

Level 5 – Continuous Improvement with Industry 4.0

Improve 8 – DoE Recap



- Try to build Quality control into each step of the process
- Minimise defects
- Prevent adding value to products which are already non-conforming
- Balance workflow to avoid overloading bottleneck constraints
- Try to smooth customer demand
- Process by FIFO (first in first out)

- Reduce the size of batches
 - Operate 'finish job, move job'
 - Detect errors sooner, if possible immediately after that characteristic is changed
-
- Design process to handle the routine not the exceptions
 - Use specialists to handle exceptions
 - Problem solve root causes of the exceptions to minimise and fix

- Automate handling and reduce movement (TIM WOODS)
 - Optimise manual systems first
 - Eliminate the 'hidden factory'
-
- Hidden Factory
 - Unofficial re-working of parts
 - Not recorded does not appear on process planning systems
 - Uses more resources than planned
 - Takes more time than expected

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

- Observational Approach
- Experimental Approach

- 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

- Experimental Approach

Planned experiments are conducted and results analysed

- Experimental Approach

This can be approached in two ways:-

- change one factor at a time, keep everything else constant and observe changes
- Multi-factor experiment in which several factors are changed simultaneously to a pre-set plan

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

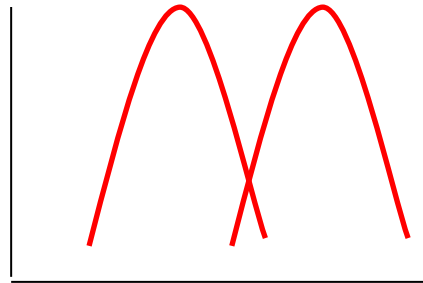
Should give maximum information with the minimum amount of effort and cost

Should be feasible within the process restraints which exist

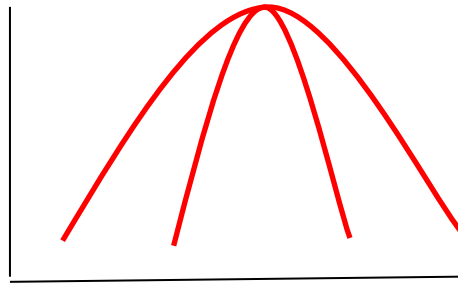
History

- 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

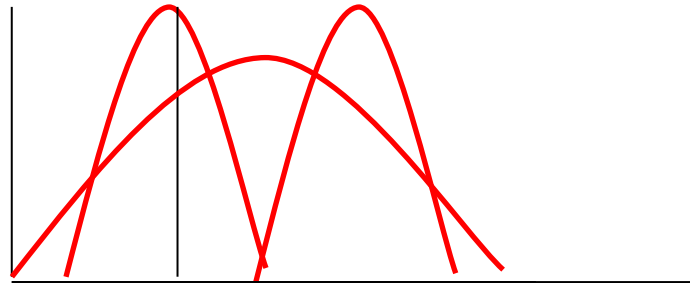
Factors can have location effects



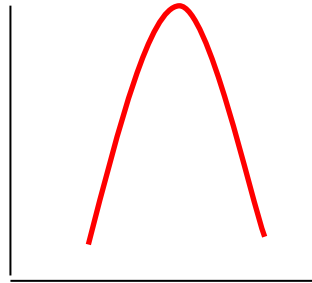
Factors can have dispersion effects



Factors can have combined effects



Factors could have no affect at all!!!



