Improve 8 – Design of Experiments

Improve - Design of Experiments

Two approaches to finding the link between critical to quality features and the input ‘X’s

- Observational Approach

- Experimental Approach

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- Observational Approach

  Where variations which occur naturally are recorded and then analysed using the tools and techniques learnt in Analyse phase

  Examples ?

- Workshop example from ‘Analyse’ phase

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- Experimental Approach

  Planned experiments are conducted and results analysed

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- Experimental Approach

  This can be approached in two ways:-

  - change one factor at a time, keep everything else constant and observe changes

  - Muti-factor experiment in which several factors are changed simultaneously to a pre-set plan

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Designed experiments aim to find which process inputs affect the outputs with the fewest possible experiments

Should lead to unbiased answers to the initial question asked

Should give maximum information with the minimum amount of effort and cost

Should be feasible within the process restraints which exist

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History

- Charles S. Peirce 1877-1878 '*Logic of Science*'
- Expanded by Sir Ronald Fisher in 1920's '*The Arrangement of Field Experiments*' – he used an example of a lady drinking tea and the effect of water, milk and sugar to make his point!

- Used extensively within :-
- Agriculture
- Biology
- Engineering

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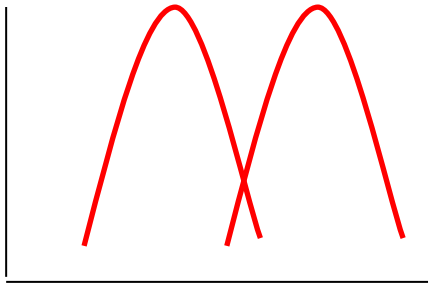
Factors can have location effects



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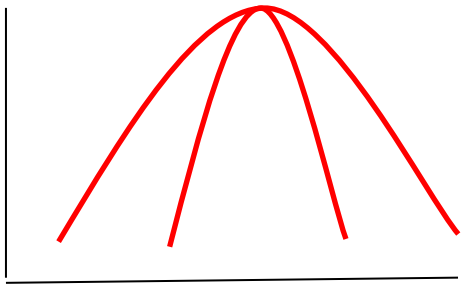
Factors can have dispersion effects



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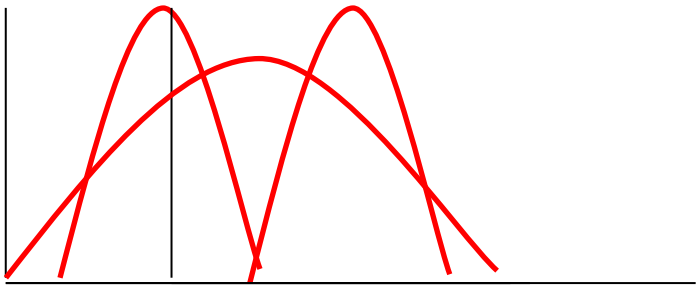
Factors can have combined effects



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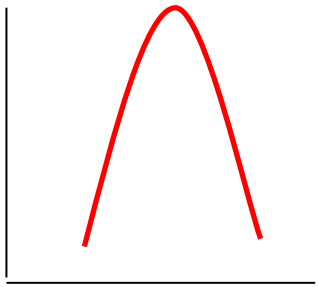
Factors could have no affect at all!!!



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Definitions

- DOE – Design of Experiments
- Factor – process variable which will be changed during experiment
- Level - High setting (temp, speed, force etc)
- Level – Low setting
- Run Order – sequence in which the experiment is run

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Full Factorial Designs

- Tests all possible combinations of factors and levels

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Full Factorial Designs

- 2 variables at 2 levels = 4 experiments required
- 3 variables at 2 levels = 8 experiments
- 7 variables at 2 levels = 128 experiments

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Example

Ioan and John are two operators on two machines, an original machine and a modified machine

Question : is the modified machine performing better than the original machine?

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One factor at a time – Everything else constant

One factor

response

four runs

Batch	Machine	Op	Defective pts	Aver age	Conc.
1	Original	Ioan	6%	5%	Keep original machine
2	Original	Ioan	4%		
3	Modified	Ioan	8%	9%	
4	Modified	Ioan	10%		

Two levels

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Several factors at a time – Everything else constant

Two factors

response

four runs

Batch	Machine	Op	Defective pts	Average	Conc.
1	Original	John	5%	5%	conclusions
2	Original	Ioan	5%		
3	Modified	John	1%	5%	
4	Modified	Ioan	9%		

Two levels

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The example we have just looked at is known as a 'standard L4 two level orthogonal array'

'Orthogonal' means balanced

Three factors at two levels with 8 runs would be known as L8 orthogonal array

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Fractional Factorial Designs

- Looks at selected sub-sets of the possible combinations contained in a full factorial experiment
- This allows you to screen many factors which will help to separate significant from non-significant
- Reduces the amount of resources needed from a full factorial
- Will not give you all of the interactions
- Requires more knowledge to understand

Fractional Factorial Designs

- If you had a full factorial D of E to run with 2 levels and 7 factors this would need 128 runs to cover all combinations
- You could alternatively decide to run a fractional factorial D of E instead (also known as a screening D of E)

Fractional Factorial Designs

- The fractional design can be run as half (1/2) , quarter (1/4) or eighth (1/8) and so forth
- This would give 64, 32 or 16 runs to complete accordingly

Fractional Factorial Designs

- There is an equation for this
- 2^{k-p}
- 2 = number of levels
- K = number of factors
- P = 1 for ½ fraction, 2 for ¼ fraction, 3 for 1/8 fraction etc..

Fractional Factorial Designs

- You will need to balance the number of runs undertaken for each factor the same number of times at both the low level as well as the high level (orthogonality)

- This will give you information on the main factors but not their interactions with each other

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What is an interaction?

- The factor we choose in our experiment are not always independent
- Setting one factor to ‘high’ can amplify the effect on another factor
- Stirring tea exaggerates the effect of adding sugar (Sir Ronald Fisher)

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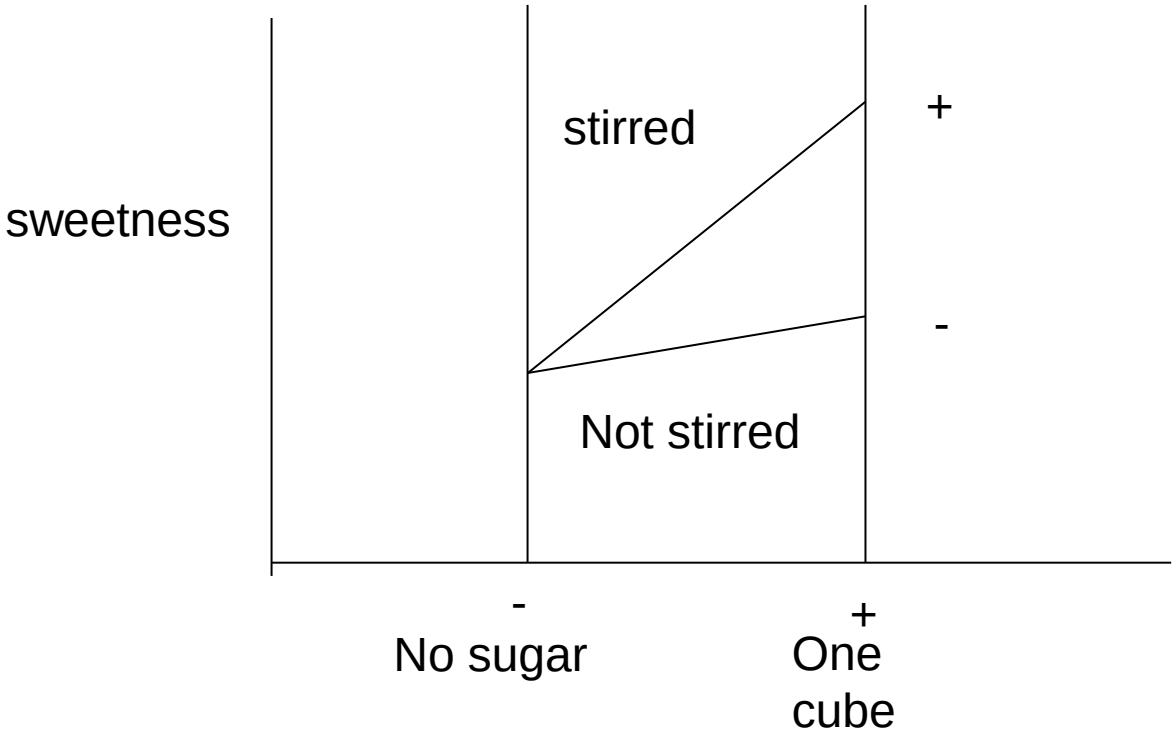
What is an interaction?



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What is an interaction?

A B C

Three factors

A x B A x C B x C A x B x C

interactions

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Fractional D of E's?

- Low cost for materials and time
- Quicker to get results

But,

- Lose information regarding interactions thus less resolution
- More complex to run and interpret results

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Worked Example

We will use regression we learnt within 'Analyse' phase to work through an example

The Unicorn Shampoo company want to understand which of their 4 inputs to the process are significant – we will use 2 levels low and high

Full Factorial with 2 way interactions only

Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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Worked Example

I have previously given a work sheet to the company to collect data from these experiments:-

Factor A - Gelling Agent Concentration 7, 10
Factor B - Agitator speed 8, 12
Factor C – Mixing Time 80, 100
Factor D – Batch Temperature 25, 35

We signify low and high using -1 (low) and 1 (high)

