

# 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

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# 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

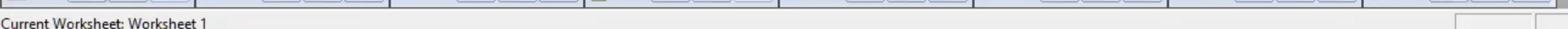
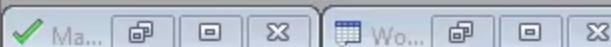
	C1	C2	C3	C4
	Temp	Sugar	Boba	Tea
1	0	20	10	5
2	0	40	30	10
3	0	60	50	15
4	5	20	30	15
5	5	40	50	5
6	5	60	10	10
7	10	20	50	10
8	10	40	10	15
9	10	60	30	5

File Edit Data Calc Stat Graph Editor Tools Window Help Assistant



Worksheet 1 \*\*\*

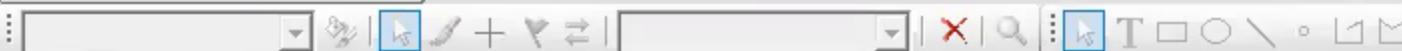
	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Temp	Sugar	Boba	Tea					
1	0	20	10	5					
2	5	40	30	10					
3	10	60	50	15					
4									
5									
6									
7									
8									
9									
10									



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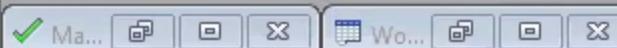


f<sub>x</sub> |  $\frac{d}{dx}$  |  $\int$  |  $\sum$  |  $\prod$  |  $\sqrt{x}$  |  $\sqrt[n]{x}$  |  $\sin$  |  $\cos$  |  $\tan$  |  $\log$  |  $e^x$  |  $\pi$  |  $\theta$  |  $\alpha$  |  $\beta$  |  $\gamma$  |  $\delta$  |  $\sigma$  |  $\mu$  |  $\sigma^2$  |  $\mu^2$  |  $\sigma^4$  |  $\mu^4$  |  $\sigma^6$  |  $\mu^6$  |  $\sigma^8$  |  $\mu^8$  |  $\sigma^{10}$  |  $\mu^{10}$  |  $\sigma^{12}$  |  $\mu^{12}$  |  $\sigma^{14}$  |  $\mu^{14}$  |  $\sigma^{16}$  |  $\mu^{16}$  |  $\sigma^{18}$  |  $\mu^{18}$  |  $\sigma^{20}$  |  $\mu^{20}$  |  $\sigma^{22}$  |  $\mu^{22}$  |  $\sigma^{24}$  |  $\mu^{24}$  |  $\sigma^{26}$  |  $\mu^{26}$  |  $\sigma^{28}$  |  $\mu^{28}$  |  $\sigma^{30}$  |  $\mu^{30}$  |  $\sigma^{32}$  |  $\mu^{32}$  |  $\sigma^{34}$  |  $\mu^{34}$  |  $\sigma^{36}$  |  $\mu^{36}$  |  $\sigma^{38}$  |  $\mu^{38}$  |  $\sigma^{40}$  |  $\mu^{40}$  |  $\sigma^{42}$  |  $\mu^{42}$  |  $\sigma^{44}$  |  $\mu^{44}$  |  $\sigma^{46}$  |  $\mu^{46}$  |  $\sigma^{48}$  |  $\mu^{48}$  |  $\sigma^{50}$  |  $\mu^{50}$  |  $\sigma^{52}$  |  $\mu^{52}$  |  $\sigma^{54}$  |  $\mu^{54}$  |  $\sigma^{56}$  |  $\mu^{56}$  |  $\sigma^{58}$  |  $\mu^{58}$  |  $\sigma^{60}$  |  $\mu^{60}$  |  $\sigma^{62}$  |  $\mu^{62}$  |  $\sigma^{64}$  |  $\mu^{64}$  |  $\sigma^{66}$  |  $\mu^{66}$  |  $\sigma^{68}$  |  $\mu^{68}$  |  $\sigma^{70}$  |  $\mu^{70}$  |  $\sigma^{72}$  |  $\mu^{72}$  |  $\sigma^{74}$  |  $\mu^{74}$  |  $\sigma^{76}$  |  $\mu^{76}$  |  $\sigma^{78}$  |  $\mu^{78}$  |  $\sigma^{80}$  |  $\mu^{80}$  |  $\sigma^{82}$  |  $\mu^{82}$  |  $\sigma^{84}$  |  $\mu^{84}$  |  $\sigma^{86}$  |  $\mu^{86}$  |  $\sigma^{88}$  |  $\mu^{88}$  |  $\sigma^{90}$  |  $\mu^{90}$  |  $\sigma^{92}$  |  $\mu^{92}$  |  $\sigma^{94}$  |  $\mu^{94}$  |  $\sigma^{96}$  |  $\mu^{96}$  |  $\sigma^{98}$  |  $\mu^{98}$  |  $\sigma^{100}$  |  $\mu^{100}$