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

Full Factorial Designs

- Tests all possible combinations of factors and levels

Full Factorial Designs

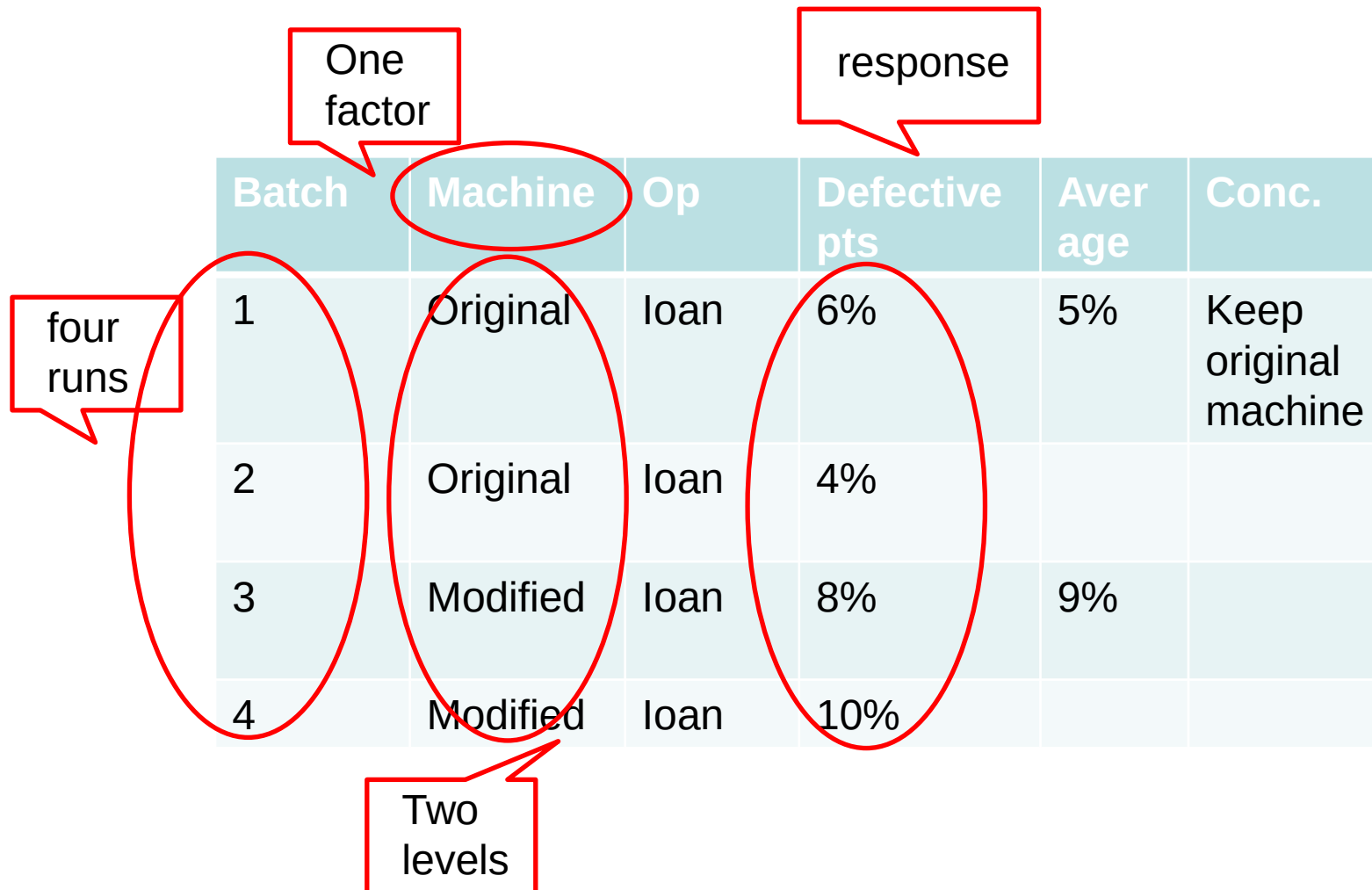
- 2 variables at 2 levels = 4 experiments required
- 3 variables at 2 levels = 8 experiments
- 7 variables at 2 levels = 128 experiments

