

芯片制程統計基礎篇

—毒茶偵探Taguchi

Design of Experiments, Taguchi

王不老說半导

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11/30/2021

1

中医 Taguchi vs 西医 DOE

西医治標，重視局部

- 聚焦在发病器官上，为了治疗发病器官不惜损伤别的器官，发病器官改善了、别的器官有时反而有了問題
- 西医，死会让你死得明白！

中医治本，重視系統

- 中医不太关心发病器官的情况，認為气血通了一切就好了，发病的器官自然也好了，所以重視人體全盤系統
- 中医，活会让你活得迷糊！

說個笑話：

西醫治標 中醫治本
中西合璧 治成標本

Taguchi vs DOE

Factorial DOE: 聚焦優化

- Good for optimizing a process
- But (full or $\frac{1}{2}$ - factorial) requires many experiments
- 結果精確

Taguchi Method: 重視全盤系統

- 所須的實驗會少很多
- 結果沒有那麼精確，但指出最重要參數

已知:

- 波霸奶茶四參數: 甜度(Sugar), 茶濃度(Tea), 波霸含量(Boba), 溫度(Temp), 每一參數有三個可能(見下圖)

試問:

- 比較Taguchi與Factorial DOE 最佳波霸奶茶的配方所須試驗數目?

C1	C2	C3	C4
Temp	Sugar	Boba	Tea
0	20	10	5
5	40	30	10
10	60	50	15

Taguchi vs DOE

Factorial DOE: 聚焦優化

- Optimizing a process is sufficient
- Full (or 1/2) factorial 要做很多實驗
- 結果很精確

Taguchi Method: 重視全盤系統

- 所須的實驗會少很多
- 結果沒有那麼精確
- 但給出”參數排行榜”

解答:

- Factorial DOE 所須試驗數 = $3^4 = 81$

- Taguchi method

- 用 Minitab 可知
- Sta/DOE/Taguchi/Create Taguchi Design/level (3), factor(4), Design (L9=3x4), Factors (input table above)

- 所須試驗數(如下圖) = 9

	C1	C2	C3	C4
	Temp	Sugar	Boba	Tea
0	0	20	10	5
5	5	40	30	10
10	10	60	50	15

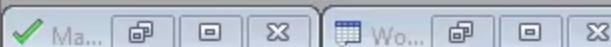
	C1	C2	C3	C4
	Temp	Sugar	Boba	Tea
1	0	20	10	5
2	0	40	30	10
3	0	60	50	15
4	5	20	30	15
5	5	40	50	5
6	5	60	10	10
7	10	20	50	10
8	10	40	10	15
9	10	60	30	5

File Edit Data Calc Stat Graph Editor Tools Window Help Assistant



Worksheet 1 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Temp	Sugar	Boba	Tea					
1	0	20	10	5					
2	5	40	30	10					
3	10	60	50	15					
4									
5									
6									
7									
8									
9									
10									



Current Worksheet: Worksheet 1

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f_x | $\frac{d}{dx}$ | \int | \sum | \prod | \sqrt{x} | $\sqrt[n]{x}$ | $\frac{1}{x}$

| Δ | ∇ | ∇^2 | $\nabla \cdot \mathbf{F}$ | $\nabla^2 \cdot \mathbf{F}$ | $\nabla^2 \times \mathbf{F}$ | $\nabla \times \mathbf{F}$ | $\nabla \cdot \nabla \phi$ | $\nabla^2 \phi$ | $\nabla^2 \times \nabla \phi$ | $\nabla \times \nabla \phi$ | $\nabla^2 \cdot \nabla \phi$ | $\nabla^2 \times \nabla^2 \phi$ | $\nabla^2 \times \nabla^2 \times \mathbf{F}$ | $\nabla^2 \times \nabla^2 \times \nabla \phi$ | $\nabla^2 \times \nabla^2 \times \nabla^2 \phi$

Worksheet 1 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Temp	Sugar	Boba	Tea					
1	0	20	10	5					
2	5	40	30	10					
3	10	60	50	15					
4									
5									
6									
7									
8									
9									
10									

✓ Ma...