This is Known as coded data or actual setting values, uncoded data

Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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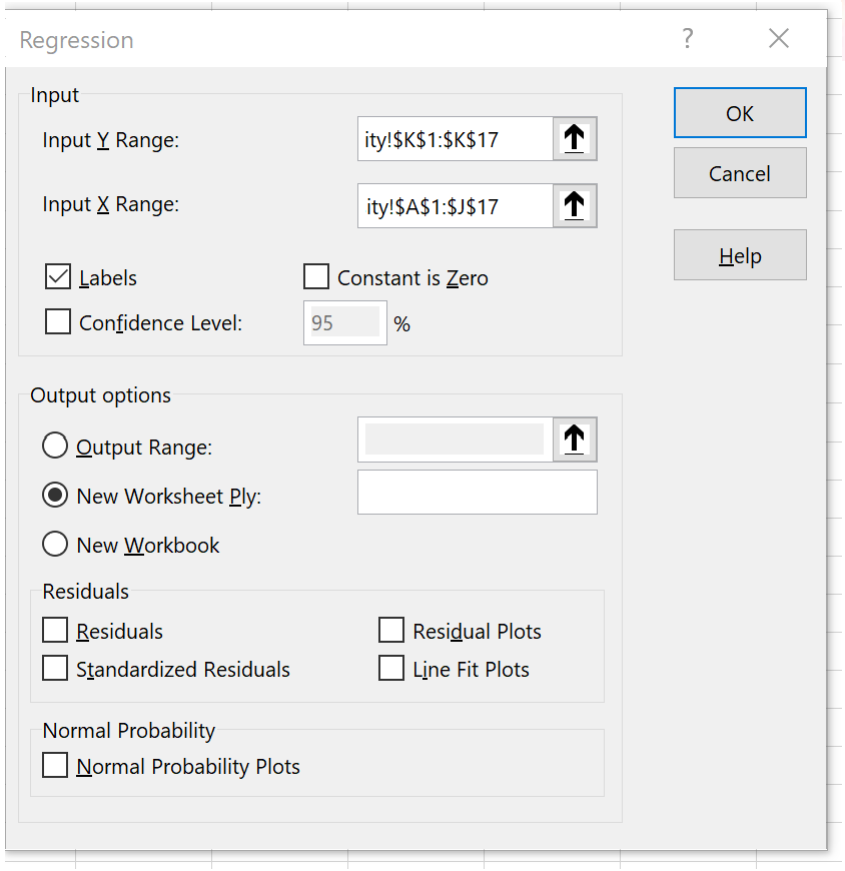
Worked Example

A	B	C	D	A*B	A*C	A*D	B*C	B*D	C*D	Response
-1	-1	-1	-1	1	1	1	1	1	1	43.577
-1	-1	-1	1	1	1	-1	1	-1	-1	46.201
-1	-1	1	-1	1	-1	1	-1	1	-1	37.082
-1	-1	1	1	1	-1	-1	-1	-1	1	34.444
-1	1	-1	-1	-1	1	1	-1	-1	1	20.759
-1	1	-1	1	-1	1	-1	-1	1	-1	38.783
-1	1	1	-1	-1	-1	1	1	-1	-1	39.549
-1	1	1	1	-1	-1	-1	1	1	1	31.986
1	-1	-1	-1	-1	-1	-1	1	1	1	12.699
1	-1	-1	1	-1	-1	1	1	-1	-1	21.394
1	-1	1	-1	-1	1	-1	-1	1	-1	26.632
1	-1	1	1	-1	1	1	-1	-1	1	24.276
1	1	-1	-1	1	-1	-1	-1	-1	1	73.123
1	1	-1	1	1	-1	1	-1	1	-1	62.977
1	1	1	-1	1	1	-1	1	-1	-1	56.464
1	1	1	1	1	1	1	1	1	1	59.965

Excerpt from ‘Lean Six Sigma for Excel’ by R.Khan 2020

Improve - Design of Experiments

Worked Example



Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

Improve - Design of Experiments

Worked Example

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.94
R Square	0.88
Adjusted R Square	0.65
Standard Error	10.10
Observations	16.00

ANOVA

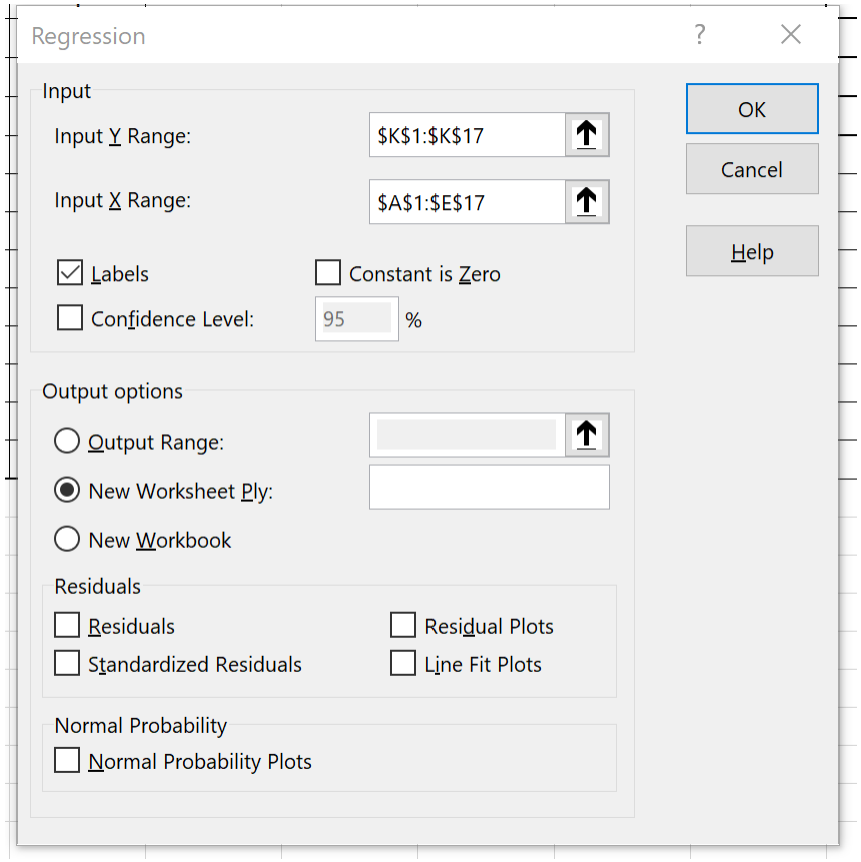
	df	SS	MS	F	Significance F
Regression	10.00	3822.10	382.21	3.74	0.08
Residual	5.00	510.51	102.10		
Total	15.00	4332.61			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	39.37	2.53	15.58	0.00	32.88	45.86	32.88	45.86
A	2.82	2.53	1.12	0.31	-3.67	9.32	-3.67	9.32
B	8.58	2.53	3.40	0.02	2.09	15.07	2.09	15.07
C	-0.57	2.53	-0.23	0.83	-7.06	5.92	-7.06	5.92
D	0.63	2.53	0.25	0.81	-5.86	7.13	-5.86	7.13
A*B	12.36	2.53	4.89	0.00	5.87	18.85	5.87	18.85
A*C	0.21	2.53	0.08	0.94	-6.28	6.71	-6.28	6.71
A*D	-0.67	2.53	-0.27	0.80	-7.17	5.82	-7.17	5.82
B*C	-0.39	2.53	-0.15	0.88	-6.88	6.10	-6.88	6.10
B*D	-0.16	2.53	-0.06	0.95	-6.65	6.34	-6.65	6.34
C*D	-1.77	2.53	-0.70	0.52	-8.26	4.73	-8.26	4.73

Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

Improve - Design of Experiments

Worked Example



Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

Worked Example

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.93							
R Square	0.87							
Adjusted R Square	0.80							
Standard Error	7.56							
Observations	16.00							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	5.00	3761.43	752.29	13.17	0.00			
Residual	10.00	571.17	57.12					
Total	15.00	4332.61						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	39.37	1.89	20.84	0.00	35.16	43.58	35.16	43.58
A	2.82	1.89	1.49	0.17	-1.39	7.03	-1.39	7.03
B	8.58	1.89	4.54	0.00	4.37	12.79	4.37	12.79
C	-0.57	1.89	-0.30	0.77	-4.78	3.64	-4.78	3.64
D	0.63	1.89	0.34	0.74	-3.58	4.84	-3.58	4.84
A*B	12.36	1.89	6.54	0.00	8.15	16.57	8.15	16.57

Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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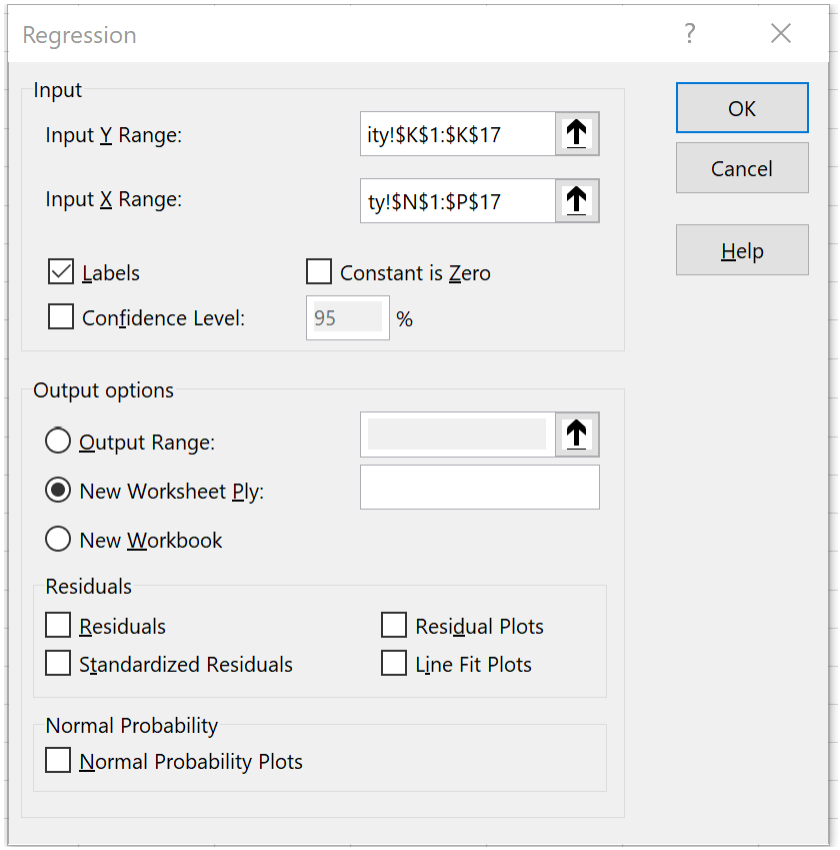
Worked Example



Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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Worked Example

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.93							
R Square	0.87							
Adjusted R Square	0.83							
Standard Error	6.97							
Observations	16.00							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3.00	3749.81	1249.94	25.74	0.00			
Residual	12.00	582.80	48.57					
Total	15.00	4332.61						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	39.37	1.74	22.60	0.00	35.57	43.17	35.57	43.17
A	2.82	1.74	1.62	0.13	-0.97	6.62	-0.97	6.62
B	8.58	1.74	4.93	0.00	4.79	12.38	4.79	12.38
A*B	12.36	1.74	7.09	0.00	8.56	16.16	8.56	16.16

Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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Worked Example

A	B	A*B
7	8	56
7	8	56
7	8	56
7	8	56
7	12	84
7	12	84
7	12	84
7	12	84
10	8	80
10	8	80
10	8	80
10	8	80
10	12	120
10	12	120
10	12	120
10	12	120

Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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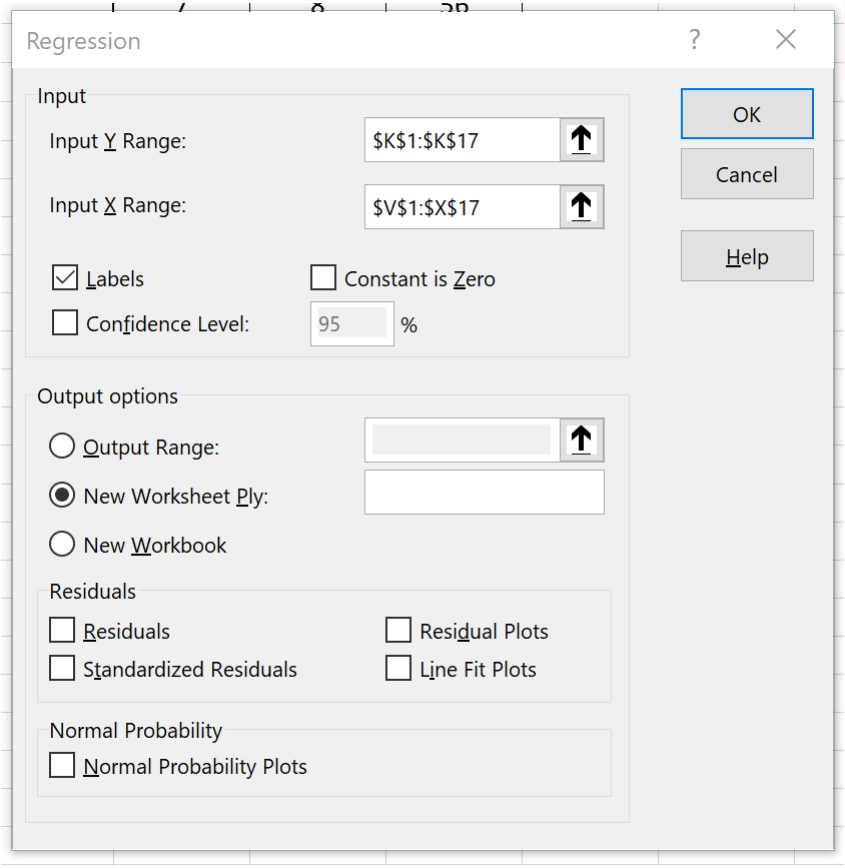
Worked Example



Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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Worked Example

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.930315							
R Square	0.865486							
Adjusted R Square	0.831858							
Standard Error	6.968949							
Observations	16							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	3749.815	1249.938	25.73677	1.63E-05			
Residual	12	582.795	48.56625					
Total	15	4332.61						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	330.6638	51.11882	6.468532	3.08E-05	219.2854	442.0421	219.2854	442.0421
A	-39.3178	5.922468	-6.63874	2.4E-05	-52.2217	-26.4138	-52.2217	-26.4138
B	-30.7285	5.012613	-6.13023	5.1E-05	-41.65	-19.8069	-41.65	-19.8069
A*B	4.119896	0.580746	7.094147	1.26E-05	2.85456	5.385232	2.85456	5.385232

Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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From straight line graph *y=mx+c*

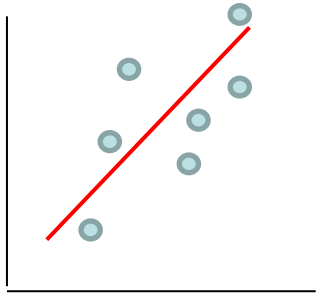
From straight line graph

Y = predicted value

M = slope

X = independent variable

C = intercept



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Worked Example

=330 + (-39.32*7 Factor A)+(-30.73*8 Factor B)+(4.12*7 Factor A*8 Factor B)

= 40.32

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Worked Example

Factor A	10	21.250	26.5	31.7	37	42.2	47.4	52.7	57.9	63.1
	9.7	23.158	27.8	32.4	37	41.6	46.2	50.9	55.5	60.1
	9.4	25.065	29.1	33.1	37.1	41.1	45.1	49.1	53.1	57.1
	9.1	26.973	30.4	33.7	37.1	40.5	43.9	47.3	50.6	54
	8.8	28.881	31.6	34.4	37.2	39.9	42.7	45.5	48.2	51
	8.5	30.788	32.9	35.1	37.2	39.4	41.5	43.7	45.8	48
	8.2	32.696	34.2	35.8	37.3	38.8	40.3	41.9	43.4	44.9
	7.9	34.603	35.5	36.4	37.3	38.2	39.2	40.1	41	41.9
	7.6	36.511	36.8	37.1	37.4	37.7	38	38.3	38.6	38.8
	7.3	38.418	38.1	37.8	37.4	37.1	36.8	36.5	36.1	35.8
	7	40.326	39.4	38.4	37.5	36.5	35.6	34.7	33.7	32.8
		8	8.5	9	9.5	10	10.5	11	11.5	12
		Factor B								

Excerpt from 'Lean Six Sigma for Excel' by R.Khan 2020

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We could have opted to included 3 way interactions and the 4 way but this would have meant lots more tests, time on experiment and analysis

We could however used Fractional Factorials as long as they were balanced between high and low but lose some resolution

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Improve - Design of Experiments

SigmaZone

Homepage Products Training Consulting About Us Articles Support

Catapult Settings

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

Hide Tips

Show me Targets

Worked Example

5 inputs (factors)

- Firing Angle
- Bungee Position
- Release Angle
- Pin Elevation
- Cup Elevation

Worked Example – Full Factorial (32 runs)

StdOrder	RunOrder	Firing Angle	Bungee position	Release angle	Pin elevation	Cup elevation	FA	BP	RA	PE	CE	response
32	1	1	1	1	1	1	120	160	160	160	270	
6	2	1	-1	1	-1	-1	120	140	160	140	220	
18	3	1	-1	-1	-1	1	120	140	140	140	270	
12	4	1	1	-1	1	-1	120	160	140	160	220	
10	5	1	-1	-1	1	-1	120	140	140	160	220	
17	6	-1	-1	-1	-1	1	90	140	140	140	270	
15	7	-1	1	1	1	-1	90	160	160	160	220	
31	8	-1	1	1	1	1	90	160	160	160	270	
22	9	1	-1	1	-1	1	120	140	160	140	270	
26	10	1	-1	-1	1	1	120	140	140	160	270	
30	11	1	-1	1	1	1	120	140	160	160	270	
24	12	1	1	1	-1	1	120	160	160	140	270	
4	13	1	1	-1	-1	-1	120	160	140	140	220	
3	14	-1	1	-1	-1	-1	90	160	140	140	220	
20	15	1	1	-1	-1	1	120	160	140	140	270	
25	16	-1	-1	-1	1	1	90	140	140	160	270	
2	17	1	-1	-1	-1	-1	120	140	140	140	220	
16	18	1	1	1	1	-1	120	160	160	160	220	
19	19	-1	1	-1	-1	1	90	160	140	140	270	
9	20	-1	-1	-1	1	-1	90	140	140	160	220	
5	21	-1	-1	1	-1	-1	90	140	160	140	220	
14	22	1	-1	1	1	-1	120	140	160	160	220	
7	23	-1	1	1	-1	-1	90	160	160	140	220	
1	24	-1	-1	-1	-1	-1	90	140	140	140	220	
8	25	1	1	1	-1	-1	120	160	160	140	220	
27	26	-1	1	-1	1	1	90	160	140	160	270	
13	27	-1	-1	1	1	-1	90	140	160	160	220	
23	28	-1	1	1	-1	1	90	160	160	140	270	
21	29	-1	-1	1	-1	1	90	140	160	140	270	
28	30	1	1	-1	1	1	120	160	140	160	270	
11	31	-1	1	-1	1	-1	90	160	140	160	220	
29	32	-1	-1	1	1	1	90	140	160	160	270	

Single Pass Machining

Champion :
Team : D.Jones
Financial Officer :

Project Report Out : Project Charter

Lean Six Sigma Team Charter: Project Definition

Areas Impacted	***Sheet Finishing***	***Financial Impact***	***See below***
Project Leader (BB)	***D.Jones***	***Project Leader Signature***	***DJ***
Champion		***Champion Signature***	
Telephone Number		***Organisational Unit.***	
Start Date		***Target Completion Date***	

Project Report Out : Project Charter

Element	Description	Team Charter				
1. Process:	The process in which the opportunity exists. (General Description).	Current practice dictates that we machine in two passes – roughing and finishing. The projects aim is to reduce this to a single operation.				
2. Project Description:	Describe the Project's Purpose and scope. (Start, Finish, Aims etc).	Use 6 sigma tools (DOE) to optimise various parameters which will produce consistent blades to customer				
3. Objective:	What improvement is targeted and what will be the impact on RTY, COPQ and C-P?		**BSL (Baseline)**	**GOAL**	**Stretch**	**units**
	(Process Performance).					
	(Cost Performance).					**£**
4. Financial impact details	Outline the details of the projected financial Impact.	Reduction of machining operation will potentially increase capacity and allow cost savings to be realised				