Example

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

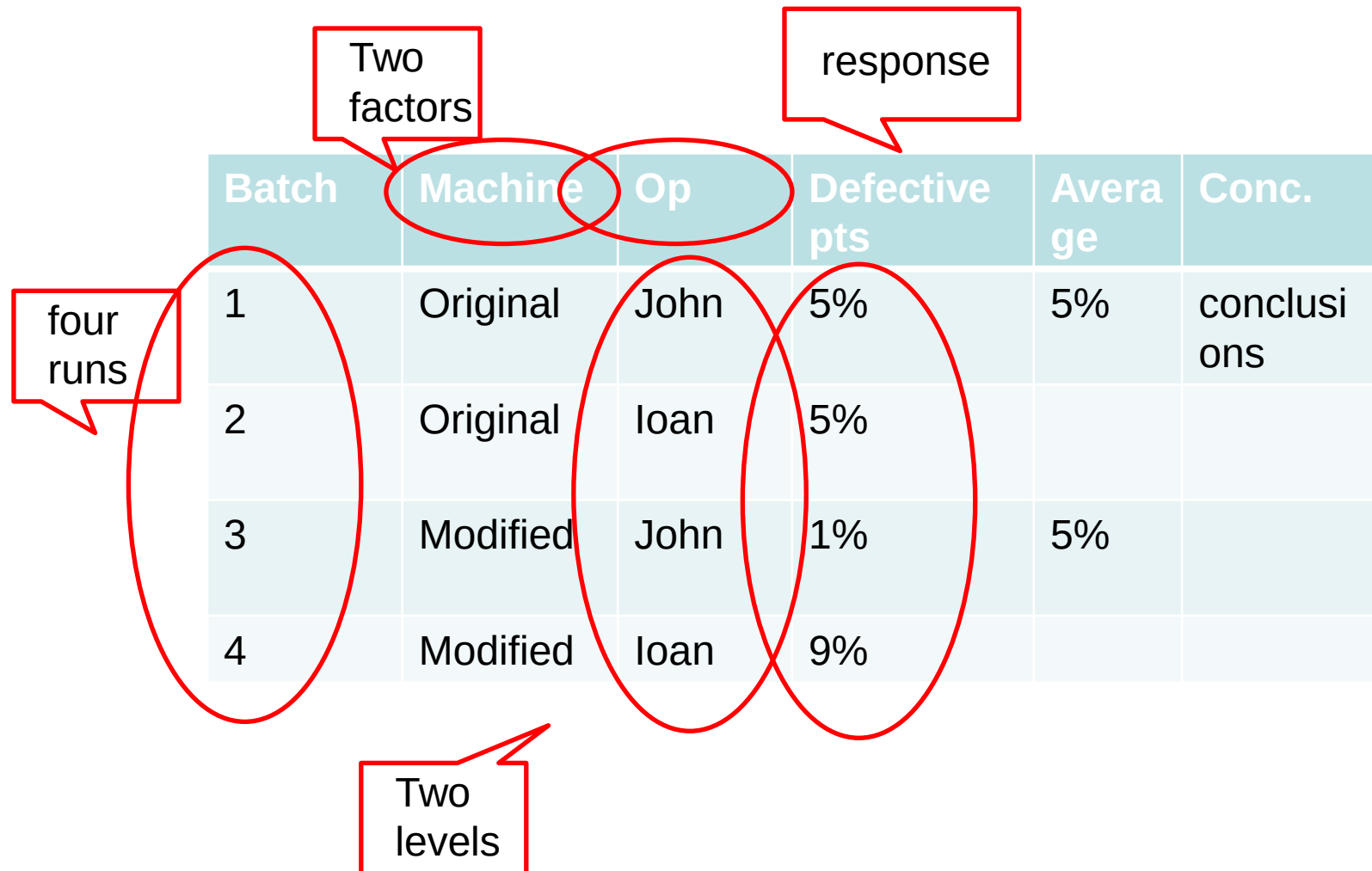
Question : is the modified machine performing better than the original machine?