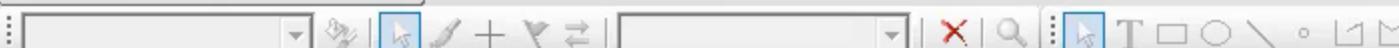


Worksheet 1 \*\*\*

	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									

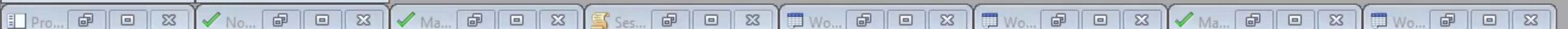
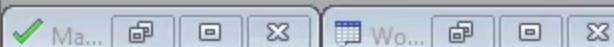
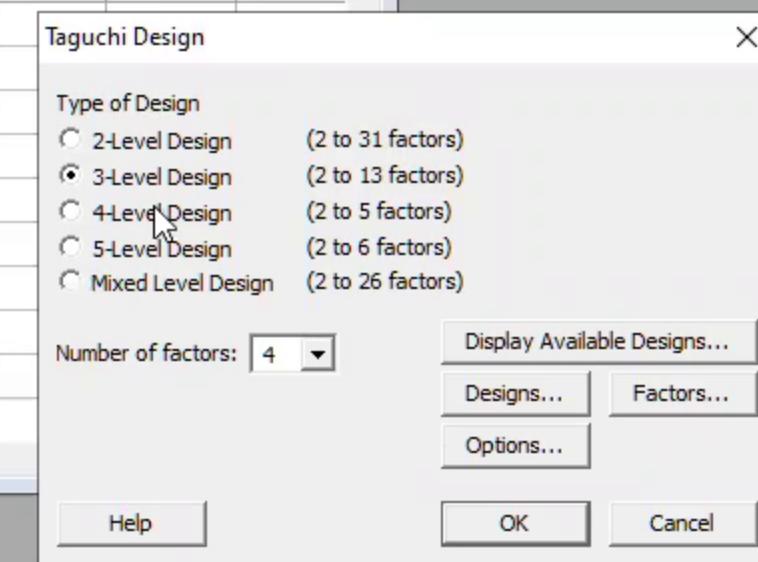


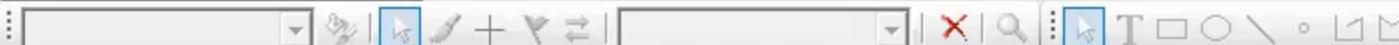
Current Worksheet: Worksheet 1



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

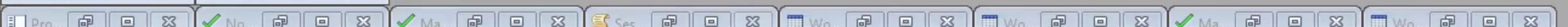
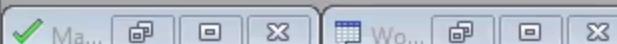
Assign Factors

