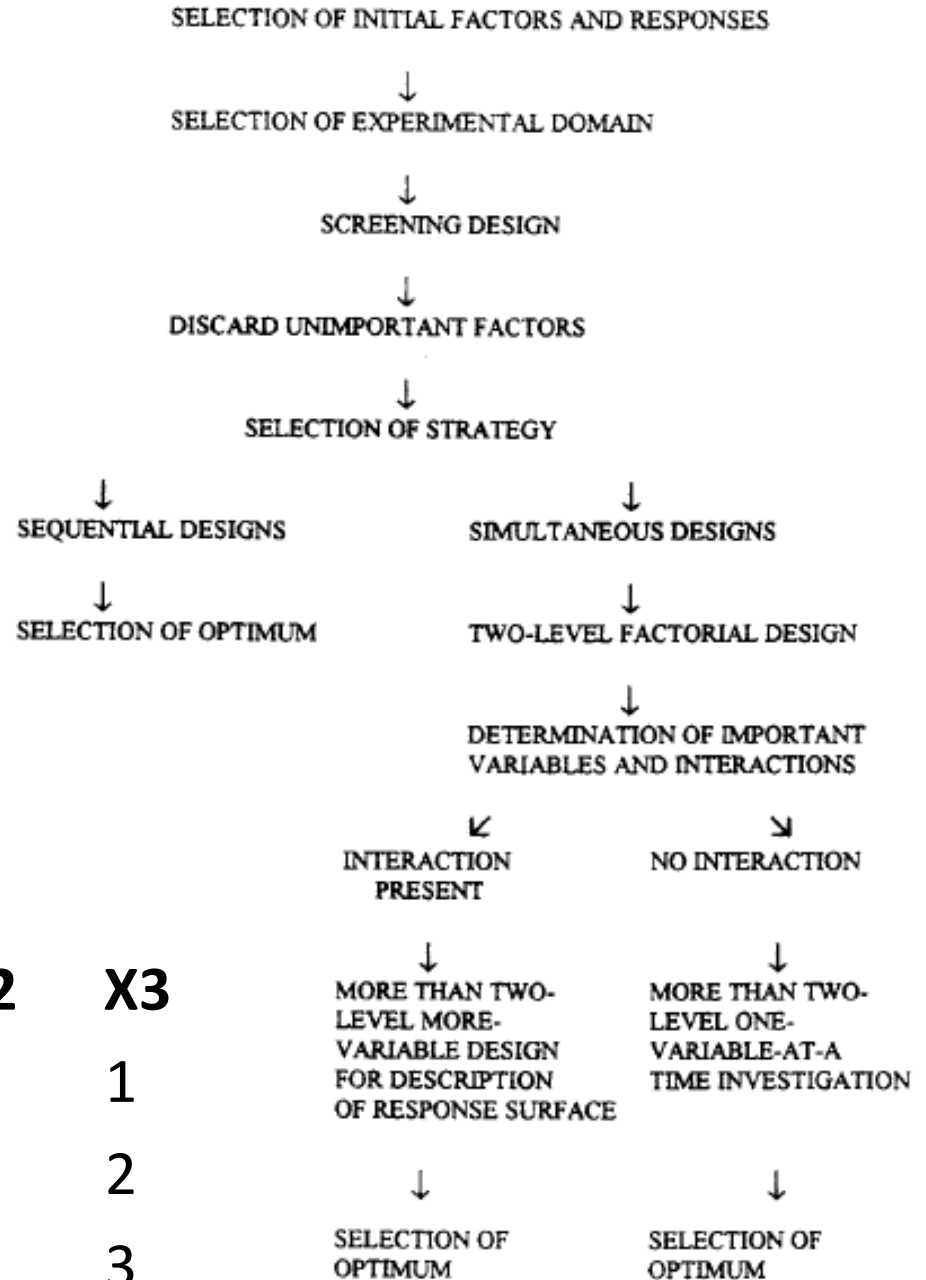
## Screening Design

X1	X2	X3
1	1	1
2	1	1
3	1	1

X1	X2	X3
1	1	1
1	2	1
1	3	1

X1	X2	X3
1	1	1
1	1	2
1	1	3

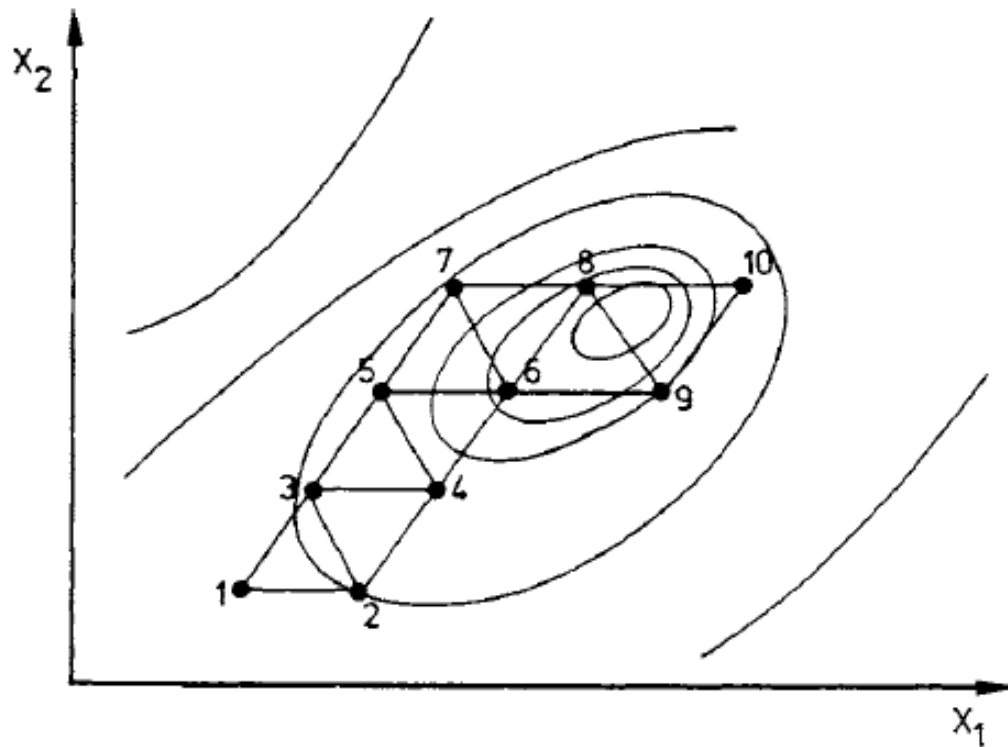
- No Mathematical Model
- No Interactions can be Detected



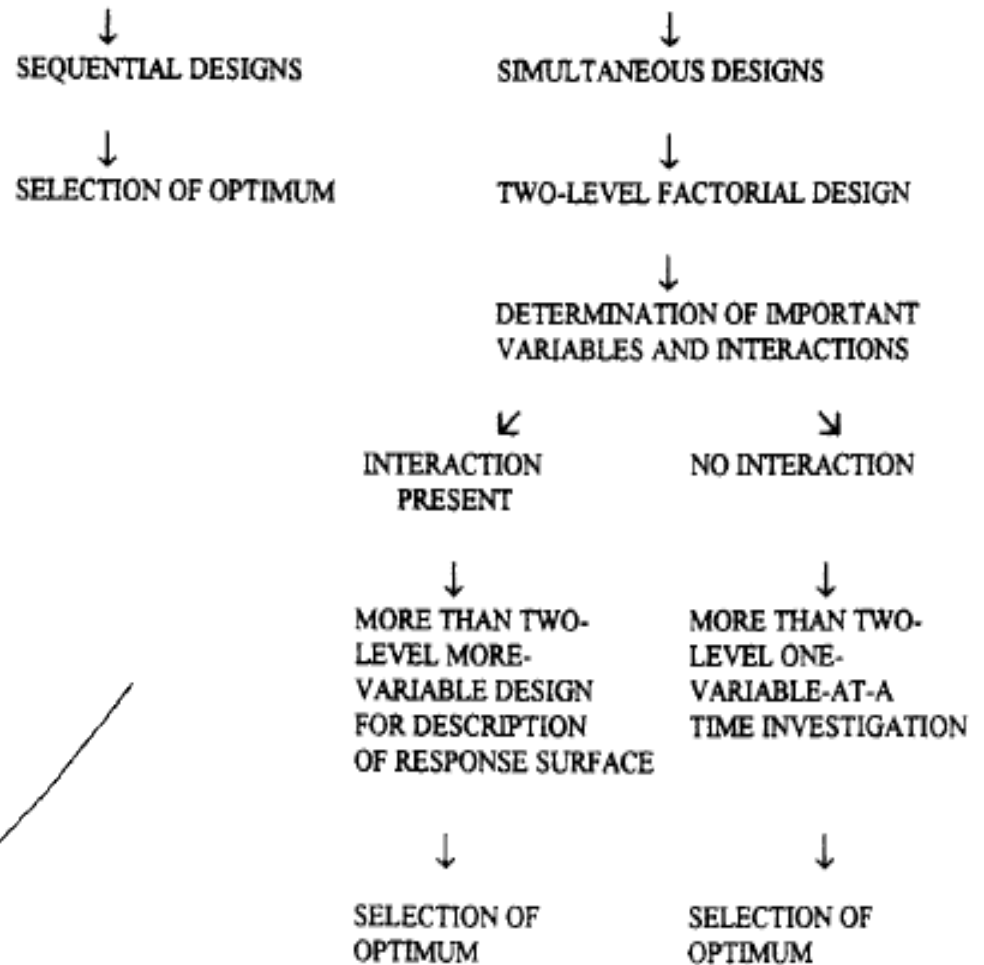
# Main Steps of Experimental Design

## Sequential Design

**No Mathematical Model**  
**No Interactions can be Detected**

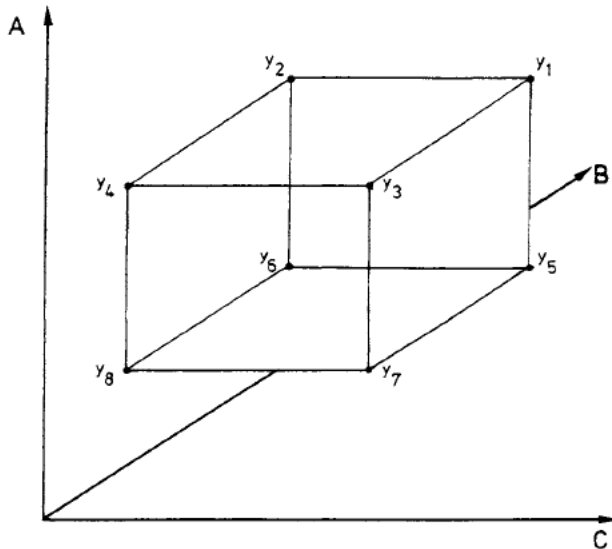
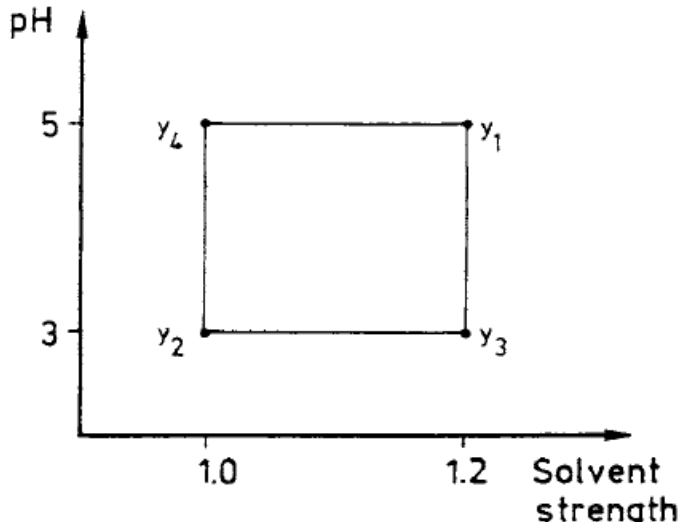