✓ Wo...

1

✓ Pro...

✓ No...

✓ Ma...

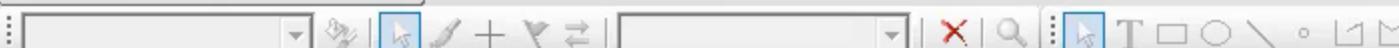
✓ Ses...

✓ Wo...

✓ Wo...

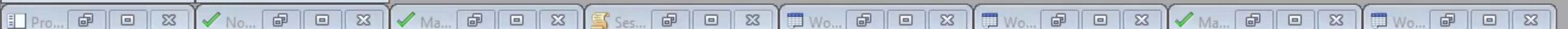
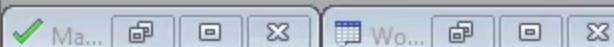
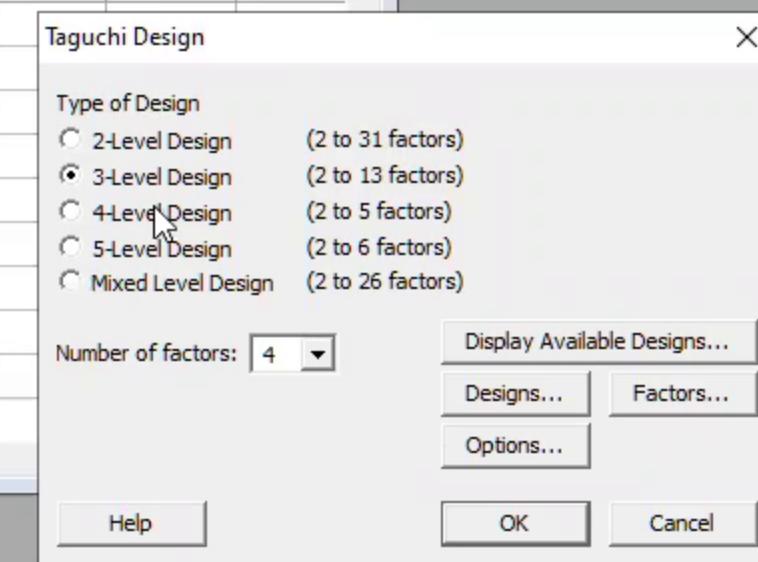
✓ Ma...

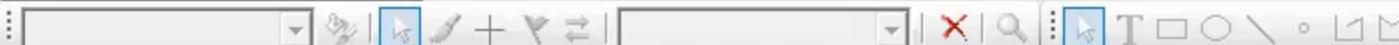
✓ Wo...



Worksheet 1 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Temp	Sugar	Boba	Tea					
1	0	20	10	5					
2	5	40	30	10					
3	10	60	50	15					
4									
5									
6									
7									
8									
9									
10									





Worksheet 1 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Temp	Sugar	Boba	Tea					
1	0	20	10	5					
2	5	40	30	10					
3	10	60	50	15					
4									
5									
6									
7									
8									
9									
10									

Taguchi Design: Factors

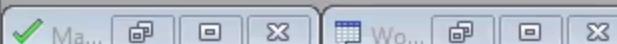
Assign Factors

To columns of the array as specified below

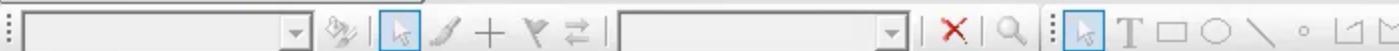
To allow estimation of selected interactions [Interactions...](#)

Fact	Name	Level Values	Column	Leve
A	Temp	0 5 10	1 ▾	3
B	Sugar	20 40 60	2 ▾	3
C	Boba	10 30 50	3 ▾	3
D	Tea	5 10 15	4 ▾	3