To columns of the array as specified below

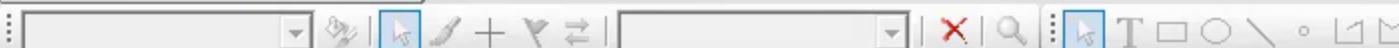
To allow estimation of selected interactions [Interactions...](#)

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

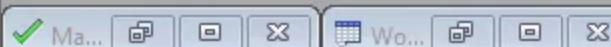
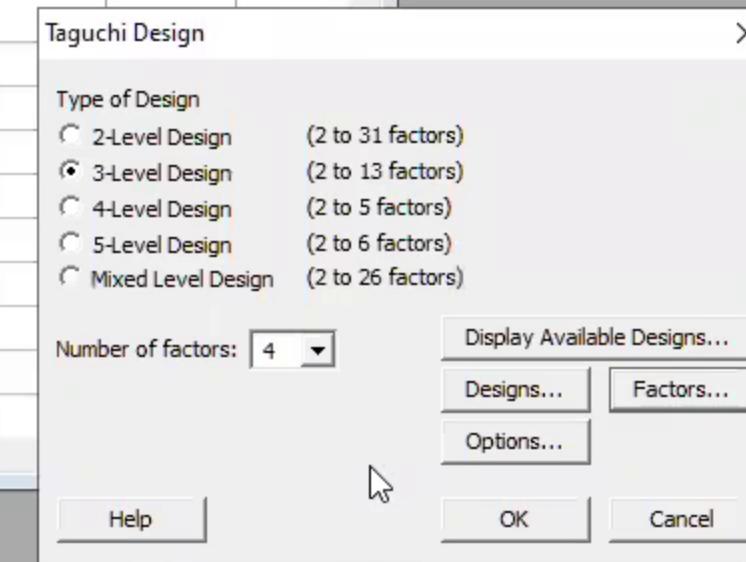


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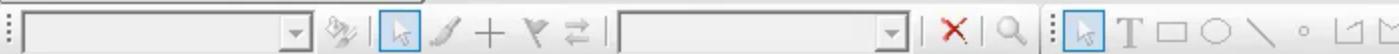
Worksheet 1 \*\*\*

	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									



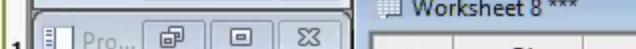
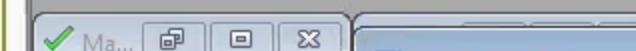
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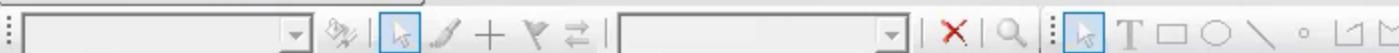
Worksheet 1

	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 8

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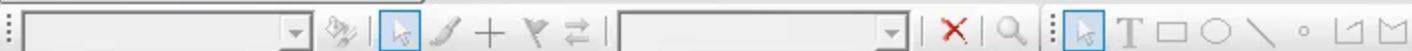
Worksheet 8 \*\*\*

	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

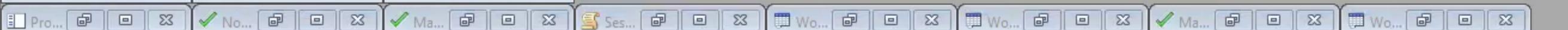
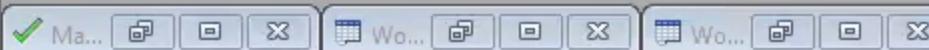
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea															
1	0	20	10	5															
2	5	40	30	10															
3	10	60	50	15															
4																			
5																			
6																			
7																			
8																			

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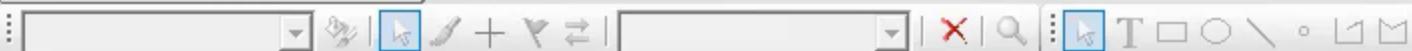