### SELECTION OF STRATEGY



# Main Steps of Experimental Design

## 2-Level Factorial Design $N=2^K$



SIMULTANEOUS DESIGNS



TWO-LEVEL FACTORIAL DESIGN



DETERMINATION OF IMPORTANT VARIABLES AND INTERACTIONS



INTERACTION PRESENT



NO INTERACTION



MORE THAN TWO-LEVEL MORE-VARIABLE DESIGN FOR DESCRIPTION OF RESPONSE SURFACE



MORE THAN TWO-LEVEL ONE-VARIABLE-AT-A-TIME INVESTIGATION



SELECTION OF OPTIMUM



SELECTION OF OPTIMUM

# Main Steps of Experimental Design

## More than 2 level Design

- Full Factorial Design ( $N=L^K$ )
- Central Composite Rotatable Design  $N= 2^K + 2K + 1$
- Box Benken Design
- Doehlert Design

# Main Steps of Experimental Design

## Full Factorial Design

- $K=3$
- $L=5$
- $N=125$



N	X1	X2	X3	Y
1	1	1	1	
2	2	1	1	
3	3	1	1	
4	4	1	1	
5	5	1	1	

N	X1	X2	X3	•	Y
11	1	3		1	
12	2	3		1	
13	3	3		1	
14	4	3		1	
15	5	3		1	

N	X1	X2	X3	•	Y
21	1	5		1	
22	2	5		1	
23	3	5		1	
24	4	5		1	
25	5	5		1	

N	X1	X2	X3	Y
6	1	2	1	
7	2	2	1	
8	3	2	1	
9	4	2	1	
10	5	2	1	

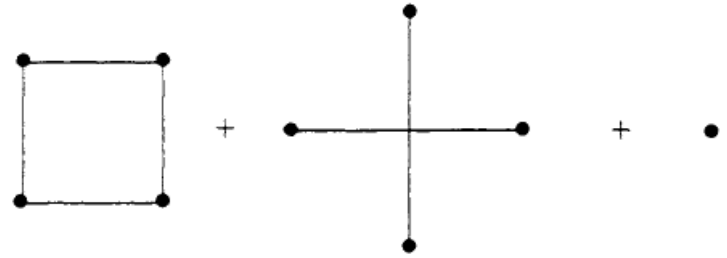
N	X1	X2	X3	•	Y
16	1	4		1	
17	2	4		1	
18	3	4		1	
19	4	4		1	
20	5	4		1	



$X3 = 2, 3, 4, 5$

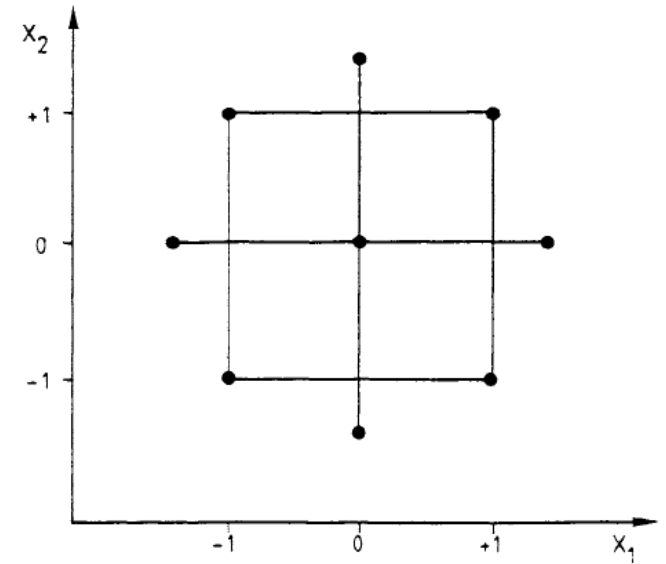
# Main Steps of Experimental Design

## CCRD Design (K=2, N=9)

$$\alpha = 2^{K/4} = 2^{1/2}$$


a)

Experiment	$x_1$	$x_2$
1	-1	-1
2	+1	-1
3	-1	+1
4	+1	+1
5	$-\sqrt{2}$	0
6	$+\sqrt{2}$	0
7	0	$-\sqrt{2}$
8	0	$+\sqrt{2}$
9 etc.	0	0

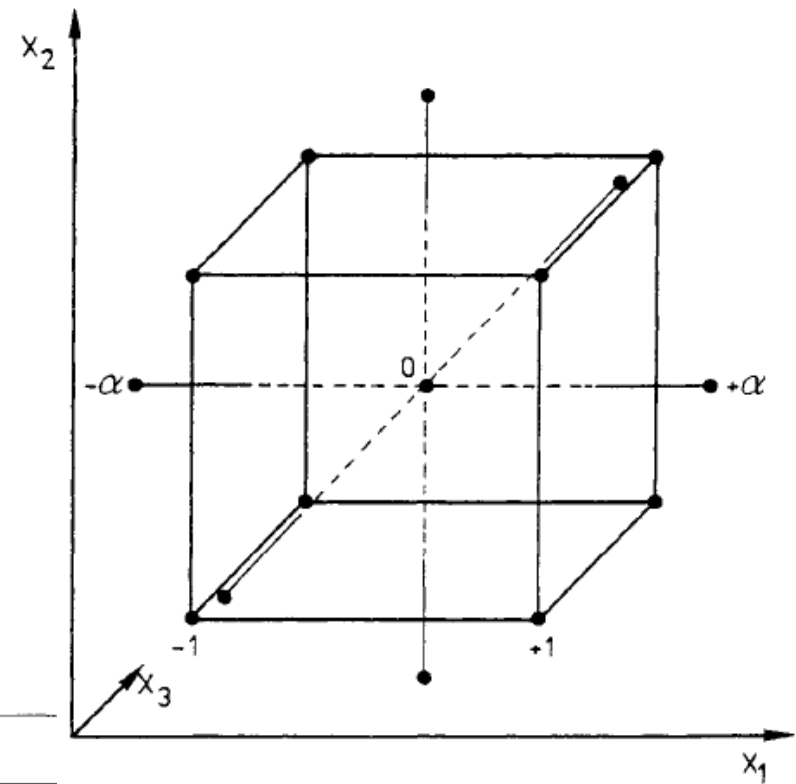


b)



# Main Steps of Experimental Design

## CCRD Design (K=3, N=15)

$$\alpha = 2^{K/4} = 2^{3/4}$$


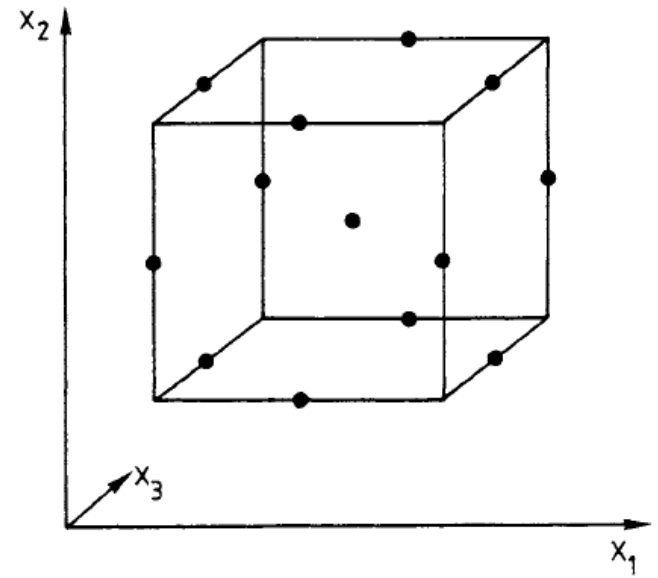
A three-factor central composite design

Experiment	$x_1$	$x_2$	$x_3$
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1
9	-1.682	0	0
10	+1.682	0	0
11	0	-1.682	0
12	0	+1.682	0
13	0	0	-1.682
14	0	0	+1.682
15 etc.	0	0	0

# Main Steps of Experimental Design

## Box-Behnken Design

- For  $K=3$ ,  $N=13$
- Less Number of Experiments
- 3 level for each factor



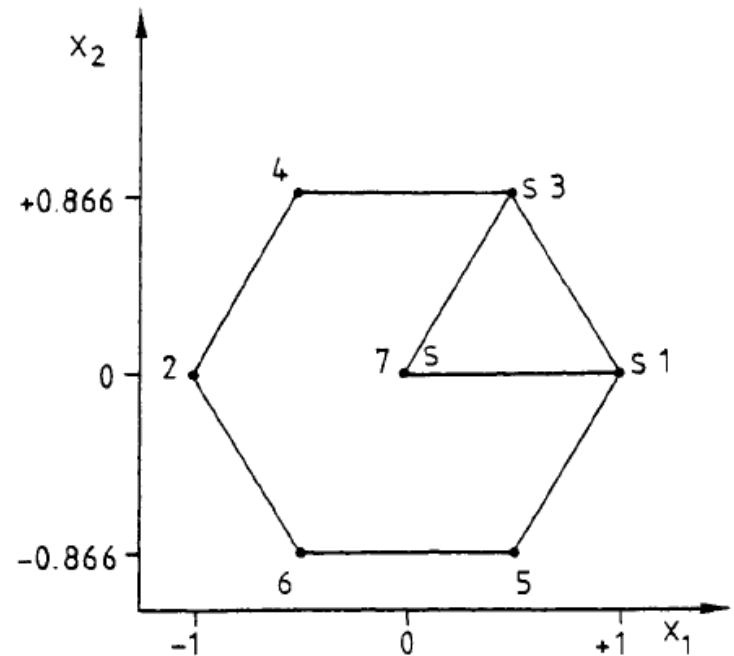
The Box-Behnken design for  $k = 3$

Expt.	$x_1$	$x_2$	$x_3$
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 etc.	0	0	0

# Main Steps of Experimental Design

## Doehlert Design

- Less Number of Experiments
- Different Levels
- Can be Transferred



Doehlert design for 2 factors

Expt.	$x_1$	$x_2$
1	1	0
2	-1	0
3	0.5	0.866
4	-0.5	0.866
5	0.5	-0.866
6	-0.5	-0.866
7	0	0

# Statistical Software

- Statistica
- Minitab 17
- Design Expert
- SPSS



**SPSS**<sup>®</sup>  
AN IBM<sup>®</sup> COMPANY

 Minitab 17

Minitab 

# STATISTICA

Version 10

**32-bit**

This product licensed to:  
Mohammed Eisa  
Baghdad University

Extract Clean Analyze Identify Predict  
Base

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**StatSoft**



Resume... Ctrl+R

Report Add to MS Word

Basic Statistics/Tables

Multiple Regression

ANOVA

Nonparametrics

Distribution Fitting

Distributions & Simulation

Advanced Linear/Nonlinear Models

Multivariate Exploratory Techniques

Industrial Statistics & Six Sigma

Power Analysis

Automated Neural Networks

PLS, PCA, Multivariate/Batch SPC

Variance Estimation and Precision

Statistics of Block Data

STATISTICA Visual Basic

Batch (ByGroup) Analysis

Probability Calculator

Quality Control Charts

Process Analysis

Experimental Design (DOE)






Multivariate Quality Control


Six Sigma (DMAIC) Shortcuts

Data: Spreadsheet1 (10v)


	1	2	3	4	5	6	7	8	9	10
	Var1								Var9	Var10
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

Quick | **Advanced**


-  **2<sup>jak</sup>(K-p) standard designs (Box, Hunter, & Hunter)**
-  3<sup>jak</sup>(K-p) and Box-Behnken designs
-  Mixed 2 and 3 level designs
-  Central composite, non-factorial, surface designs
-  Mixture designs and triangular surfaces

 OK

Cancel

 Options ▾

For full-factorial designs, hierarchically nested models or designs with unbalanced nesting, and mixed-model (random effect) designs, see also Variance Components and GLM.