Help OK Cancel

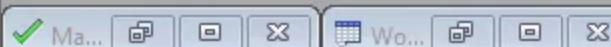
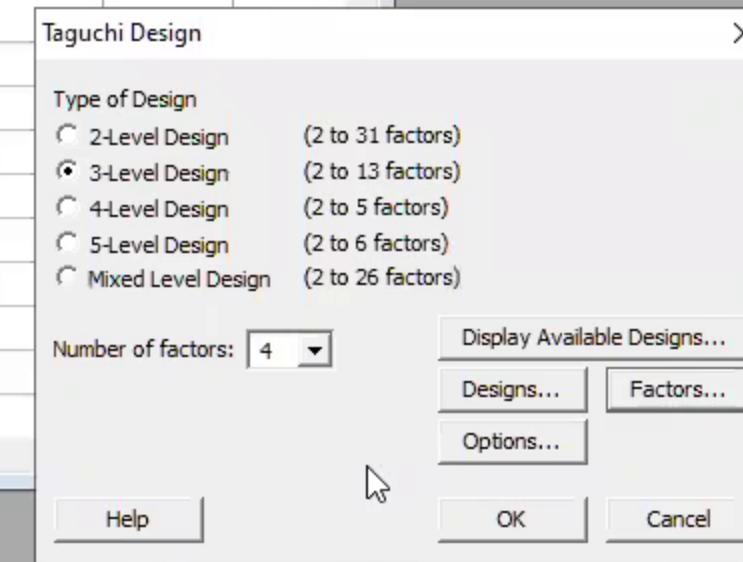


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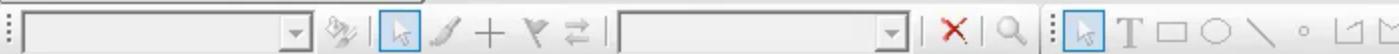
Worksheet 1 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Temp	Sugar	Boba	Tea					
1	0	20	10	5					
2	5	40	30	10					
3	10	60	50	15					
4									
5									
6									
7									
8									
9									
10									



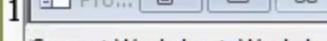
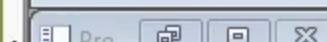
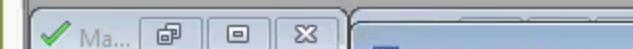
Current Worksheet: Worksheet 1

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Worksheet 1

	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Temp	Sugar	Boba	Tea					
1	0	20	10	5					
2	5	40	30	10					
3	10	60	50	15					
4									
5									
6									
7									
8									
9									
10									

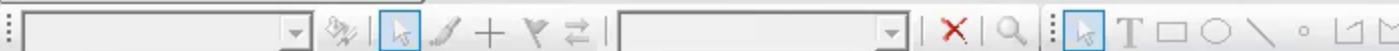


Worksheet 8 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
1																	

Current Worksheet: Worksheet 8

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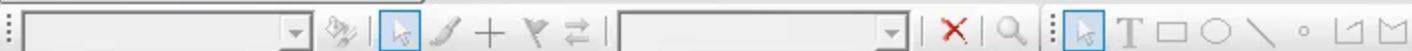
Worksheet 8 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea															
1	0	20	10	5															
2	0	40	30	10															
3	0	60	50	15															
4	5	20	30	15															
5	5	40	50	5															
6	5	60	10	10	+														
7	10	20	50	10															
8	10	40	10	15															

Worksheet 1

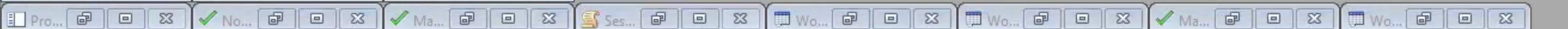
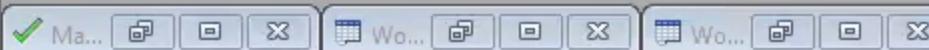
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea															
1	0	20	10	5															
2	5	40	30	10															
3	10	60	50	15															
4																			
5																			
6																			
7																			
8																			