Worksheet 8 \*\*\*

	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															

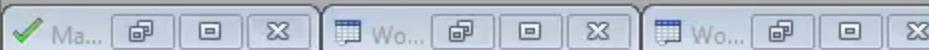


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Worksheet 8 \*\*\*

	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																			

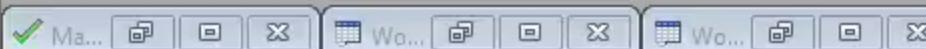


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Worksheet 8 \*\*\*

	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
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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

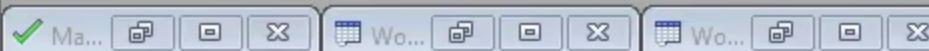
↓	C1	C2	C3	C4
	Temp	Sugar	Boba	Tea
1	0	20	10	5
2	0	40	30	10
3	0	60	50	15
4	5	20	30	15
5	5	40	50	5
6	5	60	10	10
7	10	20	50	10
8	10	40	10	15
9	10	60	30	5

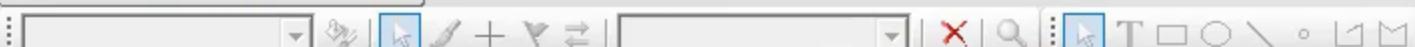
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Worksheet 8 \*\*\*

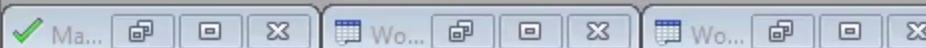
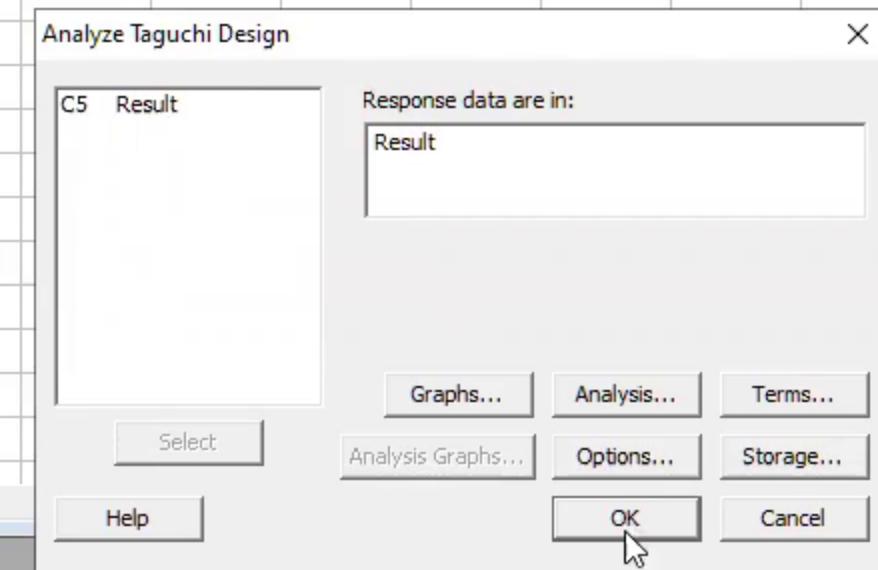
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
	Temp	Sugar	Boba	Tea															
1	0	20	10	5															
2	0	40	30	10															
3	0	60	50	15															
4	5	20	30	15															
5	5	40	50	5															
6	5	60	10	10															
7	10	20	50	10															
8	10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