 Open Data



SELECT CASES S

 W



Quick

Advanced

  $2^{k-p}$  (K-p) standard designs (Box, Hunter, & Hunter)  $3^{k-p}$  (K-p) and Box-Behnken designs Mixed 2 and 3 level designs Central composite, non-factorial, surface designs Mixture designs and triangular surfaces

OK

Cancel



Options ▾

For full-factorial designs, hierarchically nested models or designs with unbalanced nesting, and mixed-model (random effect) designs, see also Variance Components and GLM.

Open DataSELECT  
CASES

S



W

Design experiment | Analyze design

Standard design  
(resolution of cube: V+)

Small design

Factors/blocks/runs:

Factors/blocks/runs:

2/1/10	5/1/44	8/1/82
2/2/10	5/2/44	8/2/82
3/1/16	5/5/47	8/5/82
3/2/16	6/1/46	
3/3/17	6/2/46	
4/1/26	6/3/47	
4/2/26	7/1/80	
4/3/27	7/2/80	
5/1/27	7/5/83	
5/2/28	7/9/87	

4/1/18
4/2/18
5/1/24
5/2/24
6/1/30
6/2/30
7/1/40
7/2/40
8/1/54
8/2/54

Replications, additional points, labels, etc., can be specified on the next dialog; see also the 3\*\*(K-p) and Box-Behnken design option for additional designs.

OK

Cancel

Options

SELECT CHANGES

	1 Var1	2 Var2	3 Var3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

### Design of a Central Composite (Response Surface) Experiment: Spreadsheet2

STANDARD DESIGN SUMMARY: 2\*\*2 cube plus star (central composite design)  
 Number of factors: 2  
 Number of blocks: 1  
 Number of runs: 10 nc=4 ns=4 n0=2  
 Alpha for rotatability: 1.4142 Alpha for orthogonality: 1.0781

Quick | Display design | Add to design | Design characteristic | Generators & aliases

Summary: Display design

Order of runs

Standard order

Random  by blocks

Change factor names, values, etc.

Summary

Cancel

Summary Box

Options

The information shown in the Summary Box pertains to the default design; use the Display design option to change the Design characteristics.

To save the design, use option "Display design," modify the design if necessary, and save the Spreadsheet.

	1 Var1	2 Var2	3 Var3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

### Summary for Variables (Factors)

Summary for Variables (Factors)  
To change labels, values, etc., type in the desired changes, then click OK.

Factor	Factor Name	Low Value	Low Label	Center Value	Center Label	High Value	High Label	Star Low Label	Star Hi. Label
A (1)	A	-1	Low	0	CenterPt	1	High	StarLow	StarHigh
B (2)	B	-1	Low	0	CenterPt	1	High	StarLow	StarHigh

OK Cancel

	1 Var1	2 Var2	3 Var3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

### Summary for Variables (Factors)

Summary for Variables (Factors)  
To change labels, values, etc., type in the desired changes, then click OK.

Factor	Factor Name	Low Value	Low Label	Center Value	Center Label	High Value	High Label	Star Low Label	Star Hi. Label
A (1)	Fe	0.129	Low	0.2	CenterPt	0.271	High	StarLow	StarHigh
B (2)	Time	12.93	Low	20	CenterPt	27.07	High	StarLow	StarHigh

OK Cancel

Clipboard icons: Add to Workbook, Add to Report, Add to MS Word

Statistical analysis icons: GLM, GLZ, GRM, PLS, etc.

Font settings: Arial, 10, Bold, Italic, Underline, Text color, Background color, Fill, Borders, etc.

	1 Var1	2 Var2	3 Var3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

### Design of a Central Composite (Response Surface) Experiment: Spreadsheet2

STANDARD DESIGN SUMMARY: 2<sup>++</sup>(2) cube plus star (central composite design)  
 Number of factors: 2  
 Number of blocks: 1  
 Number of runs: 10 nc=4 ns=4 n0=2  
 Alpha for rotatability: 1.4142 Alpha for orthogonality: 1.0781

Quick | Display design | Add to design | Design characteristic | Generators & aliases

Summary

Cancel

Summary Box

Options

The information shown in the Summary Box pertains to the default design; use the Display design option to change the Design characteristics.

To save the design, use option "Display design," modify the design if necessary, and save the Spreadsheet.

File Edit View Insert Format Statistics Data Mining Graphs Tools Data Enterprise Window Help

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Arial 10 B I U

	1 Var1	2 Var2	3 Var3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

**Design of a Central Composite (Response Surface) Experiment: Spreadsheet2**

STANDARD DESIGN SUMMARY: 2\*\*(2) cube plus star (central composite design)  
 Number of factors: 2  
 Number of blocks: 1  
 Number of runs: 10 nc=4 ns=4 n0=2  
 Alpha for rotatability: 1.4142 Alpha for orthogonality: 1.0781

Quick | Display design | Add to design | Design characteristic | Generators & aliases

Add to the design

Number of genuine replicates:

Number of center points (per block):

Number of blank columns (dep. vars):

Summary  
 Cancel  
 Summary Box  
 Options

The information shown in the Summary Box pertains to the default design; use the Display design option to change the Design characteristics.

To save the design, use option "Display design," modify the design if necessary, and save the Spreadsheet.

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	1 Var1	2 Var2	3 Var3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

**Design of a Central Composite (Response Surface) Experiment: Spreadsheet2**

STANDARD DESIGN SUMMARY: 2\*\*(2) cube plus star (central composite design)  
 Number of factors: 2  
 Number of blocks: 1  
 Number of runs: 10 nc=4 ns=4 n0=2  
 Alpha for rotatability: 1.4142 Alpha for orthogonality: 1.0781

Quick | Display design | Add to design | Design characteristic | Generators & aliases

Add to the design

Number of genuine replicates: 0

Number of center points (per block): 3

Number of blank columns (dep. vars): 1

Summary

Cancel

Summary Box

Options

The information shown in the Summary Box pertains to the default design; use the Display design option to change the Design characteristics.

To save the design, use option "Display design," modify the design if necessary, and save the Spreadsheet.



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Clipboard icons: Add to Workbook, Add to Report, Add to MS Word

Statistical Analysis icons: GLM, GLZ, GRM, PLS, etc.

Font settings: Arial, 10, Bold, Italic, Underline

Alignment and Numbering icons: .00, +.00, etc.

atistica 111\*  
 imental Design ( ... )  
 sign of central co ... )  
 Correlations of E ... )  
 2\*\*(2) central co ... )  
 imental Design ( ... )  
 sign of central co ... )  
 2\*\*(2) central co ... )  
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 sign of central co ... )  
 2\*\*(2) central co ... )  
 2\*\*(2) central co ... )

2\*\*(2) central composite, nc=4 ns=4 n0=2 Runs=10 (Spreadsheet2)  
 + 3 center points

Standard Run	Fe	Time	DV_1
1	0.129289	12.92893	
2	0.129289	27.07107	
3	0.270711	12.92893	
4	0.270711	27.07107	
5	0.100000	20.00000	
6	0.300000	20.00000	
7	0.200000	10.00000	
8	0.200000	30.00000	
9 (C)	0.200000	20.00000	
10 (C)	0.200000	20.00000	
11 (C)	0.200000	20.00000	
12 (C)	0.200000	20.00000	
13 (C)	0.200000	20.00000	

Experimental Design (Design of central composite)  
 Correlations of E  
 2\*\*(2) central composite  
 Experimental Design (Design of central composite)  
 2\*\*(2) central composite  
 Experimental Design (Design of central composite)  
 2\*\*(2) central composite  
 2\*\*(2) central composite

2\*\*(2) central composite, nc=4 ns=4 n0=2 Runs=10 (Spreadsheet2)  
 + 3 center points

Standard Run	Fe	Time	DV_1
1	0.129289	12.92893	
2	0.129289	27.07107	
3	0.270711	12.92893	
4	0.270711	27.07107	
5	0.100000	20.00000	
6	0.300000	20.00000	
7	0.200000	10.00000	
8	0.200000	30.00000	
9 (C)	0.200000	20.00000	
10 (C)	0.200000	20.00000	
11 (C)	0.200000	20.00000	
12 (C)	0.200000	20.00000	
13 (C)	0.200000	20.00000	

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 Correlations of E ...  
 2\*\*(2) central co ...  
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 2\*\*(2) central co ...  
 imental Design ( ...  
 sign of central co ...  
 2\*\*(2) central co ...  
 2\*\*(2) central co ...

Standard Run	2**(2) central composite, nc=4 ns=4 n0=2 + 3 center points		
	Fe	Time	DV_1
1	0.129289	12.92893	
2	0.129289	27.07107	
3	0.270711	12.92893	
4	0.270711	27.07107	
5	0.100000	20.00000	
6	0.300000	20.00000	
7	0.200000	10.00000	
8	0.200000	30.00000	
9 (C)	0.200000	20.00000	
10 (C)	0.200000	20.00000	
11 (C)	0.200000	20.00000	
12 (C)	0.200000	20.00000	
13 (C)	0.200000	20.00000	

### Variable 3

Name:  Type:

Measurement Type:  Length:

Excluded  Label  Case State MD code:

Display format

General	Decimal places: <input type="text" value="2"/>
<b>Number</b>	
Date	1000.00; -1000.00
Time	1,000.00; -1,000.00
Scientific	1000.00; (1000.00)
Currency	1,000.00; (1,000.00)
Percentage	
Fraction	
Custom	

Long name (label or formula with  ):   Function guide

Labels: use any text. Formulas: use variable names or v1, v2, ..., v0 is case #.  
 Examples: (a) = mean(v1:v3, sqrt(v7), AGE) (b) = v1+v2; comment (after;)

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Vars Cases

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 imental Design (C  
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 imental Design (C  
 sign of central co  
 2\*\*(2) central co  
 imental Design (C  
 sign of central co  
 2\*\*(2) central co  
 2\*\*(2) central co

2**(2) central composite, nc=4 ns=4 n0=2 Runs=10 (Spreadsheet2) + 3 center points			
Standard Run	Fe	Time	RE%
1	0.129289	12.92893	
2	0.129289	27.07107	
3	0.270711	12.92893	
4	0.270711	27.07107	
5	0.100000	20.00000	
6	0.300000	20.00000	
7	0.200000	10.00000	
8	0.200000	30.00000	
9 (C)	0.200000	20.00000	
10 (C)	0.200000	20.00000	
11 (C)	0.200000	20.00000	
12 (C)	0.200000	20.00000	
13 (C)	0.200000	20.00000	

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GLM GLZ GRM PLS

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 sign of central co ...  
 Correlations of E ...  
 2\*\*(2) central co ...  
 imental Design ( ...  
 sign of central co ...  
 2\*\*(2) central co ...  
 imental Design ( ...  
 sign of central co ...  
 2\*\*(2) central co ...  
 2\*\*(2) central co ...