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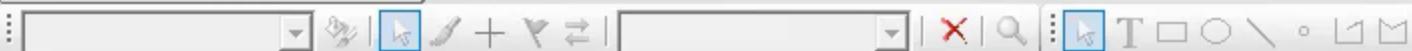


Worksheet 8 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea															
1	0	20	10	5															
2	0	40	30	10															
3	0	60	50	15															
4	5	20	30	15															
5	5	40	50	5															
6	5	60	10	10															
7	10	20	50	10															
8	10	40	10	15															

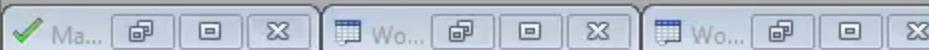


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Worksheet 8 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea															
1	0	20	10	5															
2	+0	40	30	10															
3	0	60	50	15															
4	5	20	30	15															
5	5	40	50	5															
6	5	60	10	10															
7	10	20	50	10															
8	10	40	10	15															
9	10	60	30	5															
10																			
11																			
12																			

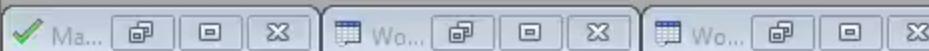


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Worksheet 8 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea															
1	0	20	10	5															
2	0	40	30	10															
3	0	60	50	15															
4	5	20	30	15															
5	5	40	50	5															
6	5	60	10	10															
7	10	20	50	10															
8	10	40	10	15															
9	10	60	30	5															
10																			
11																			
12																			



Taguchi vs DOE

Factorial DOE: 聚焦優化

- Optimizing a process is sufficient
- Full (or 1/2) factorial 做很多實驗
- 結果很精確

Taguchi Method: 重視全盤系統

- 所須的實驗會少很多
- 結果沒有那麼精確
- 但給出”參數排行榜”

解答:

- Factorial DOE 所須試驗數 = $3^4 = 81$

- Taguchi method

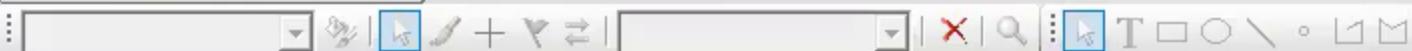
- 用Minitab 可知
- Sta/DOE/Taguchi/Create Taguchi Design/level (3), factor(4), Design (L9=3x4), Factors (input table above)

- 所須試驗數(如下圖) = 9

	C1	C2	C3	C4
	Temp	Sugar	Boba	Tea
0	0	20	10	5
5	5	40	30	10
10	10	60	50	15

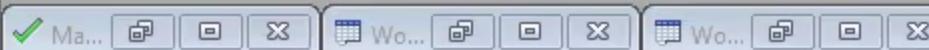
↓	C1	C2	C3	C4
	Temp	Sugar	Boba	Tea
1	0	20	10	5
2	0	40	30	10
3	0	60	50	15
4	5	20	30	15
5	5	40	50	5
6	5	60	10	10
7	10	20	50	10
8	10	40	10	15
9	10	60	30	5

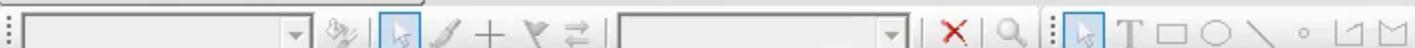
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Worksheet 8 ***