Session

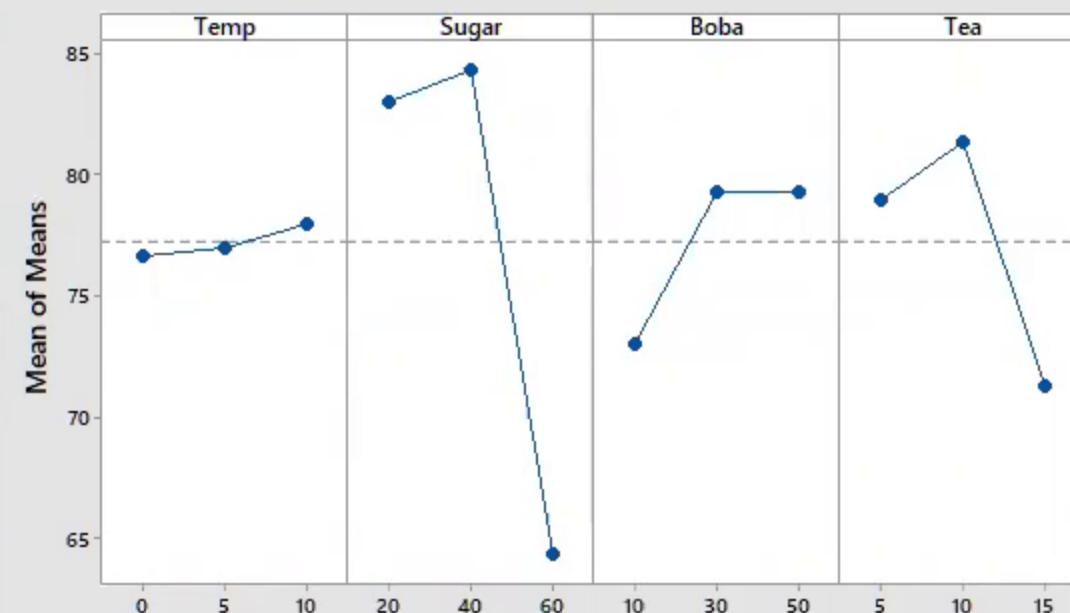
	C1	C2
1	Temp	Sugar
2	0	4
3	0	6

Worksheet 8 \*\*\*

Main Effects Plot for Means

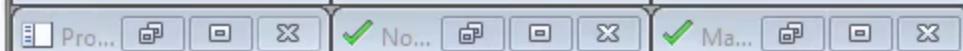
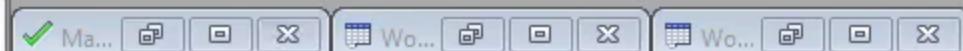
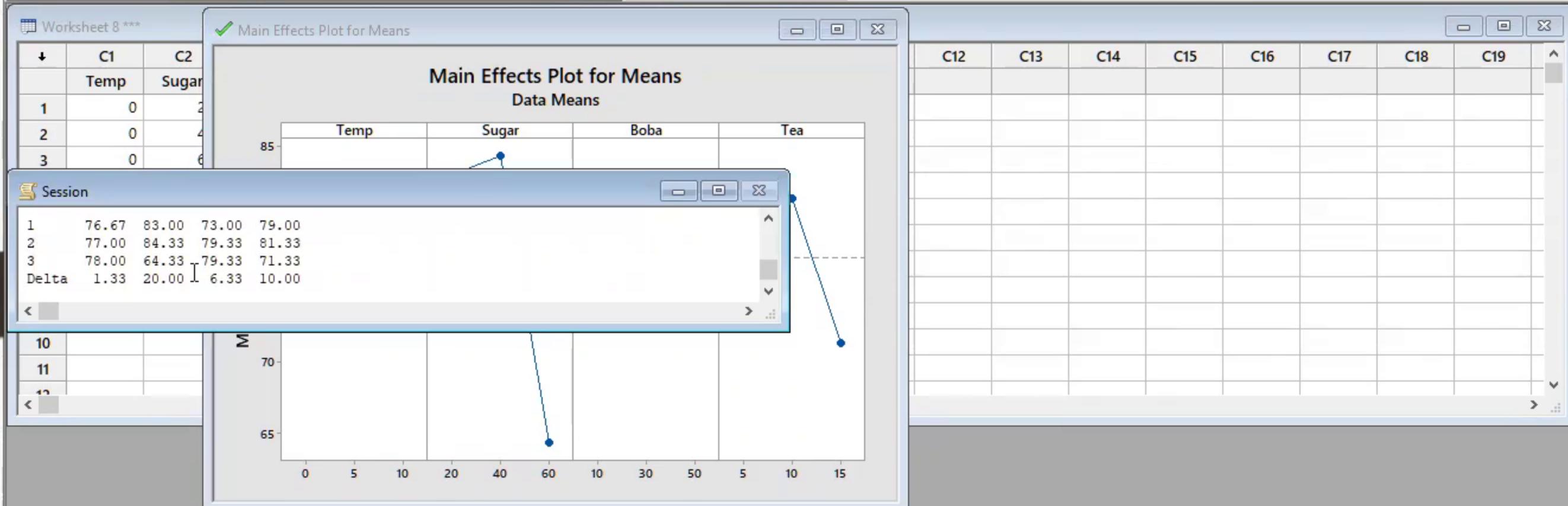
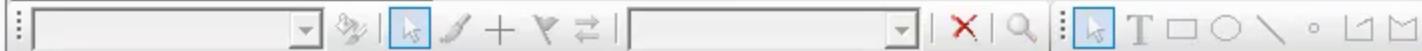
## Main Effects Plot for Means