2**(2) central composite, nc=4 ns=4 n0=2 Runs=10 (Spreadsheet2) + 3 center points			
Standard Run	Fe	Time	RE%
1	0.129289	12.92893	70
2	0.129289	27.07107	68.99
3	0.270711	12.92893	80.78
4	0.270711	27.07107	82.31
5	0.100000	20.00000	65.00
6	0.300000	20.00000	90.00
7	0.200000	10.00000	73.00
8	0.200000	30.00000	75.98
9	0.200000	20.00000	86.89
10	0.200000	20.00000	85
11	0.200000	20.00000	83
12	0.200000	20.00000	88
13	0.200000	20.00000	84.5

- New... Ctrl+N
- Open... Ctrl+O
- Open URL...
- Open Examples...
- Import Image...
- Close
- Save Ctrl+S
- Save As... F12
- Save As PDF...
- Save Item(s) As...
- Save Project...
- Save Project As...
- Open Project...
- Close Project
- SharePoint
- Get External Data
- Output Manager...
- Workbook Page Setup...
- Print Setup...
- Print Preview
- Print... Ctrl+P
- Print Active Item...
- Properties...
- 1 CCRD Statistica 111
- 2 C:\Users\...\CCRD 11
- 3 C:\Users\...\CCRD 11
- 4 C:\Users\...\Statistica\CCRD 1
- 5 Analysis of Adsorption Experiments Ph...
- 6 C:\Users\...\aaaa\Spreadsheet1

Workbook ▾ Add to Report ▾ Add to MS Word ▾

Vars ▾ Cases ▾

, nc=4 ns=4 n0=2 Runs=10 (Spreadsheet2)

RE%					
70					
68.99					
80.78					
82.31					
65.00					
90.00					
73.00					
75.98					
86.89					
85					
83					
88					
84.5					

Resume... Ctrl+R

Basic Statistics/Tables

Multiple Regression

ANOVA

Nonparametrics

Distribution Fitting

Distributions & Simulation

Advanced Linear/Nonlinear Models

Multivariate Exploratory Techniques

Industrial Statistics & Six Sigma

Power Analysis

Automated Neural Networks

PLS, PCA, Multivariate/Batch SPC

Variance Estimation and Precision

Statistics of Block Data

STATISTICA Visual Basic

Batch (ByGroup) Analysis

Probability Calculator

Quality Control Charts

Process Analysis

Experimental Design (DOE)

Multivariate Quality Control

Six Sigma (DMAIC) Shortcuts

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Correlations of E

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2\*\*(2) central co

2\*\*(2) central co

Standard Run	2**(2) c + 3 cen Fe
1	0.1292
2	0.1292
3	0.2707
4	0.2707
5	0.1000
6	0.3000
7	0.2000
8	0.2000
9	0.2000
10	0.2000
11	0.2000
12	0.2000
13	0.2000

s=10 (Spreadsheet2)

File Edit View Insert Format Statistics Data Mining Graphs Tools Data Workbook Enterprise Window Help

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Arial 10 B I U

atistica 111\*  
 imental Design ( ...  
 sign of central co ...  
 Correlations of E ...  
 2\*\*(2) central co ...  
 imental Design ( ...  
 sign of central co ...  
 2\*\*(2) central co ...  
 imental Design ( ...  
 sign of central co ...  
 2\*\*(2) central co ...  
 2\*\*(2) central co ...

Standard Run	Fe	Time	RE%
1	0.129289	12.92893	70
2	0.129289	27.07107	68.99
3	0.270711	12.92893	80.78
4	0.270711	27.07107	82.31
5	0.100000	20.00000	65.00
6	0.300000	20.00000	90.00
7	0.200000	10.00000	73.00
8	0.200000	30.00000	75.98
9	0.200000	20.00000	86.89
10	0.200000	20.00000	85
11	0.200000	20.00000	83
12	0.200000	20.00000	88
13	0.200000	20.00000	84.5

2\*\*(2) central composite, nc=4 ns=4 n0=2 Runs=10 (Spreadsheet2)  
 + 3 center points

Starting Duplicate Analysis ? X

There is already an Analysis of this type running on this Spreadsheet. Would you like to continue the current Analysis, or start a new one of the same type?

Always start new Analysis without prompting



File Edit View Insert Format Statistics Data Mining Graphs Tools Data Enterprise Window Help

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Arial 10 B I U

	1 Var1	2 Var2	3 Var3	4 Var4
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

### Design & Analysis of Experiments: Spreadsheet2

Quick | Advanced

- 2<sup>k</sup>(K-p) standard designs (Box, Hunter, & Hunter)
- 3<sup>k</sup>(K-p) and Box-Behnken designs
- Mixed 2 and 3 level designs
- Central composite, non-factorial, surface designs**
- Mixture designs and triangular surfaces

OK

Cancel

Options

For full-factorial designs, hierarchically nested models or designs with unbalanced nesting, and mixed-model (random effect) designs, see also Variance Components and GLM.

Open Data

SELECT CASES

File Edit View Insert Format Statistics Data Mining Graphs Tools Data Enterprise Window Help

Add to Workbook Add to Report Add to MS Word

Arial 10 B I U

2\*\*(2) central composite, nc=4 ns=4 n0=2  
+ 3 center points

Standard Run	Fe	Time	RE%
1	0.129289	12.92893	70
2	0.129289	27.07107	68.99
3	0.270711	12.92893	80.78
4	0.270711	27.07107	82.31
5	0.100000	20.00000	65.00
6	0.300000	20.00000	90.00
7	0.200000	10.00000	73.00
8	0.200000	30.00000	75.98
9	0.200000	20.00000	86.89
10	0.200000	20.00000	85
11	0.200000	20.00000	83
12	0.200000	20.00000	88
13	0.200000	20.00000	84.5

Open

Look in: Experimental DesignLecture

Name	Status	Date modified
Statistica	✖	12/5/2023 11:11 AM
CCD 1111	🔄	12/6/2023 12:16 AM

Type: STATISTICA Spreadsheet  
Size: 2.68 KB  
Date modified: 12/6/2023 12:16 AM  
Availability status: Sync pending

File name: CCD 1111

Files of type: STATISTICA Spreadsheet Files (\*.sta)

Open Cancel

2\*\*(2) central composite, nc=4 ns=4 n0=2 Runs=13  
+ 3 center points

Standard Run	Fe	Time	RE%
1	0.129289	12.92893	70
2	0.129289	27.07107	68.99
3	0.270711	12.92893	80.78
4	0.270711	27.07107	82.31
5	0.100000	20.00000	65.00
6	0.300000	20.00000	90.00
7	0.200000	10.00000	73.00
8	0.200000	30.00000	75.98
9	0.200000	20.00000	86.89
10	0.200000	20.00000	85
11	0.200000	20.00000	83
12	0.200000	20.00000	88
13	0.200000	20.00000	84.5

Design experiment Analyze design

Standard design (resolution of cube: V+)

Small design

Factors/blocks/runs:

2/1/10	5/1/44	8/1/82
2/2/10	5/2/44	8/2/82
3/1/16	5/5/47	8/5/82
3/2/16	6/1/46	
3/3/17	6/2/46	
4/1/26	6/3/47	
4/2/26	7/1/80	
4/3/27	7/2/80	
5/1/27	7/5/83	
5/2/28	7/9/87	

Factors/blocks/runs:

4/2/18
5/1/24
5/2/24
6/1/30
6/2/30
7/1/40
7/2/40
8/1/54
8/2/54

Replications, additional points, labels, etc., can be specified on the next dialog; see also the 3\*\*(K-p) and Box-Behnken design option for additional designs.

OK Cancel Options

2\*\*(2) central composite, nc=4 ns=4 n0=2 Runs=13  
+ 3 center points

Standard Run	Fe	Time	RE%
1	0.129289	12.92893	70
2	0.129289	27.07107	68.99
3	0.270711	12.92893	80.78
4	0.270711	27.07107	82.31
5	0.100000	20.00000	65.00
6	0.300000	20.00000	90.00
7	0.200000	10.00000	73.00
8	0.200000	30.00000	75.98
9	0.200000	20.00000	86.89
10	0.200000	20.00000	85
11	0.200000	20.00000	83
12	0.200000	20.00000	88
13	0.200000	20.00000	84.5

Design & Analysis of Central Composite (Response Surface) Experiments : CCD 1111

Design experiment | Analyze design

**Variables**

Dependent: none  
 Independent (factors): none  
 Blocking variable: none

To recode factor values (levels), use

Automatically determined factor levels from file  
 User-defined high/low factor values

Factor levels are recoded as  $x = (value - avg.) / (range / 2)$ ; where  $range = HighValue - LowValue$ , and  $avg. = (HighValue + LowValue) / 2$ ; press F1 or click ? for more info.

Use this option (dialog) to analyze central composite and non-factorial experiments; you can also use the 3\*\*(k-p) and Box-Behnken, 2\*\*(k-p), and mixed 2/3 level designs options to fit response surfaces to designs without star points.

OK Cancel Options

SELECT CASES

2\*\*(2) central composite, nc=4 ns=4 n0=2 Runs=13 + 3 center points

Standard Run	Fe	Time	RE%
1	0.129289	12.92893	70
2	0.129289	27.07107	68.99
3	0.270711	12.92893	80.78
4	0.270711	27.07107	82.31
5	0.100000	20.00000	65.00
6	0.300000	20.00000	90.00
7	0.200000	10.00000	73.00
8	0.200000	30.00000	75.98
9	0.200000	20.00000	86.89
10	0.200000	20.00000	85
11	0.200000	20.00000	83
12	0.200000	20.00000	88
13	0.200000	20.00000	84.5

Design experiment Analyze design

Select dependent and independent variables, and (optional) blocking variab...

1 - Fe  
2 - Time  
3 - RE%

1 - Fe  
2 - Time  
3 - RE%

Spread Zoom

Spread Zoom

Spread Zoom

Dependent:     Indep. (factors):     Blocking variable:

Show appropriate variables only

OK  
Cancel  
[ Bundles ]...

Use the "Show appropriate variables only" option to pre-screen variable lists and show categorical and continuous variables. Press F1 for more information.

2\*\*(2) central composite, nc=4 ns=4 n0=2 Runs=13  
+ 3 center points

Standard Run	Fe	Time	RE%
1	0.129289	12.92893	70
2	0.129289	27.07107	68.99
3	0.270711	12.92893	80.78
4	0.270711	27.07107	82.31
5	0.100000	20.00000	65.00
6	0.300000	20.00000	90.00
7	0.200000	10.00000	73.00
8	0.200000	30.00000	75.98
9	0.200000	20.00000	86.89
10	0.200000	20.00000	85
11	0.200000	20.00000	83
12	0.200000	20.00000	88
13	0.200000	20.00000	84.5

Design experiment Analyze design

**Variables**

Dependent: RE%

Independent (factors): Fe-Time

Blocking variable: none

To recode factor values (levels), use

Automatically determined factor levels from file

User-defined high/low factor values

Factor levels are recoded as  $x=(value-avg.)/(range/2)$ ; where  $range=HighValue-LowValue$ , and  $avg.=(HighValue+LowValue)/2$ ; press F1 or click ? for more info.