Project Report out : SIPOC

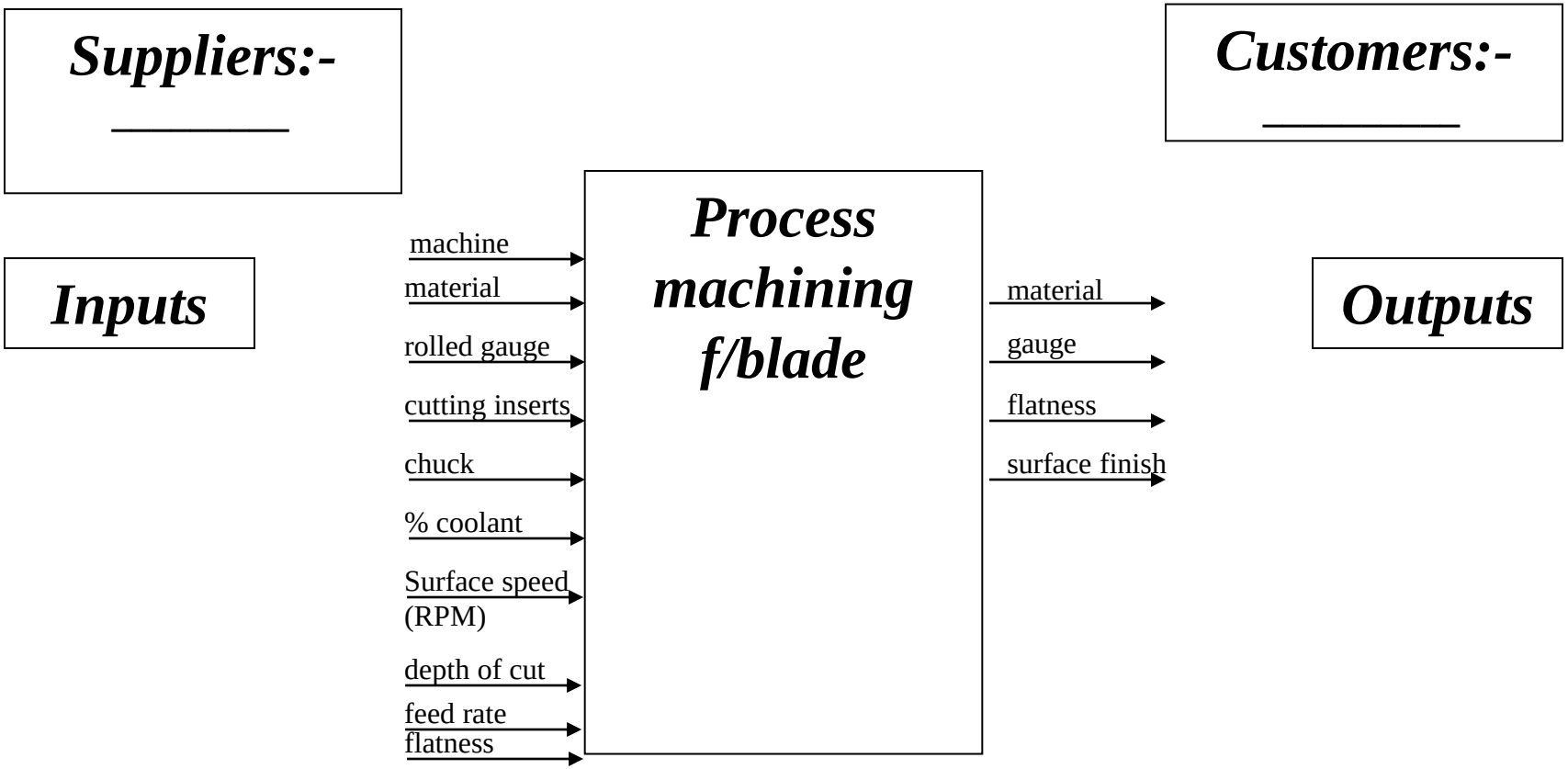
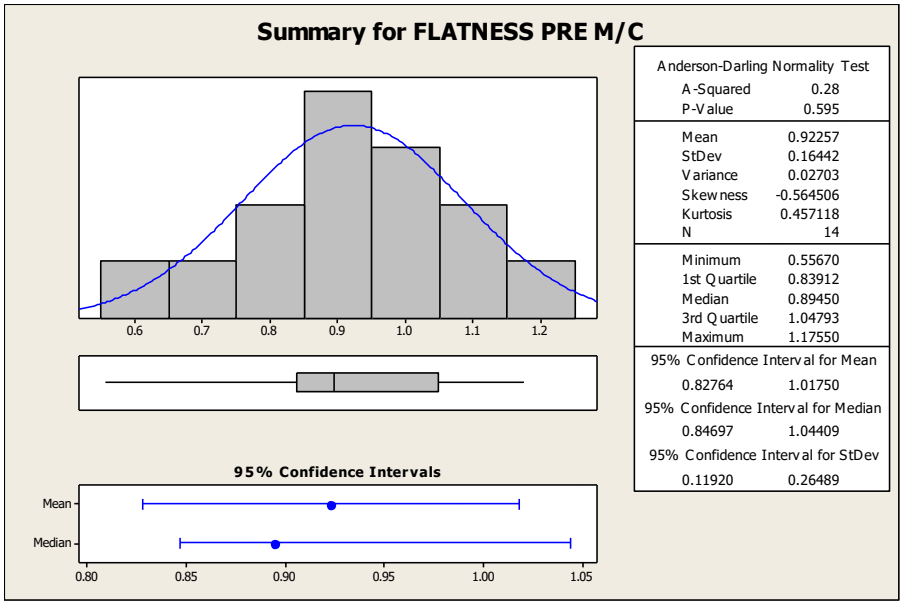
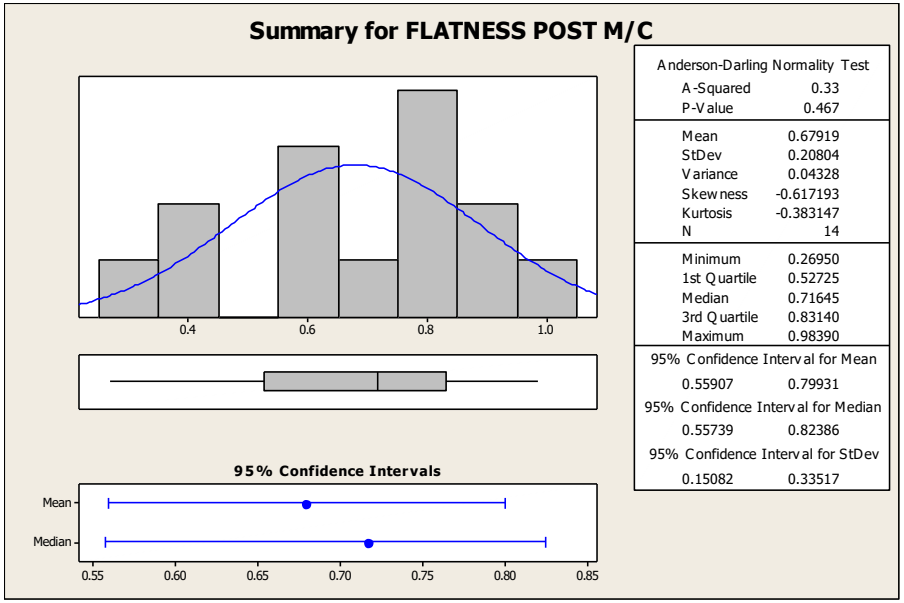


PLATE	FLATNESS PRE M/C	FLATNESS POST M/C
A3D	1.1155	0.5652
A4B	1.0624	0.8599
A3A	1.1755	0.8976
A3C	1.0132	0.758
A4A	0.849	0.6467
A2B	1.033	0.2695
A1D	0.9117	0.3916
A1B	0.8753	0.4134
A3B	0.5567	0.7952
A2C	0.859	0.7914
A2A	0.8773	0.6749
A1C	0.7348	0.6395
A1A	0.8095	0.8219
A2D	1.0431	0.9839

Single Pass Machining – Analysis of Std _____Fan Blade – normal data





Single Pass Machining – Analysis of Std _____Fan Blade – significant difference?

Two-Sample T-Test and CI: FLATNESS PRE M/C, FLATNESS POST M/C

Two-sample T for FLATNESS PRE M/C vs FLATNESS POST M/C

	N	Mean	StDev	SE Mean
FLATNESS PRE M/C	14	0.923	0.164	0.044
FLATNESS POST M/C	14	0.679	0.208	0.056

Difference = mu (FLATNESS PRE M/C) - mu (FLATNESS POST M/C)
Estimate for difference: 0.2434
95% CI for difference: (0.0971, 0.3896)
T-Test of difference = 0 (vs not =): T-Value = 3.43 P-Value = 0.002 DF = 24

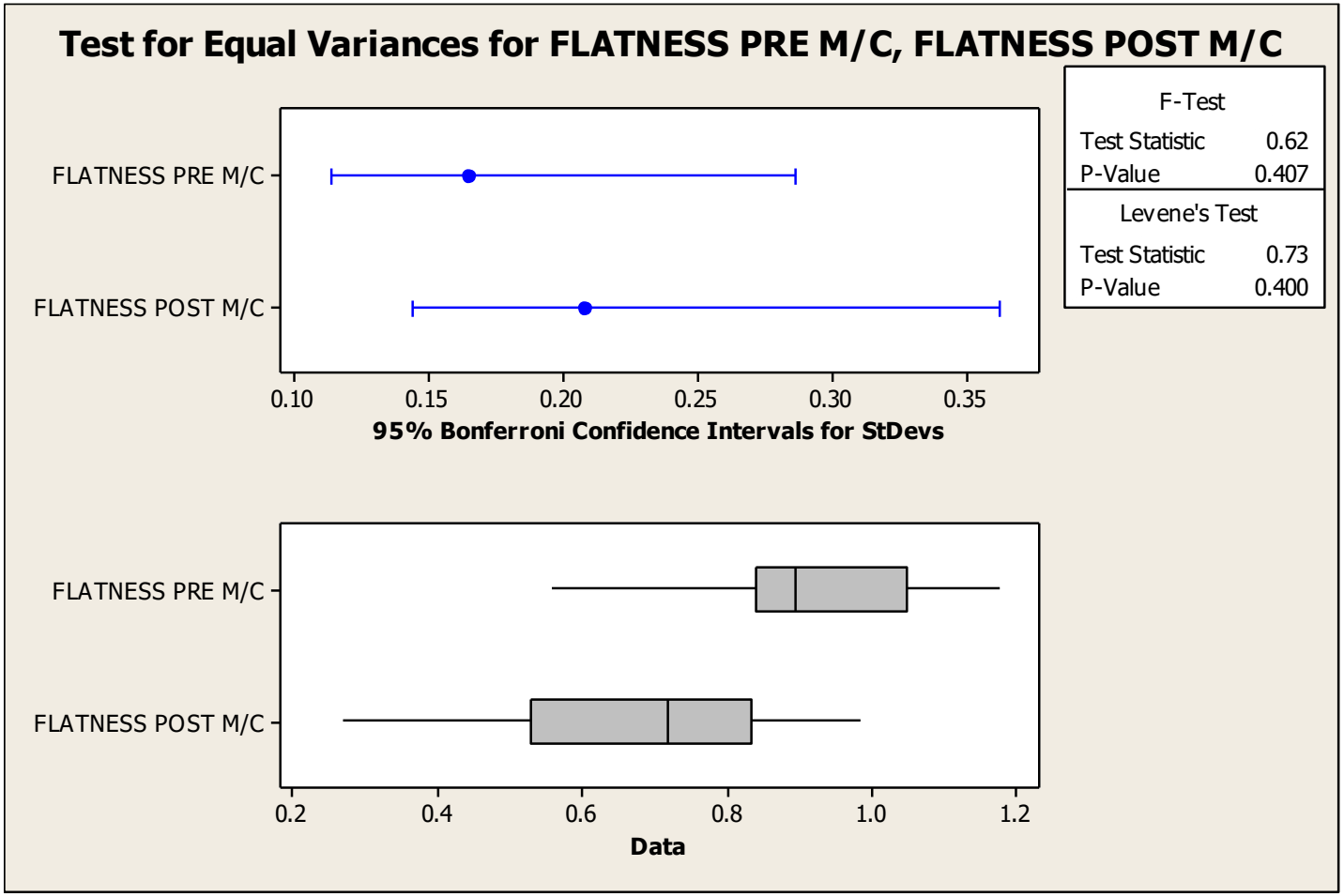
Paired T-Test and CI: FLATNESS PRE M/C, FLATNESS POST M/C

Paired T for FLATNESS PRE M/C - FLATNESS POST M/C

	N	Mean	StDev	SE Mean
FLATNESS PRE M/C	14	0.9226	0.1644	0.0439
FLATNESS POST M/C	14	0.6792	0.2080	0.0556
Difference	14	0.2434	0.2601	0.0695

95% CI for mean difference: (0.0932, 0.3936)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.50 P-Value = 0.004

Single Pass Machining – Analysis of Std _____Fan Blade – variances equal?