Data Means



C12	C13	C14	C15	C16	C17	C18	C19

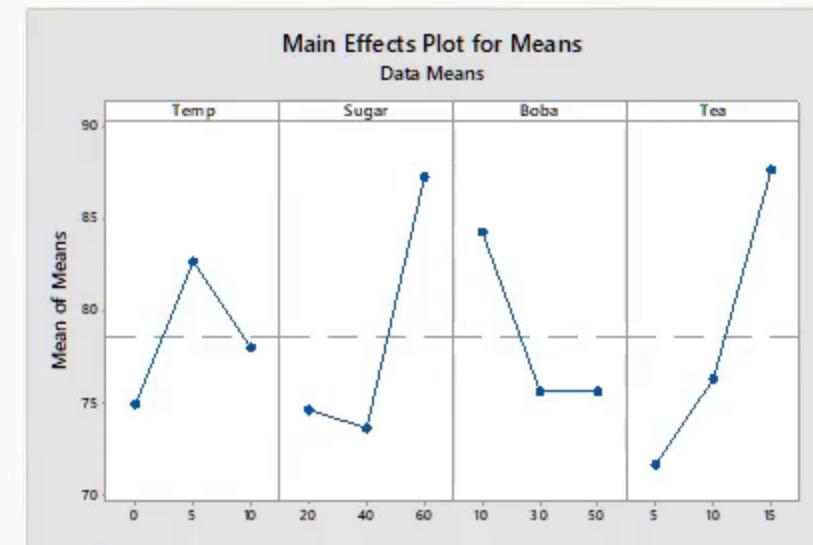
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# 台灣波霸奶茶 DOE

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

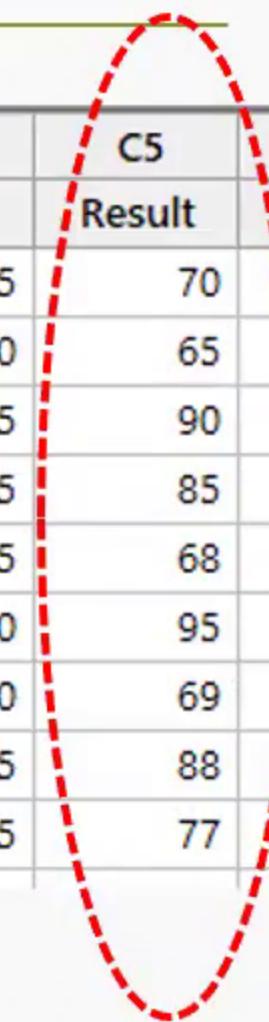
Level	Temp	Sugar	Boba	Tea
1	75.00	74.67	84.33	71.67
2	82.67	73.67	75.67	76.33
3	78.00	87.33	75.67	87.67
Delta	7.67	13.67	8.67	16.00
Rank	4	2	3	1

# 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

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  - 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