Use this option (dialog) to analyze central composite and non-factorial experiments; you can also use the 3\*\*(k-p) and Box-Behnken, 2\*\*(k-p), and mixed 2/3 level designs options to fit response surfaces to designs without star points.

OK Cancel Options

SELECT CRSES

2\*\*(2) central composite, nc=4  
+ 3 center points

Standard Run	Fe	Time	RE%
1	0.129289	12.92893	
2	0.129289	27.07107	
3	0.270711	12.92893	
4	0.270711	27.07107	
5	0.100000	20.00000	
6	0.300000	20.00000	
7	0.200000	10.00000	
8	0.200000	30.00000	
9	0.200000	20.00000	
10	0.200000	20.00000	
11	0.200000	20.00000	
12	0.200000	20.00000	
13	0.200000	20.00000	

**DESIGN SUMMARY:**  
 Number of factors (independent variables): 2  
 Total number of runs (cases, experiments): 13  
 Number of unique runs (cases experiments): 9  
 Number of blocks: 1  
 Number of replications: 0 - 4

Variable: RE%  All variables

Review/save residuals | Residual plots | Box-Cox | Prediction & profiling  
 Quick | Model | Design | ANOVA/Effects | Means

ANOVA

Predicted (estimated) response

These results are for the current model; you can change the model (add or remove interaction effects) on the Model tab.

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Arial 10 B I U

- Workbook2\*
- Experimer
- Analysi
- Effect

Effect Estimates; Var.:RE%; R-sqr=.95682; Adj.:92597 (CCD 1111)  
 2 factors, 1 Blocks, 13 Runs; MS Residual=4.810328  
 DV: RE%

Factor	Effect	Std.Err.	t(7)	p	-95.% Cnf.Limt	+95.% Cnf.Limt	Coeff.	Std.Err. Coeff.	-95.% Cnf.Limt	+95.% Cnf.Limt
Mean/Interc.	85.4780	0.980849	87.14691	0.000000	83.1587	87.79734	85.47800	0.980849	83.15866	87.79734
(1)Fe (L)	14.8638	1.550859	9.58426	0.000028	11.1966	18.53103	7.43192	0.775430	5.59832	9.26552
Fe (Q)	-8.2155	1.663111	-4.93984	0.001675	-12.1481	-4.28287	-4.10775	0.831556	-6.07407	-2.14143
(2)Time (L)	1.1836	1.550859	0.76318	0.470288	-2.4836	4.85079	0.59179	0.775430	-1.24180	2.42539
Time (Q)	-11.2255	1.663111	-6.74970	0.000265	-15.1581	-7.29287	-5.61275	0.831556	-7.57907	-3.64643
1L by 2L	1.2700	2.193246	0.57905	0.580702	-3.9162	6.45620	0.63500	1.096623	-1.95810	3.22810



Workbook2\*

- Experim...
- Analysi...
- Effect...

Factor	Effect Estimate	Effect
<b>Mean/Interc.</b>	<b>85.4780</b>	
(1)Fe (L)	14.8638	
Fe (Q)	-8.2155	
(2)Time (L)	1.1836	
Time (Q)	-11.2255	
1L by 2L	1.2700	

Analysis of a Central Composite (Response Surface) Experiment: CCD 1111

**DESIGN SUMMARY:**  
 Number of factors (independent variables): 2  
 Total number of runs (cases, experiments): 13  
 Number of unique runs (cases experiments): 9  
 Number of blocks: 1  
 Number of replications: 0 - 4

Variable: RE%  All variables

|  |  |  |   
 |  |  |  |  |

**ANOVA**

- 
- 
-

**Predicted (estimated) response**

- 
- 
-

These results are for the current model; you can change the model (add or remove interaction effects) on the Model tab.

File Edit View Insert Format Statistics Data Mining Graphs Tools Data Workbook Enterprise Window Help

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Arial 10 B I U

Vars Cases

- Workbook2\*
- Expeximer
- Analysi
- Effect
- ANC

ANOVA; Var.:RE%; R-sqr=.95682; Adj.:92597 (CCD 1111)  
 2 factors, 1 Blocks, 13 Runs; MS Residual=4.810328  
 DV: RE%

Factor	SS	df	MS	F	p
(1)Fe (L)	441.8672	1	441.8672	91.85801	0.000028
Fe (Q)	117.3816	1	117.3816	24.40200	0.001675
(2)Time (L)	2.8018	1	2.8018	0.58245	0.470288
Time (Q)	219.1510	1	219.1510	45.55844	0.000265
1L by 2L	1.6129	1	1.6129	0.33530	0.580702
Error	33.6723	7	4.8103		
Total SS	779.7469	12			

Workbook2\*

- Experimenter
- Analysis
  - Effect
  - ANOVA

Factor	SS
(1)Fe (L)	441.8672
Fe (Q)	117.3816
(2)Time (L)	2.8018
Time (Q)	219.1510
1L by 2L	1.6129
Error	33.6723
Total SS	779.7469

DESIGN SUMMARY:  
 Number of factors (independent variables): 2  
 Total number of runs (cases, experiments): 13  
 Number of unique runs (cases experiments): 9  
 Number of blocks: 1  
 Number of replications: 0 - 4

Variable: RE%  All variables

|  |  |

|  |  |  |

ANOVA

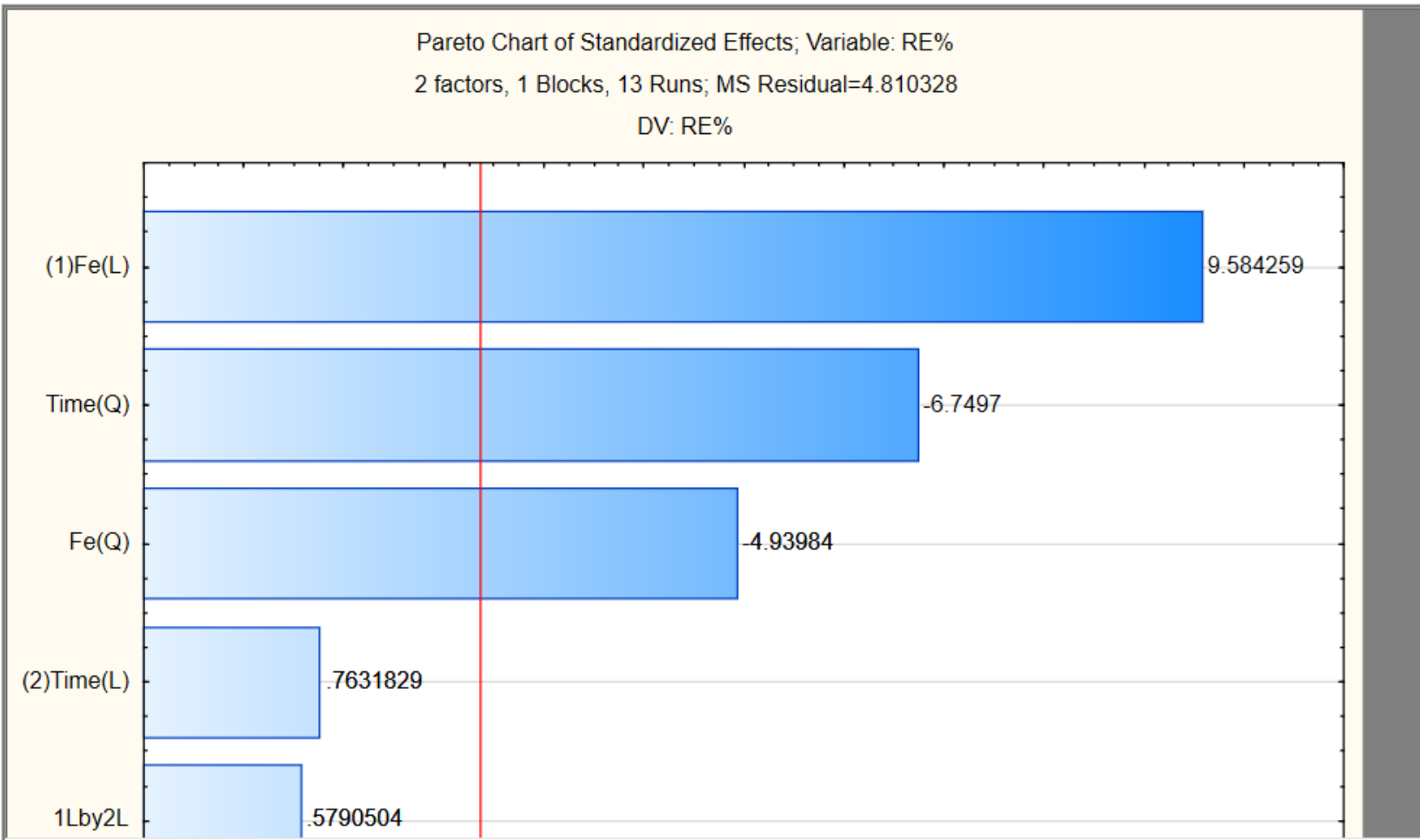
- 
- 
- 

Predicted (estimated) response

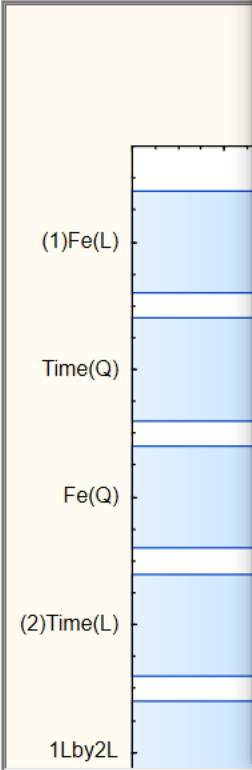
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These results are for the current model; you can change the model (add or remove interaction effects) on the Model tab.

- Workbook2\*
- Experim...
- Analysi...
- Effect...
- ANC...
- Pare...
- Pare...



- Workbook2\*
- Experim...
- Analysi...
- Effec...
- ANC...
- Pare...
- Pare...