Next Steps:-

- **Final inspect, pack and despatch to _____**
- **Slot and split each blade and measure flatness**
- **Analyse results**
- **Undertake DOE (12 runs) on Trent ___ series of fan blades and measure splitting and machining operations separately**

Improve

• DOE to understand interactions between various machining parameters

- **Use DOE tool to optimise on the amount of trial runs so the effect of various process inputs is understood with regard to inducing stress at machining – measured by plate flatness**

Factors:-

- **Depth of Cut – effected by the input gauge of plates after rolling**
- **Insert wear on cutting tool – amount of wear through shift may induce stress**
- **RPM – surface speed of inserts through material**
- **Feed/insert – amount of material each insert cuts**

- **Project managed through process**
- **Driven by __ to realise additional capacity/cost savings**
- **Specification (_____) since 1990's has stated that machining of fan blade products for __ be undertaken in 2 passes to minimise the stress induced which may warp plates at subsequent ops**
- **Roughing cut typically __mm depth of cut (DOC) – on 1 machine/op**
- **Finishing cut typically __mm depth of cut – on 1 machine/op**
- **Speeds and feeds also set by _____ and process outline**
- **Single Pass Machining aims to undertake this operation in 1 cut combining the roughing and finishing together**
- **Benefits increase capacity / potential cost savings**
- **Use Design of Experiments to optimise various process inputs**

2 Levels – High and Low:-

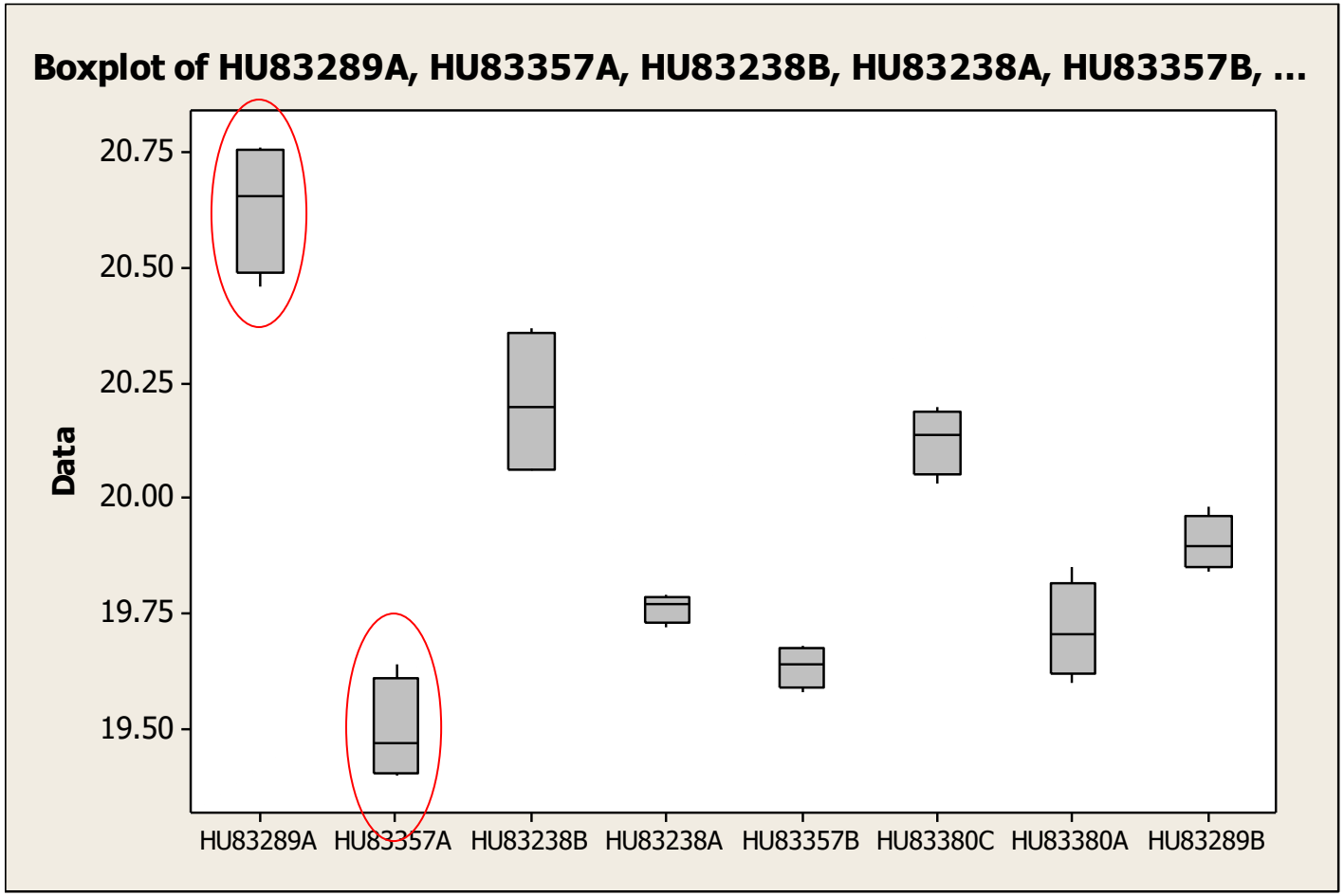
- **Depth of Cut – top end of rolling tolerance / bottom end of rolling tolerance**
- **Insert wear on cutting tool – new inserts / used inserts (after __ passes – changed after __)**
- **RPM – __ / __ (__ rpm current roughing – __rpm current finishing)**
- **Feed/insert – __mm/min and ___mm/min (currently 100mm/min)**

constants:-

- **Undertake on 1 machine/operator – use No __ miller (CNC controlled – easier to change RPM/Feed parameters)**
- **Maintain coolant strength of 5% (nominal) throughout trial**

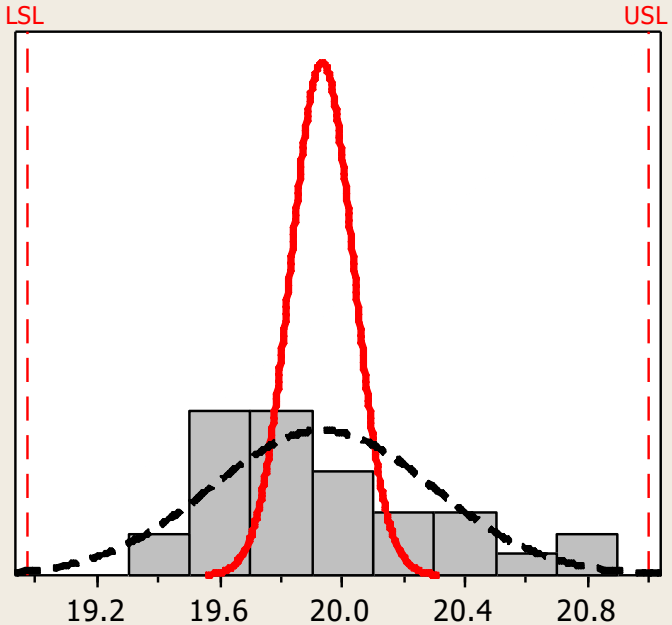
Due to high value of products, need to minimise the amounts of plates machined

- **4 Factors**
- **2 Levels**
- **1/2 fractional factorial gives 8 runs using various parameters**
- **2 additional plates to be machined using standard (roughing and finishing) operations**
- **Total of 10 plates to be machined, checked for flatness, split/ mc'd and re-checked for flatness**


Boxplot of HU83289A, HU83357A, HU83238B, HU83238A, HU83357B, ...
Data
20.75
20.50
20.25
20.00
19.75
19.50
HU83289A
HU83357A
HU83238B
HU83238A
HU83357B
HU83380C
HU83380A
HU83289B

Process Capability of V2500 Rolled Gauge

Process Data	
LSL	18.973
Target	*
USL	21
Sample Mean	19.9347
Sample N	32
StDev(Within)	0.102525
StDev(Overall)	0.363211



Within
Overall

Potential (Within) Capability	
Cp	3.30
CPL	3.13
CPU	3.46
Cpk	3.13

Overall Capability	
Pp	0.93
PPL	0.88
PPU	0.98
Ppk	0.88
Cpm	*

Observed Performance	
PPM < LSL	0.00
PPM > USL	0.00
PPM Total	0.00

Exp. Within Performance	
PPM < LSL	0.00
PPM > USL	0.00
PPM Total	0.00

Exp. Overall Performance	
PPM < LSL	4051.65
PPM > USL	1678.32
PPM Total	5729.96

Sequence of trials generated by minitab – additional 2 off machined using standard parameters at start and finish of trial

inserts	feed	RPM	DOC
old	78	17	1.1
old	78	23	1.7
old	125	17	1.7
old	125	23	1.1
new	78	17	1.7
new	78	23	1.1
new	125	17	1.1
new	125	23	1.7

Single Pass Machining – Results after TIMET m/c

Run No	Inserts	Feed	RPM	Gauge	Act. DOC	Plate ID	Flatness Pre	gauge				Roughness				Flatness after m/c	gauge after m/c				Meter	Visual	Bow after splitting
2	old (39th pass)	78	17	1.1	1.23	HU83357A11	0.234	19.55	19.55	19.6	19.6	0.2	0.4	0.3	0.5	0.268	17.15	17.18	17.13	17.16		Slight m/c marks on leading edge	
3	old (40th pass)	78	23	1.7	1.73	HU83289A11	0.244	20.65	20.5	20.6	20.45	1.01	0.2	0.4	0.5	0.274	17.17	17.13	16.97	17.15	36	Slight m/c marks on leading edge	
4	old (41st pass)	125	17	1.7	1.85	HU83289A15	0.333	20.95	21.05	20.65	20.75	0.6	0.2	0.2	0.5	0.154	17.18	17.14	17.15	17.18	53	Slight m/c marks on leading edge	
5	old (42nd pass)	125	23	1.1	1.28	HU83357A14	0.47	19.75	19.7	19.6	19.6	0.5	0.8	0.4	0.5	0.351	17.17	17.13	17.11	17.15	36	Slight m/c marks on leading edge	
6	new (1st pass)	78	17	1.7	1.73	HU83289A13	0.261	20.85	20.48	20.25	20.45	0.2	0.3	0.3	0.2	0.108	17.18	17.14	17.12	17.16			
7	new (2nd pass)	78	23	1.1	1.23	HU83357A12	0.461	19.55	19.58	19.6	19.65	0.1	0.4	0.2	0.3	0.361	17.07	17.12	17.1	17.14	35		
8	new (3rd pass)	125	17	1.1	1.26	HU83357A13	0.317	19.72	19.9	19.65	19.7	0.2	0.4	0.2	0.2	0.3	17.12	17.17	17.1	17.15	55		
9	new (4th pass)	125	23	1.7	1.75	HU83289A5	0.105	20.55	20.45	20.62	20.55	0.2	0.3	0.2	0.2	0.106	17.1	17.15	17.04	17.13			
1	1blade old (38th pass)	100	17/23	2 passes		HU83357A10	0.325	19.65	19.6	19.7	19.6	0.3	0.4	0.2	0.5	0.277	17.1	17.17	17.13	17.17	50		
10	2 blade new (5th pass)	100	17/23	2 passes		HU83289A4	0.096	20.42	20.55	20.45	20.21	0.1	0.3	0.2	0.3	0.076	17.07	17.09	17.12	17.13	50		

Assumptions:

old inserts = ones which have already had 37 passes completed. I.e 5 passes left.