One factor at a time – Everything else constant



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

Several factors at a time – Everything else constant



Two factors

response

four runs

Two levels

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

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

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 $\frac{1}{2}$ fraction, 2 for $\frac{1}{4}$ fraction, 3 for $\frac{1}{8}$ fraction etc..

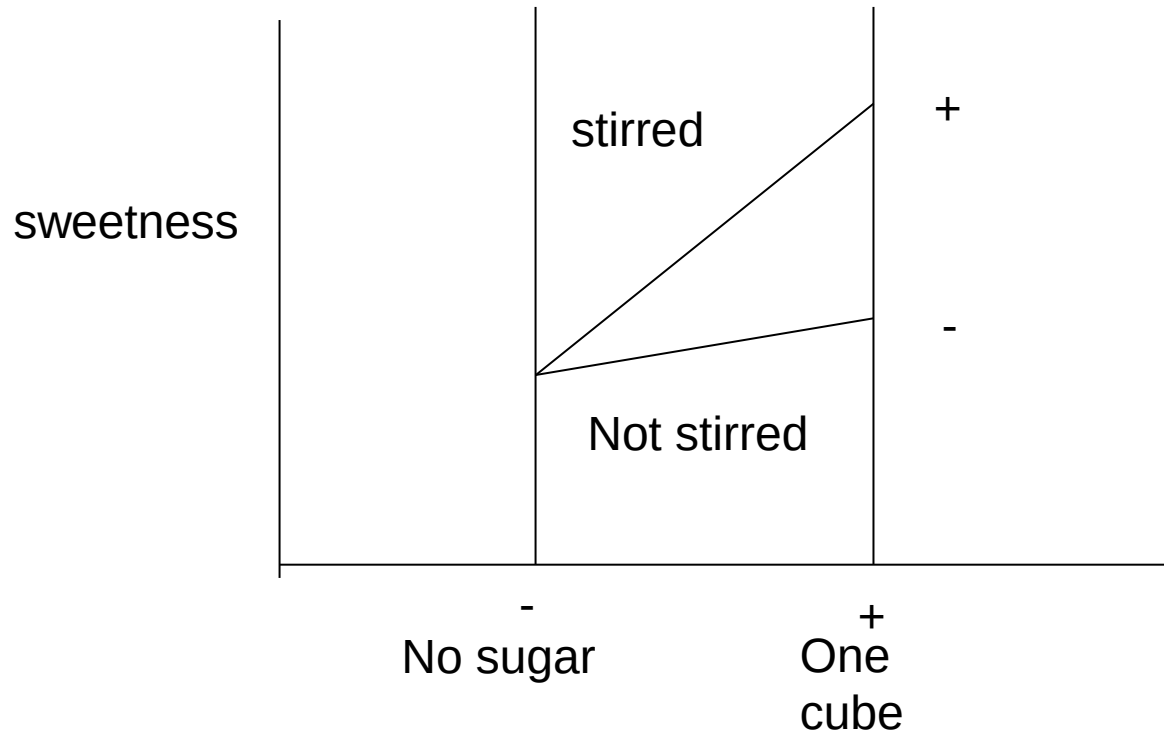
Fractional Factorial Designs

- 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

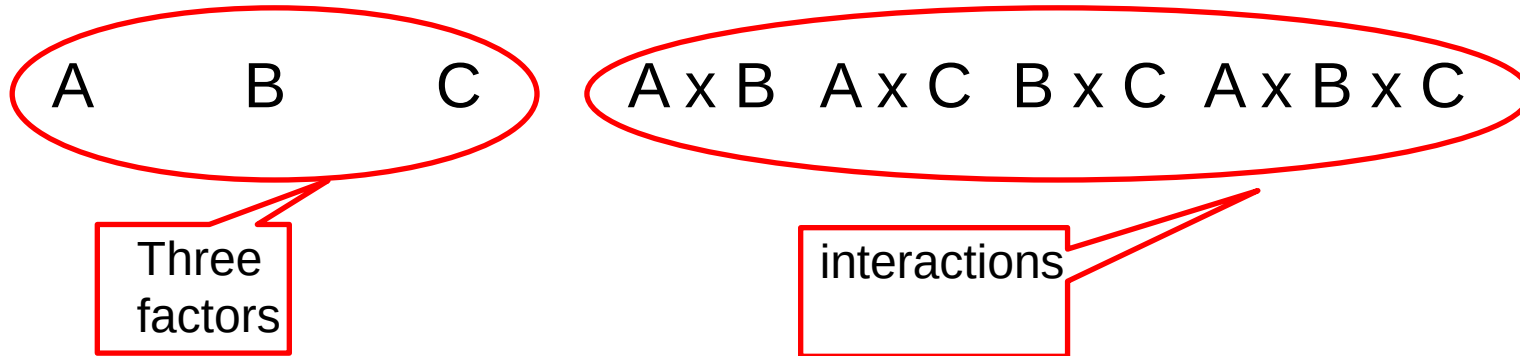
What is an interaction?

- 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)

What is an interaction?



What is an interaction?



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

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

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

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

Worked Example



Regression

Input

Input Y Range:

Input X Range:

☒ Labels ☐ Constant is Zero

☐ Confidence Level: %

Output options

☐ Output Range:

☒ New Worksheet Ply:

☐ New Workbook

Residuals

☐ Residuals ☐ Residual Plots

☐ Standardized Residuals ☐ Line Fit Plots

Normal Probability

☐ Normal Probability Plots

OK Cancel Help

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	0.21	-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

Worked Example

Regression

Input

Input Y Range:

Input X Range:

☒ Labels ☐ Constant is Zero

☐ Confidence Level: %

Output options

☐ Output Range:

☒ New Worksheet Ply:

☐ New Workbook

Residuals

☐ Residuals ☐ Residual Plots

☐ Standardized Residuals ☐ Line Fit Plots

Normal Probability

☐ Normal Probability Plots

OK Cancel Help



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