DESIGN SUMMARY:  
Number of factors (independent variables): 2  
Total number of runs (cases, experiments): 13  
Number of unique runs (cases experiments): 9  
Number of blocks: 1  
Number of replications: 0 - 4

Variable: RE%  All variables

|  |  |

|  |  |  |

ANOVA

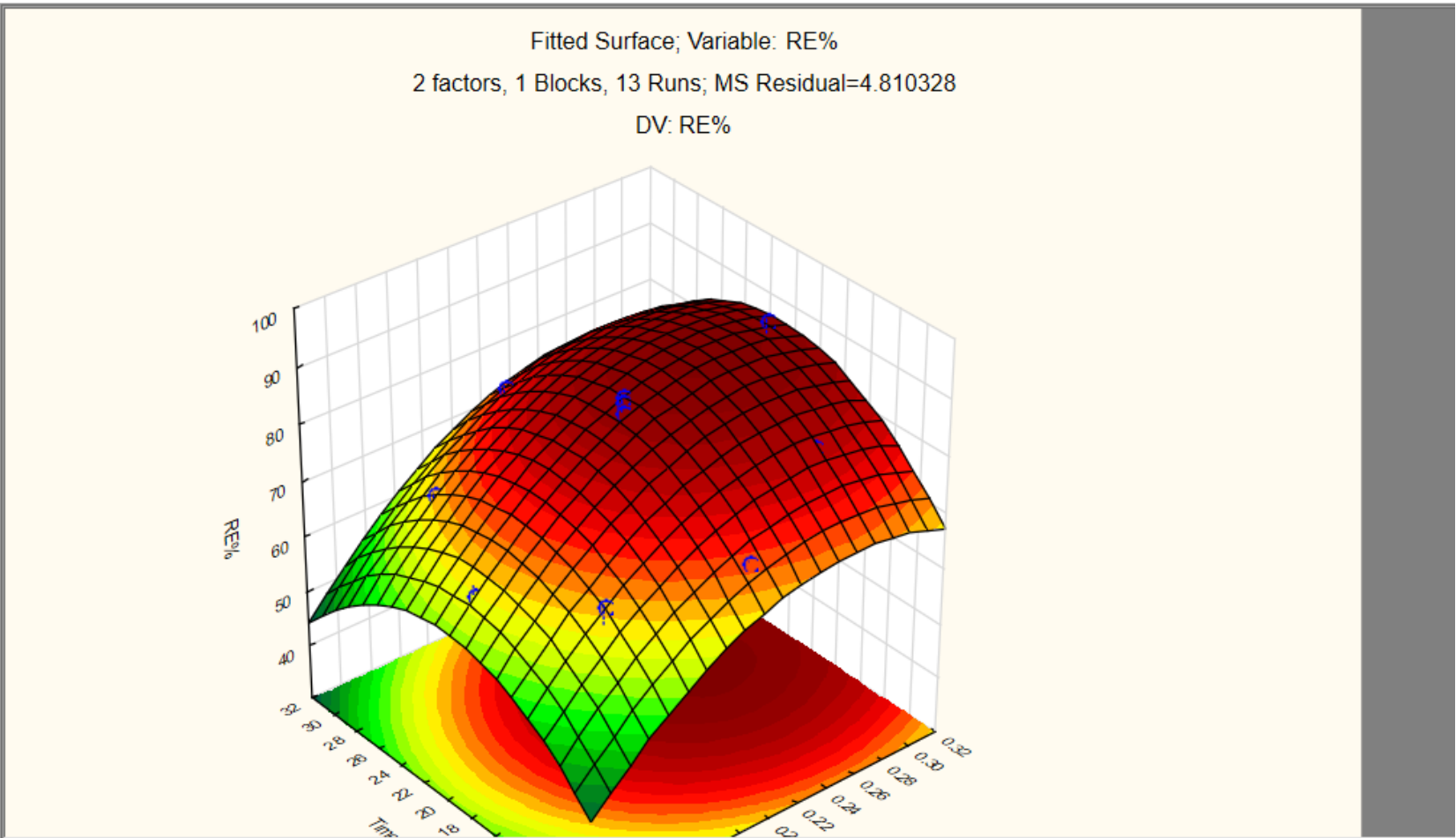
- 
- 
- 

Predicted (estimated) response

- 
- 
- 

These results are for the current model; you can change the model (add or remove interaction effects) on the Model tab.

- Workbook2\*
- Experim...
- Analysi...
- Effect...
- ANC...
- Pare...
- Pare...
- Fitte...



STATISTICA - [Workbook2\* - Fitted Surface; Variable: RE%]

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Normal Graph... Analysis of a Central Composite (Response Surface) Experiment: CCD 1111

Workbook2\*  
 Experiment  
 Analysis  
 Effect  
 ANOVA  
 Pareto  
 Pareto  
 Fitted  
 Fitted

DESIGN SUMMARY:  
 Number of factors (independent variables): 2  
 Total number of runs (cases, experiments): 13  
 Number of unique runs (cases experiments): 9  
 Number of blocks: 1  
 Number of replications: 0 - 4

Variable: RE%  Print results  All variables

ANOVA

Predicted (estimated) response

These results are for the current model; you can change the model (add or remove interaction effects) on the Model tab.

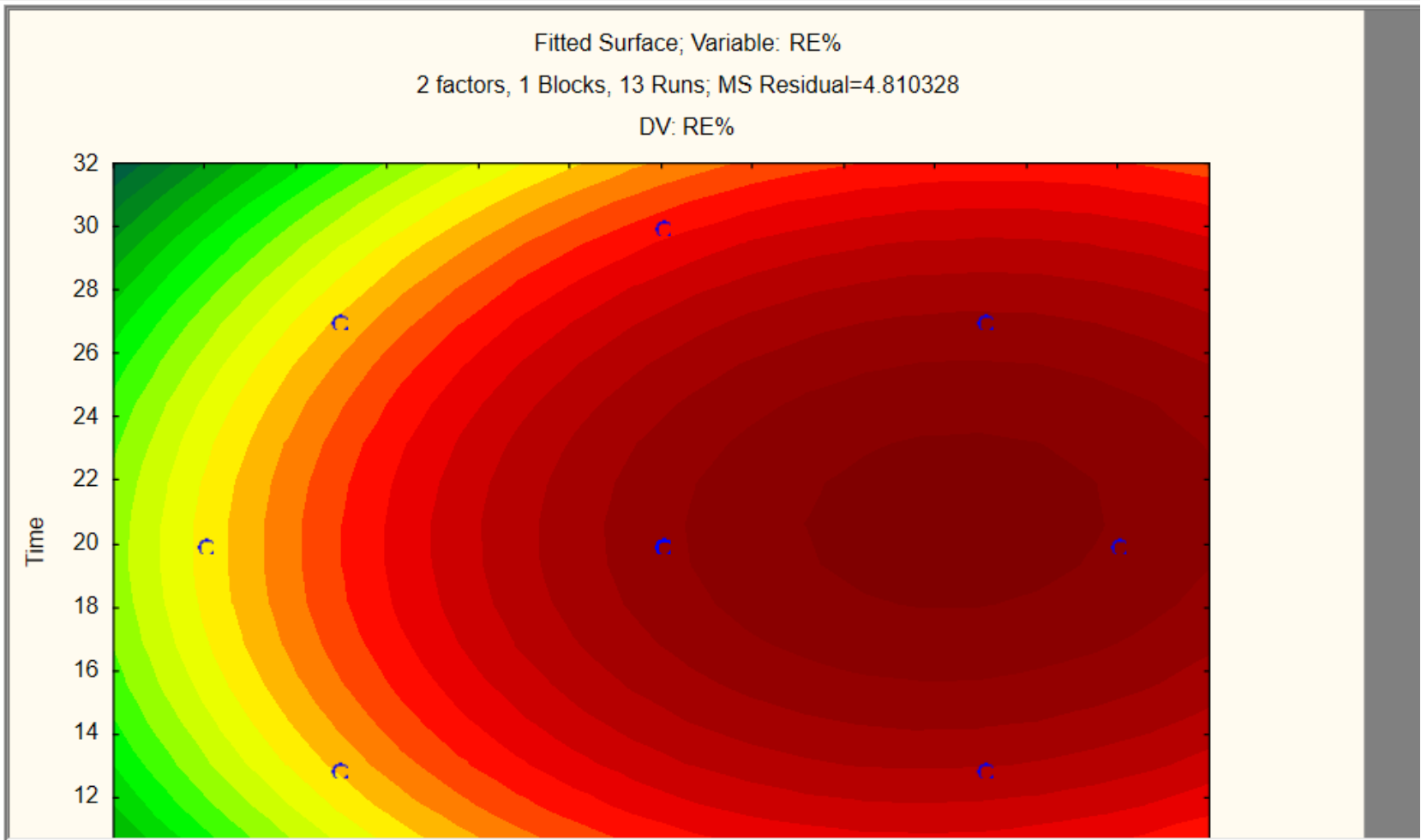
Time

Pareto Chart of Standardized Effects; Variable: RE% Pareto Chart of Standardized Effects; Variable: RE% Fitted Surface; Variable: RE% Fitted Surface; Variable: RE%

Analysis of a Central C...

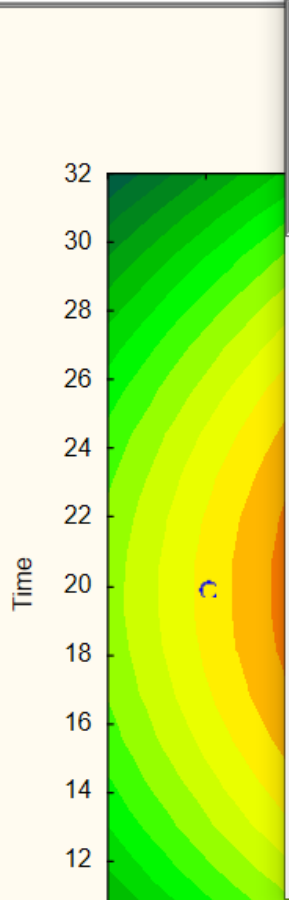
Ready CCD 1111 CAP NUM REC

- Workbook2\*
- Experiment
- Analysis
  - Effect
  - ANC
  - Pare
  - Pare
  - Fitte
  - Fitte





- Workbook2\*
- Experiment
- Analysis
  - Effect
  - ANOVA
  - Pareto
  - Pareto
  - Fitted
  - Fitted



DESIGN SUMMARY:  
 Number of factors (independent variables): 2  
 Total number of runs (cases, experiments): 13  
 Number of unique runs (cases experiments): 9  
 Number of blocks: 1  
 Number of replications: 0 - 4

Variable: RE%  All variables

Review/save residuals	Residual plots	Box-Cox	Prediction & profiling
Quick	Model	Design	ANOVA/Effects

ANOVA

- 
- 
-

Predicted (estimated) response

- 
- 
-

These results are for the current model; you can change the model (add or remove interaction effects) on the Model tab.

File Edit View Insert Format Statistics Data Mining Graphs Tools Data Workbook Enterprise Window Help

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Arial 10 B I U

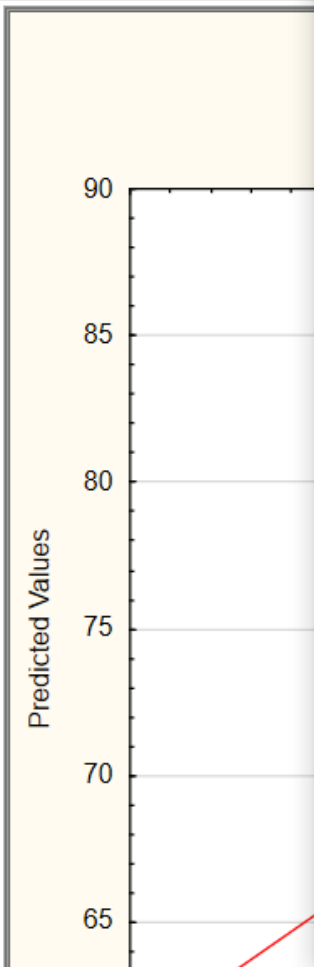
- Workbook2\*
- Experimer
- Analysis
  - Effec
  - ANC
  - Pare
  - Pare
  - Fitte
  - Fitte
  - Resp
  - Eige
  - Criti

Critical values; Variable: RE% (CCD 1111)  
 Solution: maximum  
 Predicted value at solution: 88.90038

Factor	Observed Minimum	Critical Values	Observed Maximum
Fe	0.10000	0.26454	0.30000
Time	10.00000	20.73785	30.00000

Fitted Surface; Variable: RE%    Response surface; Variable: RE% (CCD 1111)    Eigenvalues and eigenvectors : Variable: RE%

- Workbook2\*
- Experim...
- Analysi...
- Effec...
- ANC...
- Pare...
- Pare...
- Fitte...
- Fitte...
- Resp...
- Eige...
- Critic...
- Desi...
- Fitte...
- Obs...