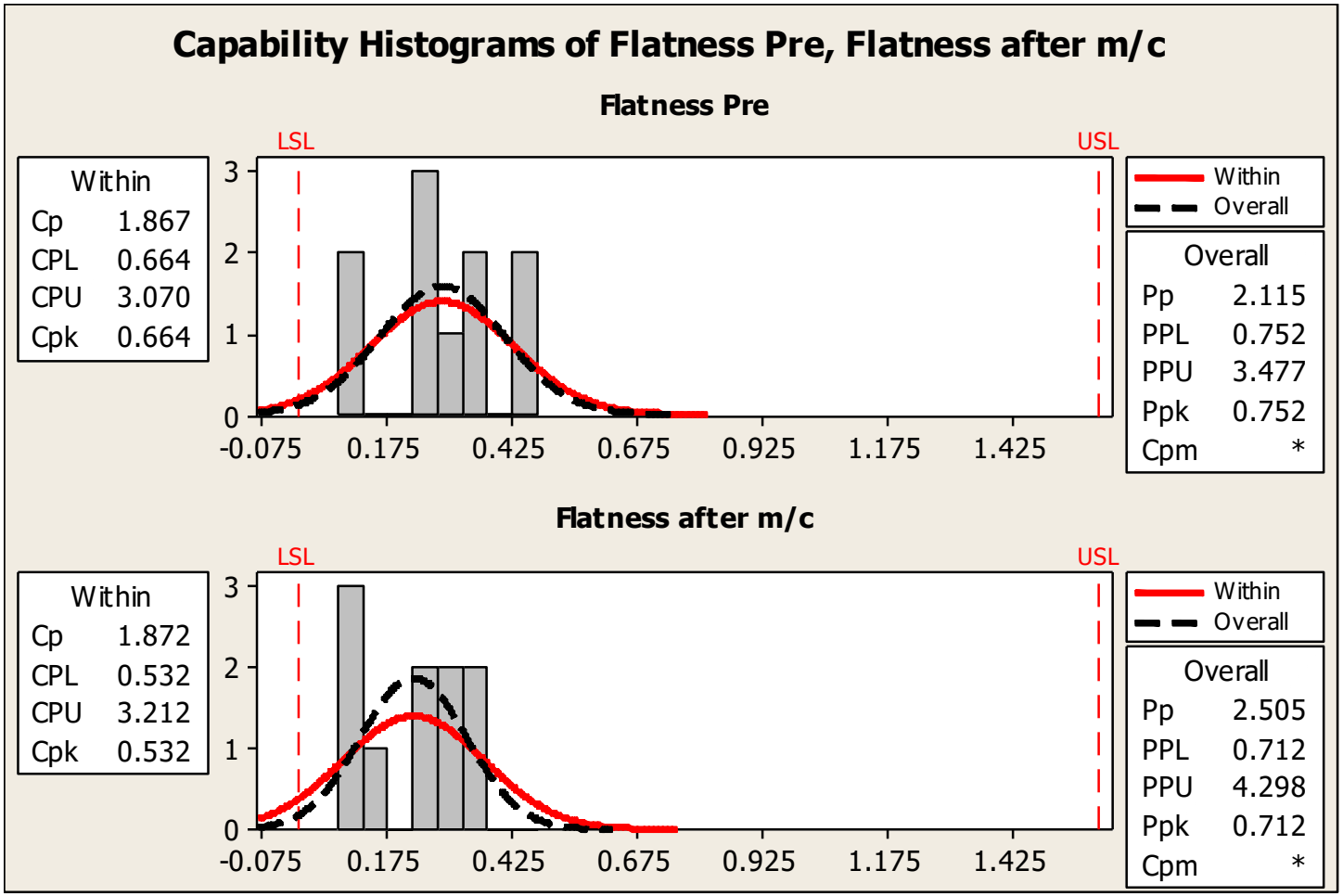
Feed rate = 78mm/min and 125mm/min - 25mm either side of 100mm/min standard.

RPM = 17 used for roughing and 23 for finishing.

Gauge = 2 batches from sample which is at each end of rolling gauge tolerance.

No 9 and 10 are control blades to be machined to current specification.

Coolant concentration to be controlled at 5% - nominal between 4% and 6%. Checked throughout trial.


Capability Histograms of Flatness Pre, Flatness after m/c
Flatness Pre
LSL
USL
Within
Cp 1.867
CPL 0.664
CPU 3.070
Cpk 0.664
Within
Overall
Overall
Pp 2.115
PPL 0.752
PPU 3.477
Ppk 0.752
Cpm *
-0.075 0.175 0.425 0.675 0.925 1.175 1.425
Flatness after m/c
LSL
USL
Within
Cp 1.872
CPL 0.532
CPU 3.212
Cpk 0.532
Within
Overall
Overall
Pp 2.505
PPL 0.712
PPU 4.298
Ppk 0.712
Cpm *
-0.075 0.175 0.425 0.675 0.925 1.175 1.425

Results for: Flatness

Paired T-Test and CI: Flatness Pre, Flatness after m/c

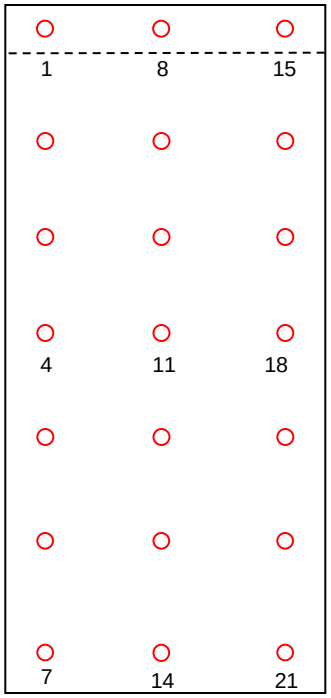
Paired T for Flatness Pre - Flatness after m/c

	N	Mean	StDev	SE Mean
Flatness Pre	10	0.2846	0.1261	0.0399
Flatness after m/c	10	0.2275	0.1064	0.0337
Difference	10	0.0571	0.0761	0.0241

95% CI for mean difference: (0.0027, 0.1115)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.37 P-Value = 0.042

Single Pass Machining – Method of measuring blades returned from customer

operator	: DJ	
Part name	: CH1477	
serial number	: 1	
Device	: P08-05-07-22799	
device version	: 1.55	
today is	: 6/17/2008	
units	: Millimeters	
Label		
C_DEVICEPOS001	ActualZ	
M_PLANE001		
M_LINE001		
M_LINE002		
C_POINT001		
C_COORDSYS001		
C_ALIGNMENT001		
M_COMPNT001	0.0683	
M_COMPNT002	0.0805	
M_COMPNT003	0.0961	
M_COMPNT004	0.1473	
M_COMPNT005	0.1329	
M_COMPNT006	0.118	
M_COMPNT007	0.0605	
M_COMPNT008	0.0801	
M_COMPNT009	0.0792	
M_COMPNT010	0.12	
M_COMPNT011	0.2209	
M_COMPNT012	0.2364	
M_COMPNT013	0.1914	
M_COMPNT014	0.067	
M_COMPNT015	0.088	
M_COMPNT016	0.2	
M_COMPNT017	0.2473	
M_COMPNT018	0.24	
M_COMPNT019	0.1462	
M_COMPNT020	0.089	
M_COMPNT021	0.0952	



Single Pass Machining – Results after Slotting/Splitting and m/c

Run No	Inserts	Feed	RPM	Gauge	Act. DOC	Plate ID	Flatness Pre m/c	Roughness				Flatness post m/c	gauge after m/c				Visual	flatness after splitting/mc R	flatness after splitting/mc R2
2	old (39th pass)	78	17	1.1	1.23	HU83357A11	0.234	0.2	0.4	0.3	0.5	0.268	17.15	17.18	17.13	17.16	Slight m/c marks on leading edge	0.252	0.557
3	old (40th pass)	78	23	1.7	1.73	HU83289A11	0.244	1.01	0.2	0.4	0.5	0.274	17.17	17.13	16.97	17.15	Slight m/c marks on leading edge	0.276	0.491
4	old (41st pass)	125	17	1.7	1.85	HU83289A15	0.333	0.6	0.2	0.2	0.5	0.154	17.18	17.14	17.15	17.18	Slight m/c marks on leading edge	0.247	0.376
5	old (42nd pass)	125	23	1.1	1.28	HU83357A14	0.47	0.5	0.8	0.4	0.5	0.351	17.17	17.13	17.11	17.15	Slight m/c marks on leading edge	0.332	0.414
6	new (1st pass)	78	17	1.7	1.73	HU83289A13	0.261	0.2	0.3	0.3	0.2	0.108	17.18	17.14	17.12	17.16		0.68	0.336
7	new (2nd pass)	78	23	1.1	1.23	HU83357A12	0.461	0.1	0.4	0.2	0.3	0.361	17.07	17.12	17.1	17.14		0.352	0.807
8	new (3rd pass)	125	17	1.1	1.26	HU83357A13	0.317	0.2	0.4	0.2	0.2	0.3	17.12	17.17	17.1	17.15		2.043	2.3
9	new (4th pass)	125	23	1.7	1.75	HU83289A5	0.105	0.2	0.3	0.2	0.2	0.106	17.1	17.15	17.04	17.13		0.57	0.478
1	1blade old (38th pass)	100	17/23	2 passes		HU83357A10	0.325	0.3	0.4	0.2	0.5	0.277	17.1	17.17	17.13	17.17		0.966	0.34
10	2 blade new (5th pass)	100	17/23	2 passes		HU83289A4	0.096	0.1	0.3	0.2	0.3	0.076	17.07	17.09	17.12	17.13		1.179	0.252

Assumptions:

old inserts = ones which have already had 37 passes completed. I.e 5 passes left.