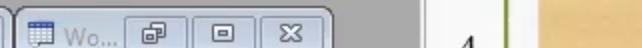
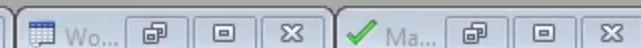
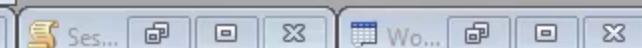
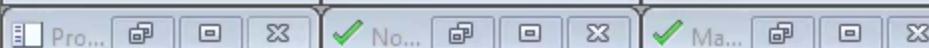
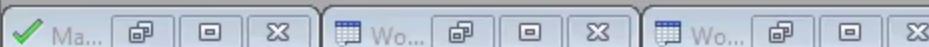
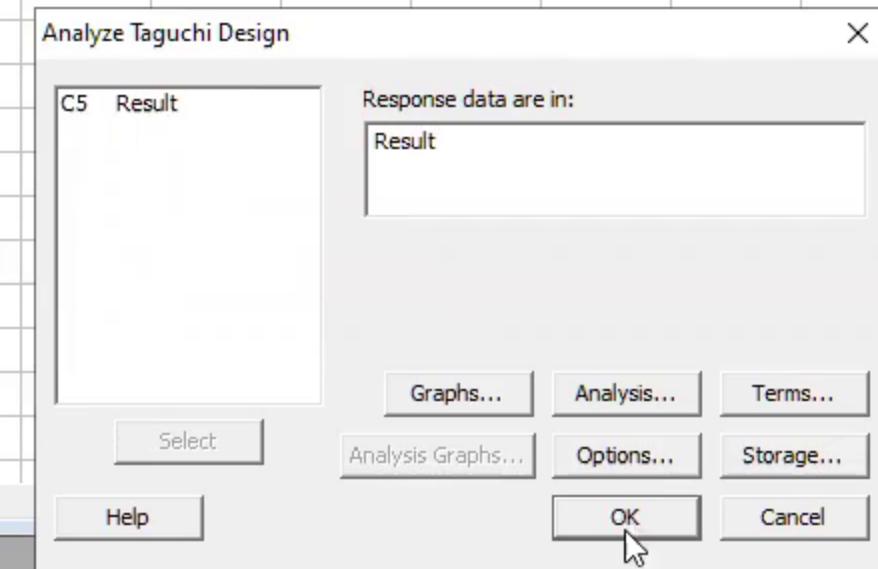
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea															
1	0	20	10	5															
2	0	40	30	10															
3	0	60	50	15															
4	5	20	30	15															
5	5	40	50	5															
6	5	60	10	10															
7	10	20	50	10															
8	10	40	10	15															
9	10	60	30	5															
10																			
11																			
12																			





Worksheet 8 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea	Result														
1	0	20	10	5	80														
2	0	40	30	10	90														
3	0	60	50	15	60														
4	5	20	30	15	79														
5	5	40	50	5	88														
6	5	60	10	10	64														
7	10	20	50	10	90														
8	10	40	10	15	75														
9	10	60	30	5	69														
10																			
11																			
12																			