**DESIGN SUMMARY:**  
 Number of factors (independent variables): 2  
 Total number of runs (cases, experiments): 13  
 Number of unique runs (cases experiments): 9  
 Number of blocks: 1  
 Number of replications: 0 - 4

Variable: RE% Print results  All variables Summary

Quick | Model | Design | ANOVA/Effects | Means

Review/save residuals | Residual plots | Box-Cox | Prediction & profiling

Response desirability profiling  Predicted vs. observed values

Surface plot (fitted response)  Predict dependent variable values

Contour plot (fitted response)

Show fitted function

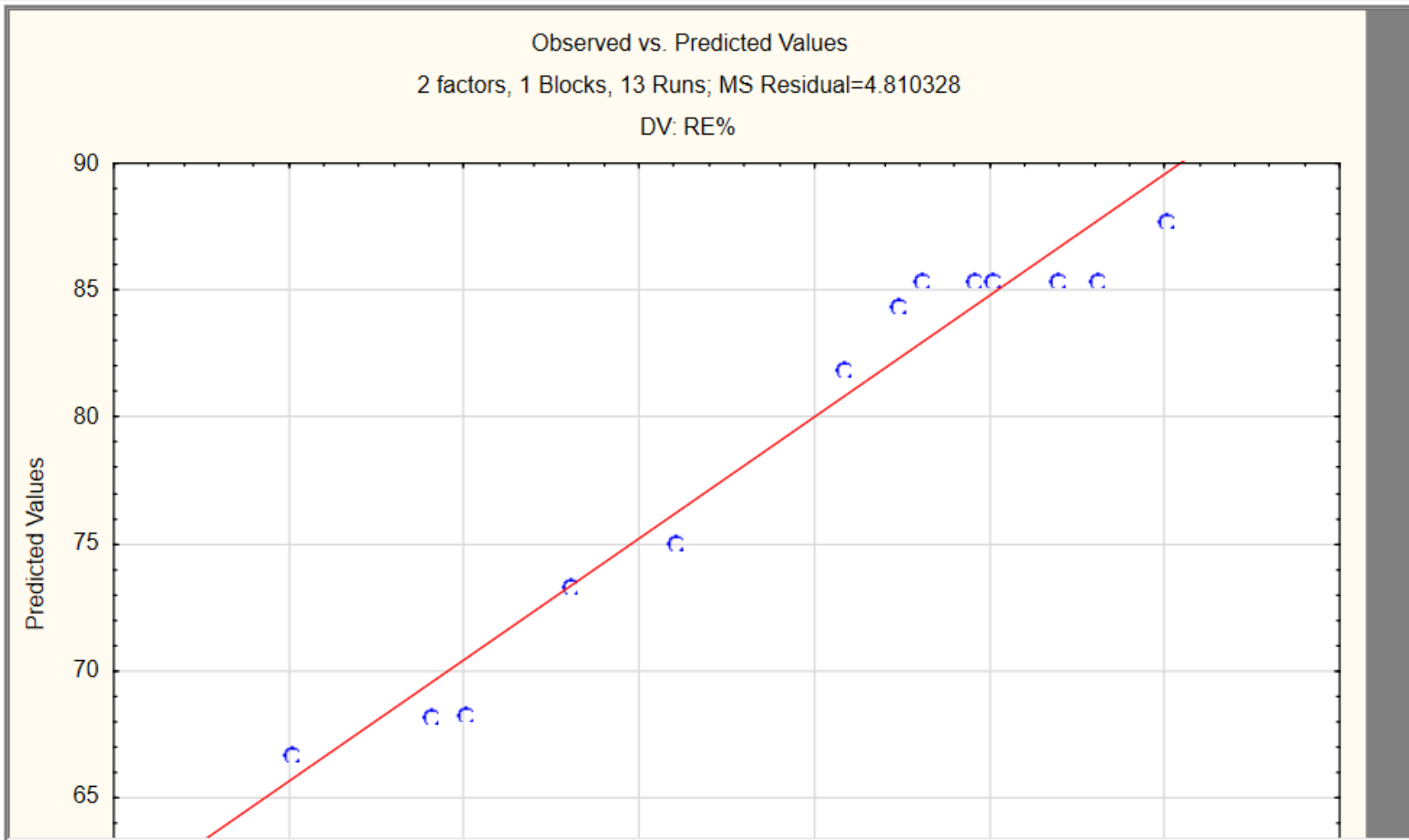
Show area contours

Critical values (min, max, saddle)

These results are for the current model; you can change the model (add or remove interaction effects) on the Model tab.

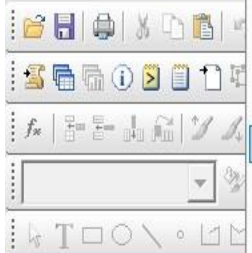
Cancel Options By Group

- Workbook2\*
- Experim...
- Analysi...
- Effect...
- ANC...
- Pare...
- Pare...
- Fitte...
- Fitte...
- Resp...
- Eige...
- Criti...
- Desi...
- Fitte...
- Obse...
- Obse...





# Minitab 17



- Basic Statistics
- Regression
- ANOVA
- DOE**
  - Factorial
  - Response Surface**
    - # Create Response Surface Design...**
    - # Define Custom Response Surface Design...
    - # Select Optimal
    - # Analyze Respo
    - Predict...
    - Factorial Plots...
    - Contour Plot...
    - Surface Plot...
    - Overlaid Contour Plot...
    - Response Optimizer...
  - Mixture
  - Taguchi
  - Modify Design...
  - Display Design...
- Control Charts
- Quality Tools
- Reliability/Survival
- Multivariate
- Time Series
- Tables
- Nonparametrics
- Equivalence Tests
- Power and Sample Size

**Create Response Surface Design**  
Create a central composite or Box-Behnken design.

Session

12/5

Welcome to Minitab

Worksheet 1 \*\*\*

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
1																
2																
3																
4																
5																



Session

12/5/2023 2:01:20 AM

Welcome to Minitab, press F1 for help.

Create Response Surface Design

Type of Design

- Central composite (2 to 10 continuous factors)
- Box-Behnken (3,4,5,6,7,9, or 10 continuous factors)

Number of continuous factors: 2

Number of categorical factors:

- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

Display Available Designs...

Designs... Factors...

Options... Results...

OK Cancel

Help

Worksheet 1 \*\*\*

	C1	C2	C3	C4	C5	C12	C13	C14	C15	C16
1										
2										
3										
4										
5										



Create Response Surface Design: Display Available Designs

Available Response Surface Designs

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

Help OK

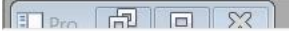
Session

12/5/2023 2:01:20 AM

Welcome to Minitab, press F1 for help

Worksheet 1 \*\*\*

	C1	C2	C3	C4
1				
2				
3				
4				
5				







Session

12/5/2023 2:01:20 AM

Welcome to Minitab, press F1 for help.

Worksheet 1 \*\*\*

	C1	C2	C3	C4	C5	C12	C13	C14	C15	C16
1										
2										
3										
4										
5										

Current Worksheet: Worksheet 1

Editable

### Create Response Surface Design: Designs

Designs	Runs	Blocks	Center Points			Default Alpha
			Total	Cube	Axial	
Full	13	1	5	0	0	1.414
Full	14	2	6	3	3	1.414

Number of Center Points

Default

Custom

Cube block:  Axial block:

Value of Alpha

Default

Face Centered

Custom:

Number of replicates:

Block on replicates

Help OK Cancel



Session

12/5/2023 2:01:20 AM

Welcome to Minitab, press F1 for help.

Worksheet 1 \*\*\*

	C1	C2	C3	C4	C5
1					
2					
3					
4					
5					

Create Response Surface Design: Factors

Levels Define

Central  
 Box-Behn

Number of factors: 2

Number of levels: 2

Factor	Name	Low	High
A	A	-1	1
B	B	-1	1

Help OK Cancel

	C12	C13	C14	C15	C16



Session

12/5/2023 2:01:20 AM

Welcome to Minitab, press F1 for help.

Worksheet 1 \*\*\*

	C1	C2	C3	C4	C5
1					
2					
3					
4					
5					

Create Response Surface Design: Factors

Levels Define

Cube points

Axial points

Factor	Name	Low	High
A	A	-1	1
B	B	-1	1

Help OK Cancel



### Central Composite Design

Factors: 2 Replicates: 1  
Base runs: 13 Total runs: 13  
Base blocks: 1 Total blocks: 1  
Two-level factorial: Full factorial  
Cube points: 4  
Center points in cube: 5  
Axial points: 4  
Center points in axial: 0  
 $\alpha$ : 1.41421

#### Design Table

Run	Blk	A	B
1	1	-1.00000	-1.00000
2	1	1.00000	-1.00000
3	1	-1.00000	1.00000
4	1	1.00000	1.00000
5	1	-1.41421	0.00000
6	1	1.41421	0.00000
7	1	0.00000	-1.41421
8	1	0.00000	1.41421
9	1	0.00000	0.00000
10	1	0.00000	0.00000
11	1	0.00000	0.00000
12	1	0.00000	0.00000
13	1	0.00000	0.00000



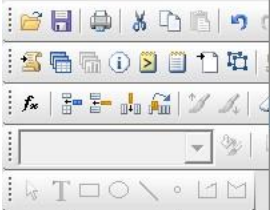
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
	StdOrder	RunOrder	PtType	Blocks	Fe	Time										
1	1	1	1	1	0.129289	12.9289										
2	2	2	1	1	0.270711	12.9289										
3	3	3	1	1	0.129289	27.0711										
4	4	4	1	1	0.270711	27.0711										
5	5	5	-1	1	0.100000	20.0000										
6	6	6	-1	1	0.300000	20.0000										
7	7	7	-1	1	0.200000	10.0000										
8	8	8	-1	1	0.200000	30.0000										
9	9	9	0	1	0.200000	20.0000										
10	10	10	0	1	0.200000	20.0000										
11	11	11	0	1	0.200000	20.0000										
12	12	12	0	1	0.200000	20.0000										
13	13	13	0	1	0.200000	20.0000										
14																
15																
16																



	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
	StdOrder	RunOrder	PtType	Blocks	Fe	Time	RE%									
1	1	1	1	1	0.129289	12.9289										
2	2	2	1	1	0.270711	12.9289										
3	3	3	1	1	0.129289	27.0711										
4	4	4	1	1	0.270711	27.0711										
5	5	5	-1	1	0.100000	20.0000										
6	6	6	-1	1	0.300000	20.0000										
7	7	7	-1	1	0.200000	10.0000										
8	8	8	-1	1	0.200000	30.0000										
9	9	9	0	1	0.200000	20.0000										
10	10	10	0	1	0.200000	20.0000										
11	11	11	0	1	0.200000	20.0000										
12	12	12	0	1	0.200000	20.0000										
13	13	13	0	1	0.200000	20.0000										
14																
15																
16																