Feed rate = 78mm/min and 125mm/min - 25mm either side of 100mm/min standard.

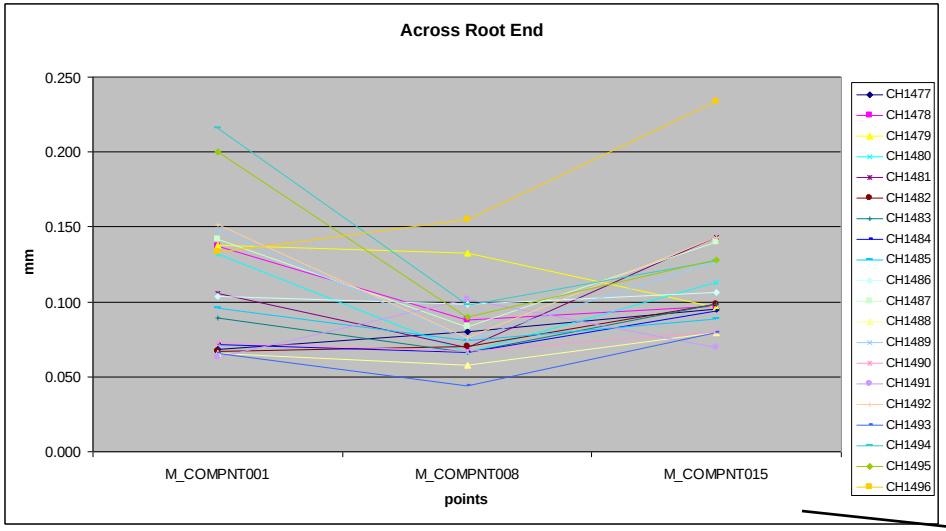
RPM = 17 used for roughing and 23 for finishing.

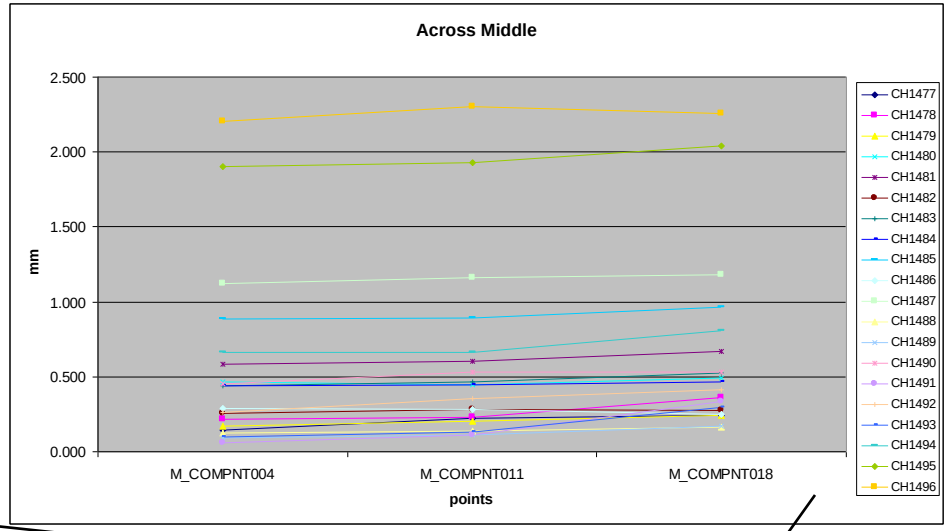
Gauge = 2 batches from sample which is at each end of rolling gauge tolerance.

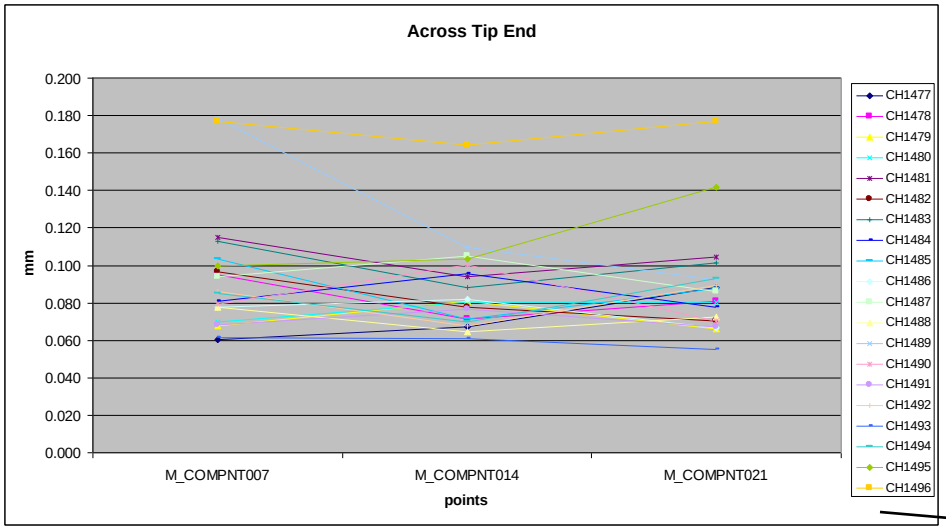
No 9 and 10 are control blades to be machined to current specification.

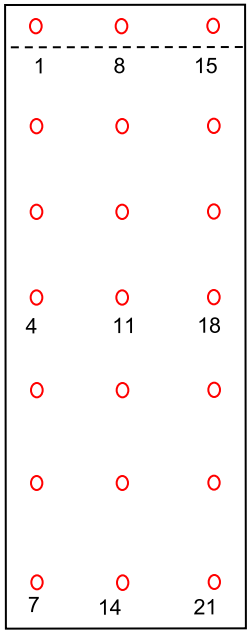
Coolant concentration to be controlled at 5% - nominal between 4% and 6%. Checked throughout trial.

Single Pass Machining – Data Across Blade Widths

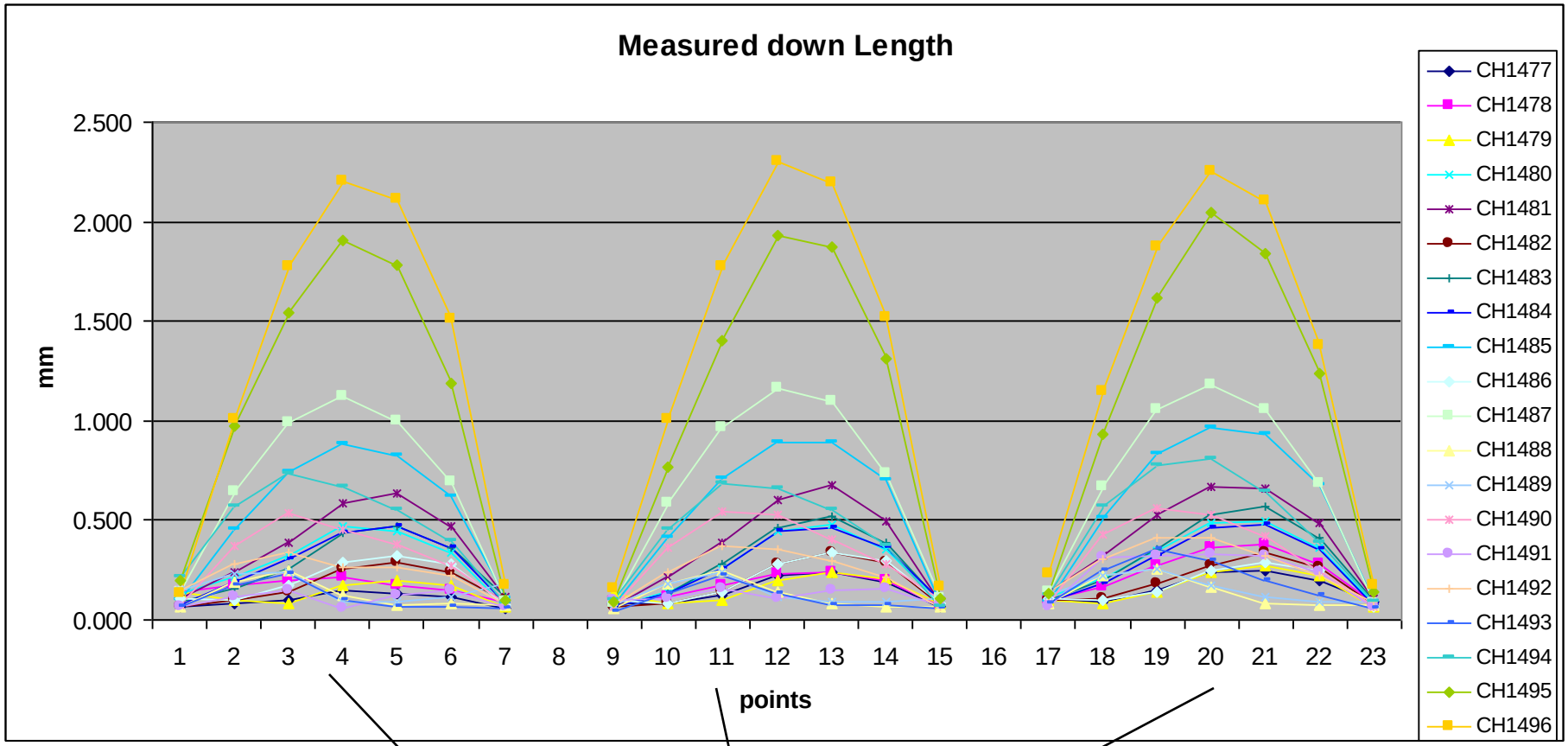


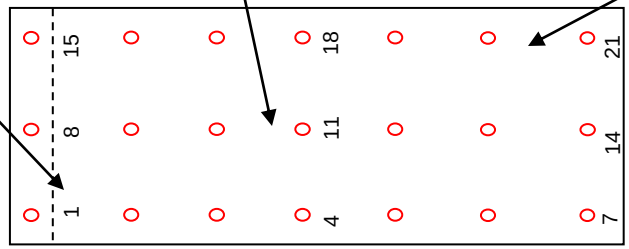






Single Pass Machining – Data Measured down Length





Single Pass Machining – Main Factors – little significance

Factorial Fit: result versus Tips, Feed, Speed, DOC

Estimated Effects and Coefficients for result (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		0.5940	0.1932	3.08	0.054
Tips	0.6345	0.3172	0.1932	1.64	0.199
Feed	0.4080	0.2040	0.1932	1.06	0.368
Speed	-0.4230	-0.2115	0.1932	-1.09	0.354
DOC	-0.3015	-0.1507	0.1932	-0.78	0.492