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Worksheet 8 ***

	C1	C2
1	Temp	Sugar
2	0	40
3	0	60

Session

* ERROR * No graphs w

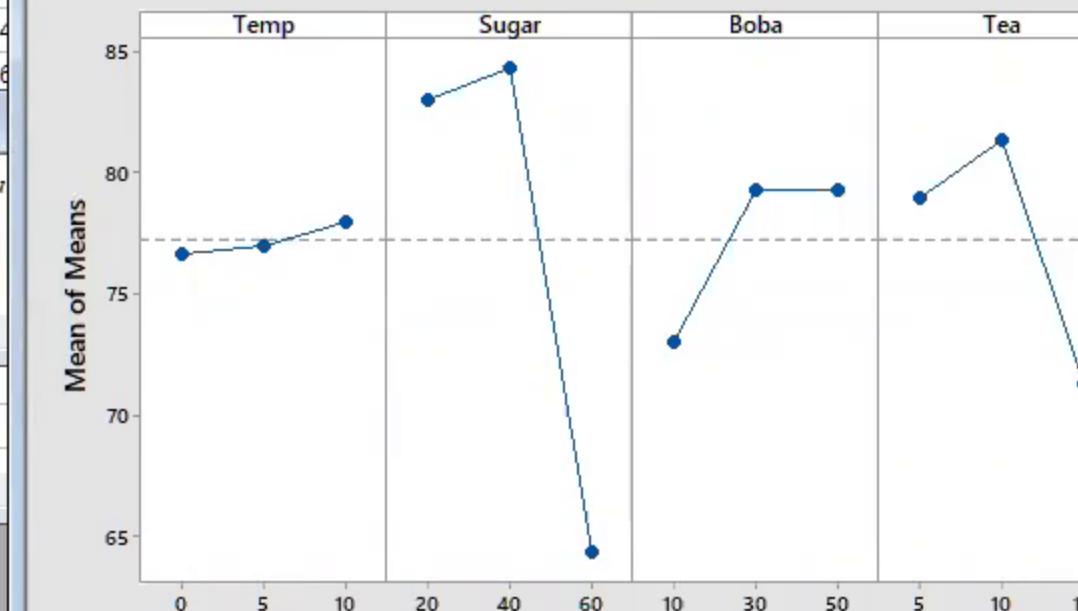


10
11
12

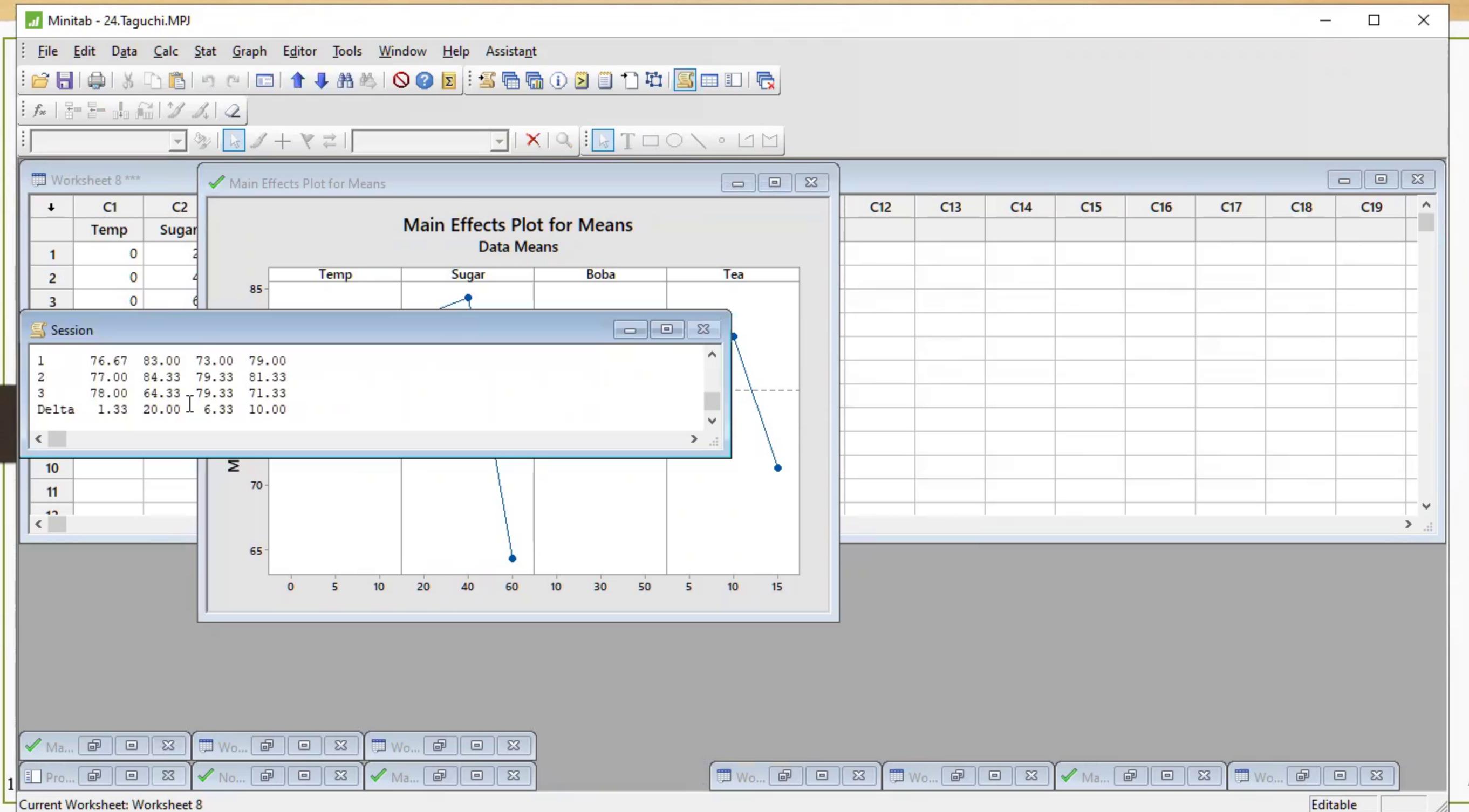
Main Effects Plot for Means

Main Effects Plot for Means

Data Means



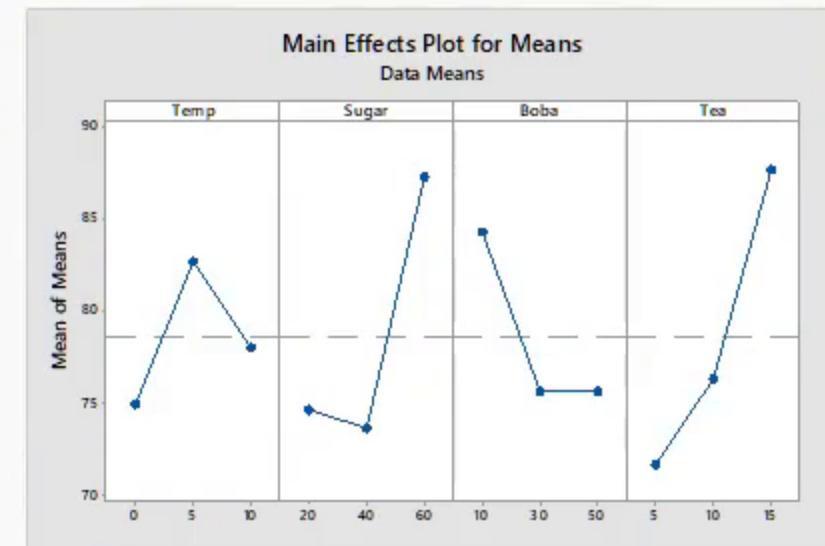
C12	C13	C14	C15	C16	C17	C18	C19



台灣波霸奶茶 DOE

解答：

- Minitab 用 **Analyze Taguchi Design** 分析前頁所得結果
 - Sta/DOE/Factorial/**Analyze Taguchi Design**/ (select Result column) + Options(select Larger is better)
- Minitab 立馬給出參數重要性排行榜：
 - 茶濃度(Tea)第一
 - 甜度(Sugar)第二
- Taguchi 只能提供參數排行榜，無法再優化了



Level	Temp	Sugar	Boba	Tea
1	37.42	37.42	38.45	37.09
2	38.26	37.27	37.53	37.53
3	37.80	38.79	37.50	38.85
Delta	0.85	1.52	0.94	1.76
Rank	4	2	3	1