	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
	StdOrder	RunOrder	PtType	Blocks	Fe	Time	RE%									
1	1	1	1	1	0.129289	12.9289	70.00									
2	2	2	1	1	0.270711	12.9289	80.78									
3	3	3	1	1	0.129289	27.0711	68.99									
4	4	4	1	1	0.270711	27.0711	82.31									
5	5	5	-1	1	0.100000	20.0000	65.00									
6	6	6	-1	1	0.300000	20.0000	90.00									
7	7	7	-1	1	0.200000	10.0000	73.00									
8	8	8	-1	1	0.200000	30.0000	75.98									
9	9	9	0	1	0.200000	20.0000	86.89									
10	10	10	0	1	0.200000	20.0000	85.00									
11	11	11	0	1	0.200000	20.0000	83.00									
12	12	12	0	1	0.200000	20.0000	88.00									
13	13	13	0	1	0.200000	20.0000	84.50									
14																
15																
16																



- Basic Statistics
- Regression
- ANOVA
- DOE**
  - Factorial
    - Response Surface**
      - Create Response Surface Design...
      - Define Custom Response Surface Design...
      - Select Optimal Design...
      - Analyze Response Surface Design...**
      - Predict...
      - Factorial Plots...
      - Contour Plot...
      - Surface Plot...
      - Overlaid Contour Plot...
      - Response Optimizer...
    - Mixture
    - Taguchi
  - Modify Design...
  - Display Design...
- Control Charts
- Quality Tools
- Reliability/Survival
- Multivariate
- Time Series
- Tables
- Nonparametrics
- Equivalence Tests
- Power and Sample Size

	C1	C2						C12	C13	C14	C15	C16
	StdOrder	RunOrder										
1	1											
2	2											
3	3											
4	4											
5	5	5	-1	1	0.100000	20.0000						
6	6	6	-1	1	0.300000	20.0000						
7	7	7	-1	1	0.200000	10.0000	73.00					
8	8	8	-1	1	0.200000	30.0000	75.98					
9	9	9	0	1	0.200000	20.0000	86.89					
10	10	10	0	1	0.200000	20.0000	85.00					
11	11	11	0	1	0.200000	20.0000	83.00					
12	12	12	0	1	0.200000	20.0000	88.00					
13	13	13	0	1	0.200000	20.0000	84.50					
14												
15												
16												

**Analyze Response Surface Design**  
Fit a model to a response surface design.





	C1	C2	C3	C4
	StdOrder	RunOrder	PtType	Blocks
1	1	1	1	1
2	2	2	1	1
3	3	3	1	1
4	4	4	1	1
5	5	5	-1	1
6	6	6	-1	1
7	7	7	-1	1
8	8	8	-1	1
9	9	9	0	1
10	10	10	0	1
11	11	11	0	1
12	12	12	0	1
13	13	13	0	1
14				
15				
16				

Analyze Response Surface Design

C7 RE%

Responses:

Terms... Options... Stepwise...  
Graphs... Results... Storage...  
Help OK Cancel

	C12	C13	C14	C15	C16
12	0.200000	20.0000	88.00		
13	0.200000	20.0000	84.50		
14					
15					
16					



	C1	C2	C3	C4
	StdOrder	RunOrder	PtType	Blocks
1	1	1	1	1
2	2	2	1	1
3	3	3	1	1
4	4	4	1	1
5	5	5	-1	1
6	6	6	-1	1
7	7	7	-1	1
8	8	8	-1	1
9	9	9	0	1
10	10	10	0	1
11	11	11	0	1
12	12	12	0	1
13	13	13	0	1
14				
15				
16				

### Analyze Response Surface Design

C7 RE%

Responses:  
'RE%'

Select

Help

Terms... Options... Stepwise...  
Graphs... Results... Storage...  
OK Cancel

0.200000	20.0000	88.00									
0.200000	20.0000	84.50									



	C1	C2	C3	C4															
	StdOrder	RunOrder	PtType	Blocks															
1	1	1	1	1	1														
2	2	2	1	1	1														
3	3	3	1	1	1														
4	4	4	1	1	1														
5	5	5	-1	1	1														
6	6	6	-1	1	1														
7	7	7	-1	1	1														
8	8	8	-1	1	1														
9	9	9	0	1	1														
10	10	10	0	1	1														
11	11	11	0	1	1														
12	12	12	0	1	0.200000	20.0000	88.00												
13	13	13	0	1	0.200000	20.0000	84.50												
14																			
15																			
16																			

Analyze Response Surface Design: Terms

Include the following terms: **Full quadratic**

Available Terms:

Selected Terms:

- A:Fe
- B:Time
- AA
- BB
- AB

Include blocks in the model

Help OK Cancel



	C1	C2	C3	C4	C7	C8	C9	C12	C13	C14	C15	C16
	StdOrder	RunOrder	PtType	Blocks								
1	1	1	1	1								
2	2	2	1	1								
3	3	3	1	1								
4	4	4	1	1								
5	5	5	-1	1								
6	6	6	-1	1								
7	7	7	-1	1								
8	8	8	-1	1								
9	9	9	0	1								
10	10	10	0	1								
11	11	11	0	1								
12	12	12	0	1	0.200000	20.0000	88.00					
13	13	13	0	1	0.200000	20.0000	84.50					
14												
15												
16												

Analyze Response Surface Design: Graphs

Residuals for Plots:  
 Regular  Standardized  Deleted

Residual Plots  
 Individual plots  
 Histogram  
 Normal plot  
 Residuals versus fits  
 Residuals versus order  
 Four in one

Residuals versus variables:

Select Help OK Cancel



↓	C1	C2	C3	C4
	StdOrder	RunOrder	PtType	Blocks
1	1	1	1	1
2	2	2	1	1
3	3	3	1	1
4	4	4	1	1
5	5	5	-1	1
6	6	6	-1	1
7	7	7	-1	1
8	8	8	-1	1
9	9	9	0	1
10	10	10	0	1
11	11	11	0	1
12	12	12	0	1
13	13	13	0	1
14				
15				
16				

### Analyze Response Surface Design: Results

Display of results: **Simple tables**

- Method
- Analysis of variance
- Model summary
- Coefficients: **Default coefficients**
- Regression equation: **Separate equation for each set of factor levels**
- Fits and diagnostics: **Only for unusual observations**

Buttons: Help, OK, Cancel

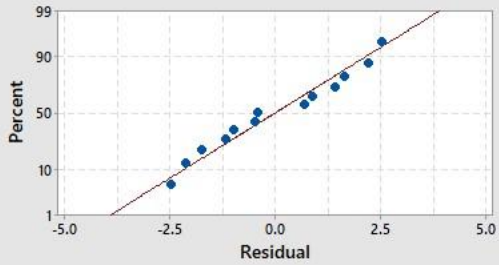
C7	C8	C9	C10
0.200000	20.0000	88.00	
0.200000	20.0000	84.50	

C12	C13	C14	C15	C16

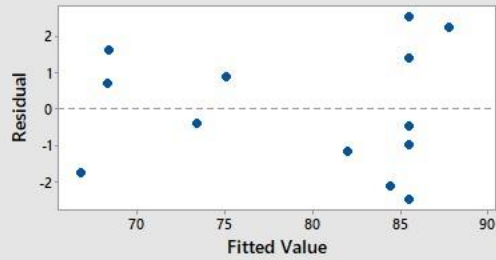


### Residual Plots for RE%

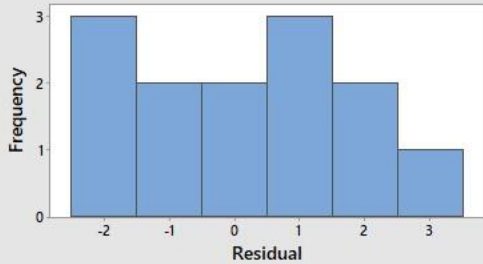
Normal Probability Plot



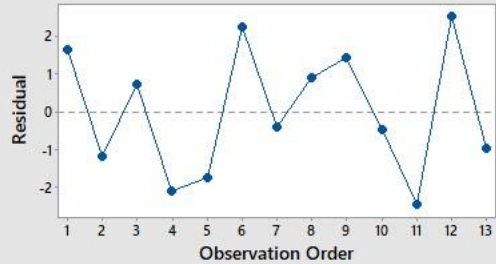
Versus Fits



Histogram



Versus Order





## Response Surface Regression: RE% versus Fe, Time

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	746.075	149.215	31.02	0.000
Linear	2	444.669	222.334	46.22	0.000
Fe	1	441.867	441.867	91.86	0.000
Time	1	2.802	2.802	0.58	0.470
Square	2	299.793	149.896	31.16	0.000
Fe*Fe	1	117.382	117.382	24.40	0.002
Time*Time	1	219.151	219.151	45.56	0.000
2-Way Interaction	1	1.613	1.613	0.34	0.581
Fe*Time	1	1.613	1.613	0.34	0.581
Error	7	33.672	4.810		
Lack-of-Fit	3	17.993	5.998	1.53	0.337
Pure Error	4	15.680	3.920		
Total	12	779.747			

### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.19325	95.68%	92.60%	80.45%



## Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.19325	95.68%	92.60%	80.45%

## Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		85.478	0.981	87.15	0.000	
Fe	14.864	7.432	0.775	9.58	0.000	1.00
Time	1.184	0.592	0.775	0.76	0.470	1.00
Fe*Fe	-8.215	-4.108	0.832	-4.94	0.002	1.02
Time*Time	-11.226	-5.613	0.832	-6.75	0.000	1.02
Fe*Time	1.27	0.63	1.10	0.58	0.581	1.00

## Regression Equation in Uncoded Units

$$RE\% = -9.9 + 408.3 \text{ Fe} + 4.320 \text{ Time} - 822 \text{ Fe*Fe} - 0.1123 \text{ Time*Time} + 1.27 \text{ Fe*Time}$$

## Residual Plots for RE%

|





- Scatterplot...
- Matrix Plot...
- Bubble Plot...
- Marginal Plot...
- Histogram...
- Dotplot...
- Stem-and-Leaf...
- Probability Plot...
- Empirical CDF...
- Probability Distribution Plot...
- Boxplot...
- Interval Plot...
- Individual Value Plot...
- Line Plot...
- Bar Chart...
- Pie Chart...
- Time Series Plot...
- Area Graph...
- Contour Plot...
- 3D Scatterplot...
- 3D Surface Plot...

**3D Surface Plot**  
 Examine the relationship between a response variable (Z) and two predictor variables (X and Y) by viewing a three-dimensional surface of the predicted response.

Model Summary

S	R-sq	R-sq (adj)
2.19325	95.68%	92.1%

Coded Coefficients

Term	Effect	Coefficient	Standard Error	T-Value	P-Value	VIF
Constant		85.0	0.000			
Fe	14.864	7.0	0.000			1.00
Time	1.184	0.0	0.470			1.00
Fe*Fe	-8.215	-4.0				
Time*Time	-11.226	-5.0				
Fe*Time	1.27	0.0				

Regression Equation in RE% = -9.9 + 408.3 Fe + 1.27 Time + 1.27 Fe\*Time

**Residual Plots for RE%**



A hand is holding a white rectangular card against a light-colored wooden background. The card features the text "Thank you for listening" in a bold, black, sans-serif font, arranged in three lines. The text is surrounded by several small, solid red hearts scattered around it. The hand is visible on the left side of the card, with the thumb and index finger holding it.

**Thank  
you for  
listening**