S = 0.546354 PRESS = 6.36805
R-Sq = 65.20% R-Sq(pred) = 0.00% R-Sq(adj) = 18.80%

Analysis of Variance for result (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	1.6778	1.6778	0.4194	1.41	0.406
Residual Error	3	0.8955	0.8955	0.2985		
Total	7	2.5733				

Factorial Fit: result 2 versus Tips, Feed, Speed, DOC

Estimated Effects and Coefficients for result 2 (coded units)

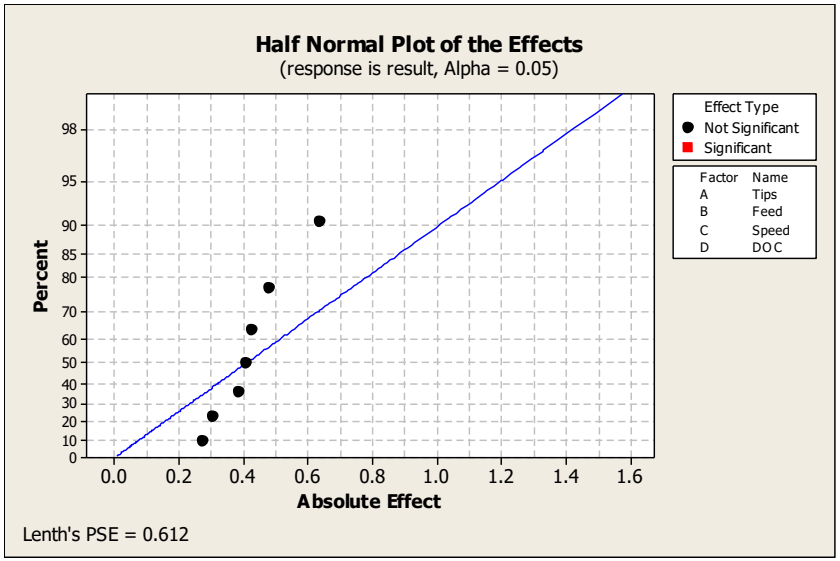
Term	Effect	Coef	SE Coef	T	P
Constant		0.7199	0.2296	3.13	0.052
Tips	0.5207	0.2604	0.2296	1.13	0.339
Feed	0.3443	0.1721	0.2296	0.75	0.508
Speed	-0.3448	-0.1724	0.2296	-0.75	0.507
DOC	-0.5992	-0.2996	0.2296	-1.30	0.283

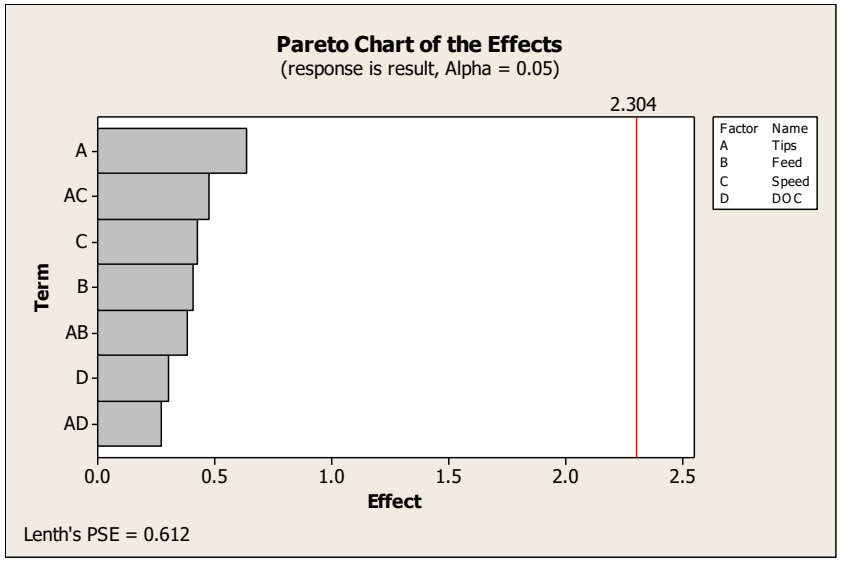
S = 0.649535 PRESS = 9.00044
R-Sq = 57.82% R-Sq(pred) = 0.00% R-Sq(adj) = 1.59%

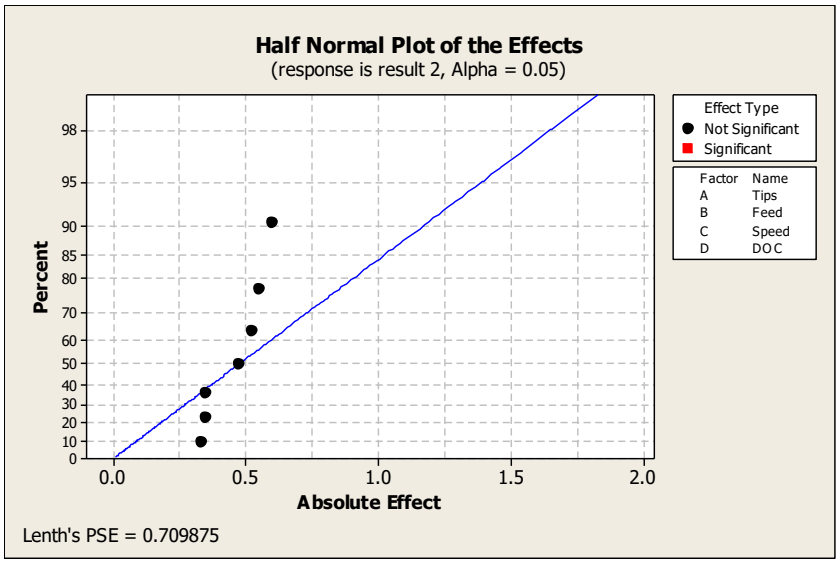
Analysis of Variance for result 2 (coded units)

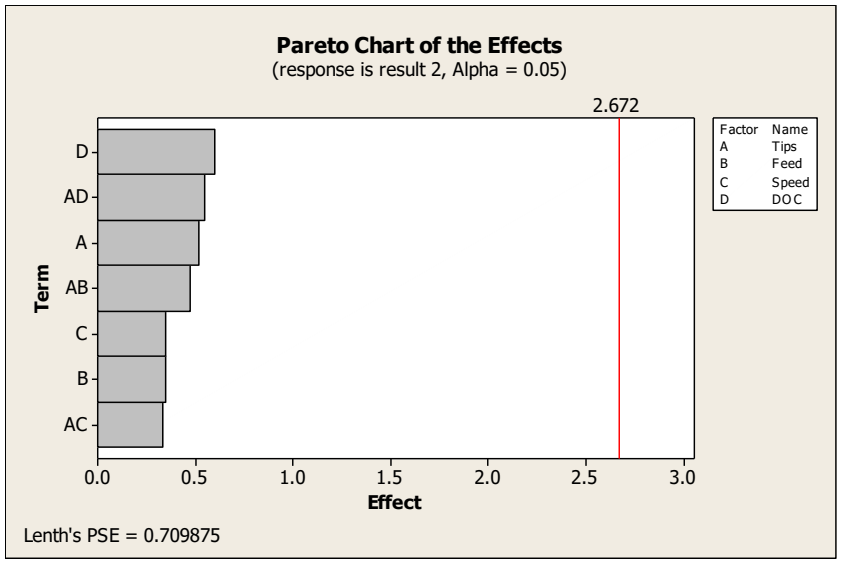
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	1.735	1.735	0.4338	1.03	0.511
Residual Error	3	1.266	1.266	0.4219		
Total	7	3.001				

Single Pass Machining – Factors – little significance









Single Pass Machining – Main Factors – still little significance!

Factorial Fit: trans R versus Tips, Feed, Speed, DOC

Estimated Effects and Coefficients for trans R (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		8.486	1.482	5.73	0.011
Tips	-10.197	-5.098	1.482	-3.44	0.041
Feed	-2.582	-1.291	1.482	-0.87	0.448
Speed	-0.298	-0.149	1.482	-0.10	0.926
DOC	0.407	0.204	1.482	0.14	0.899

S = 4.19202 PRESS = 374.891
R-Sq = 80.80% R-Sq(pred) = 0.00% R-Sq(adj) = 55.19%

Analysis of Variance for trans R (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	221.79	221.79	55.45	3.16	0.186
Residual Error	3	52.72	52.72	17.57		
Total	7	274.51				

Factorial Fit: trans R2 versus Tips, Feed, Speed, DOC

Estimated Effects and Coefficients for trans R2 (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		3.0496	0.6319	4.83	0.017
Tips	-0.9419	-0.4710	0.6319	-0.75	0.510
Feed	-0.1026	-0.0513	0.6319	-0.08	0.940
Speed	-0.3235	-0.1617	0.6319	-0.26	0.815
DOC	2.0395	1.0197	0.6319	1.61	0.205

S = 1.78741 PRESS = 68.1566
R-Sq = 51.86% R-Sq(pred) = 0.00% R-Sq(adj) = 0.00%

Analysis of Variance for trans R2 (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	10.324	10.324	2.581	0.81	0.594
Residual Error	3	9.585	9.585	3.195		
Total	7	19.908				

Next Steps:-

- **Final inspect, pack and despatch to customer** ✓
- **Slot and split each blade and measure flatness** ✓
- **Analyse results and optimise parameters** ✓
- **Set parameters and undertake confirmation run**

  ___ mm/min Feed optimised for new/old tips

  _____Speed = _____mm feed/tip
- **Slot and split – process to finished part – measure between each operation**
- **Undertake similar exercise on balance of fan blades and measure splitting and machining operations separately**

- **Depth of Cut (DOC) does not seem to be of significance on either data sets – actual measurements or transformed data**
- **Results may be skewed due to the fact that there are two processes, splitting and machining, being evaluated after processes**
- **Further information is ideally required to understand fully:-**

➢ **Collect data for each op. splitting and machining**

➢ **Additional experiment to include mid points for each factors**

➢ **Confirmation run to optimise material removal with tip life and surface finish**

Control

- **System to be developed so revised factors are controlled:-**

➢ **Process Outline to be updated**

➢ **_____to be updated (to include actual speeds/feeds etc)**

➢ **Work Order Traveller to include machining speeds/feeds**

➢ **SOP to be updated and operators formerly communicated to (TBT)**

➢ **Machine parameters to be displayed so checking is easier**

➢ **Criteria to be added to the 'area audit' which will bring the checks into day to day activities**