Response Table for Means

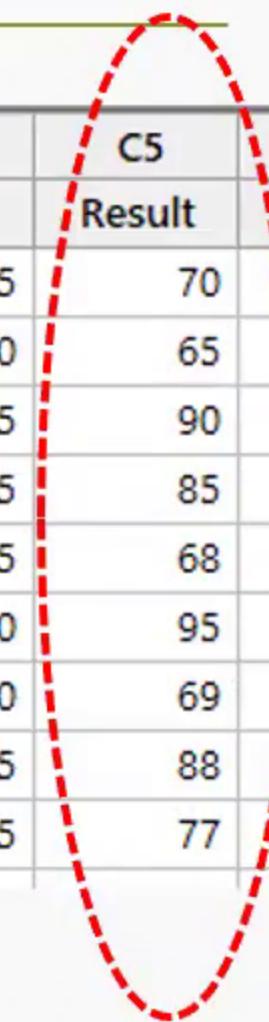
Level	Temp	Sugar	Boba	Tea
1	75.00	74.67	84.33	71.67
2	82.67	73.67	75.67	76.33
3	78.00	87.33	75.67	87.67
Delta	7.67	13.67	8.67	16.00
Rank	4	2	3	1

台灣波霸奶茶 Taguchi

解答:

- Minitab 设计產生9個試驗如右圖
 - 找9人來試喝評分
- **Result:**
 - 實驗的結果(每個人的試喝評分)
見右紅線區
- 下一頁，Minitab將對以上結果進行
Taguchi 分析

↓	C1	C2	C3	C4	C5	Result
	Temp	Sugar	Boba	Tea		
1	0	20	10	5		70
2	0	40	30	10		65
3	0	60	50	15		90
4	5	20	30	15		85
5	5	40	50	5		68
6	5	60	10	10		95
7	10	20	50	10		69
8	10	40	10	15		88
9	10	60	30	5		77



聰明的Taguchi vs DOE

Factorial DOE: 有些笨

Taguchi Method: 聰明而懶，卻適合海底撈針

已知：

- 有八杯波霸奶茶(1-8)，但其中有一杯被了下毒
- 試問：
- 如何用最少的實驗 (Taguchi方法也) 得知哪一杯有毒？

解答：

- Taguchi方法建議只需三個驗毒實驗如下
 - Sample A = 1,2,3,4 (混合1,2,3,4杯)
 - Sample B = 1,2,5,6
 - Sample C = 1,3,5,7
- 驗毒結果（“-”無毒，“+”有毒）
 - 共有八個結果(A,B,C而每個皆只有兩種可能，所以 $2 \times 2 \times 2 = 8$)
 - Result 1 = “---” → 第8杯有毒(因8不在ABC內)
 - Result 2 = “+--” → 第4杯有毒(因只有A有4)
 - Result 3 = “-+-” → 第6杯有毒(因只有B有6)
 - 以此類推，可得知那一杯有毒！

聰明的Taguchi vs DOE

Factorial DOE: 有些笨

Taguchi Method: 聰明而懶，卻適合海底撈針

已知：

- 有八杯波霸奶茶(1-8)，但其中有一杯被了下毒
- 試問：
- 如何用最少的實驗(**Taguchi方法也**)得知哪一杯有毒？

解答：

- Taguchi方法建議只需三個驗毒實驗如下
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聰明的Taguchi vs DOE

Factorial DOE: 有些笨

Taguchi Method: 聰明而懶，卻適合海底撈針

已知：

- 有1000杯波霸奶茶，但其中有一杯被了下毒
- 有1,000,000杯波霸奶茶，但其中有一杯被了下毒
- 試問：
 - 如何用最少的實驗(Taguchi方法也)得知哪一杯有毒？

解答1: 1000杯波霸奶茶，一杯被了
下毒

• Taguchi建議

- 只需 $\log_2(1000)=10$ 個驗毒實驗
- 每個樣本由500杯混和(Taguchi會幫你)

解答1: 1,000,000杯波霸奶茶，一杯被了下毒

• Taguchi建議

- 只需 $\log_2(1000000) = 20$ 個驗毒實驗