Worked Example



Regression

Input

Input Y Range:

Input X Range:

☒ Labels ☐ Constant is Zero

☐ Confidence Level: %

Output options

☐ Output Range:

☒ New Worksheet Ply:

☐ New Workbook

Residuals

☐ Residuals ☐ Residual Plots

☐ Standardized Residuals ☐ Line Fit Plots

Normal Probability

☐ Normal Probability Plots

OK

Cancel

Help

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

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



Worked Example



Regression

Input

Input Y Range: \$K\$1:\$K\$17 ↑

Input X Range: \$V\$1:\$X\$17 ↑

☒ Labels ☐ Constant is Zero

☐ Confidence Level: 95 %

Output options

☐ Output Range: ↑

☒ New Worksheet Ply:

☐ New Workbook

Residuals

☐ Residuals ☐ Residual Plots

☐ Standardized Residuals ☐ Line Fit Plots

Normal Probability

☐ Normal Probability Plots

OK Cancel Help

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

From straight line graph $y=mx+c$

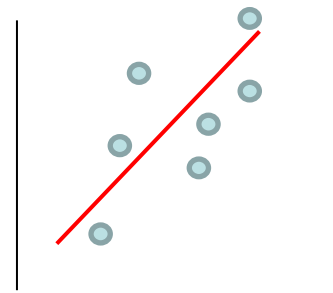
From straight line graph

$Y = \text{predicted value}$

$M = \text{slope}$

$X = \text{independent variable}$

$C = \text{intercept}$



Worked Example



$$= 330 + (-39.32 \times 7 \text{ Factor A}) + (-30.73 \times 8 \text{ Factor B}) + (4.12 \times 7 \text{ Factor A} \times 8 \text{ Factor B})$$

$$= 40.32$$

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								



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

Improve - Design of Experiments

Show me Targets

Catapult Settings

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

Hide Tips



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

Element	Description	Team Charter				
1. Process:	Pr 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:	Pr 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:	O 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

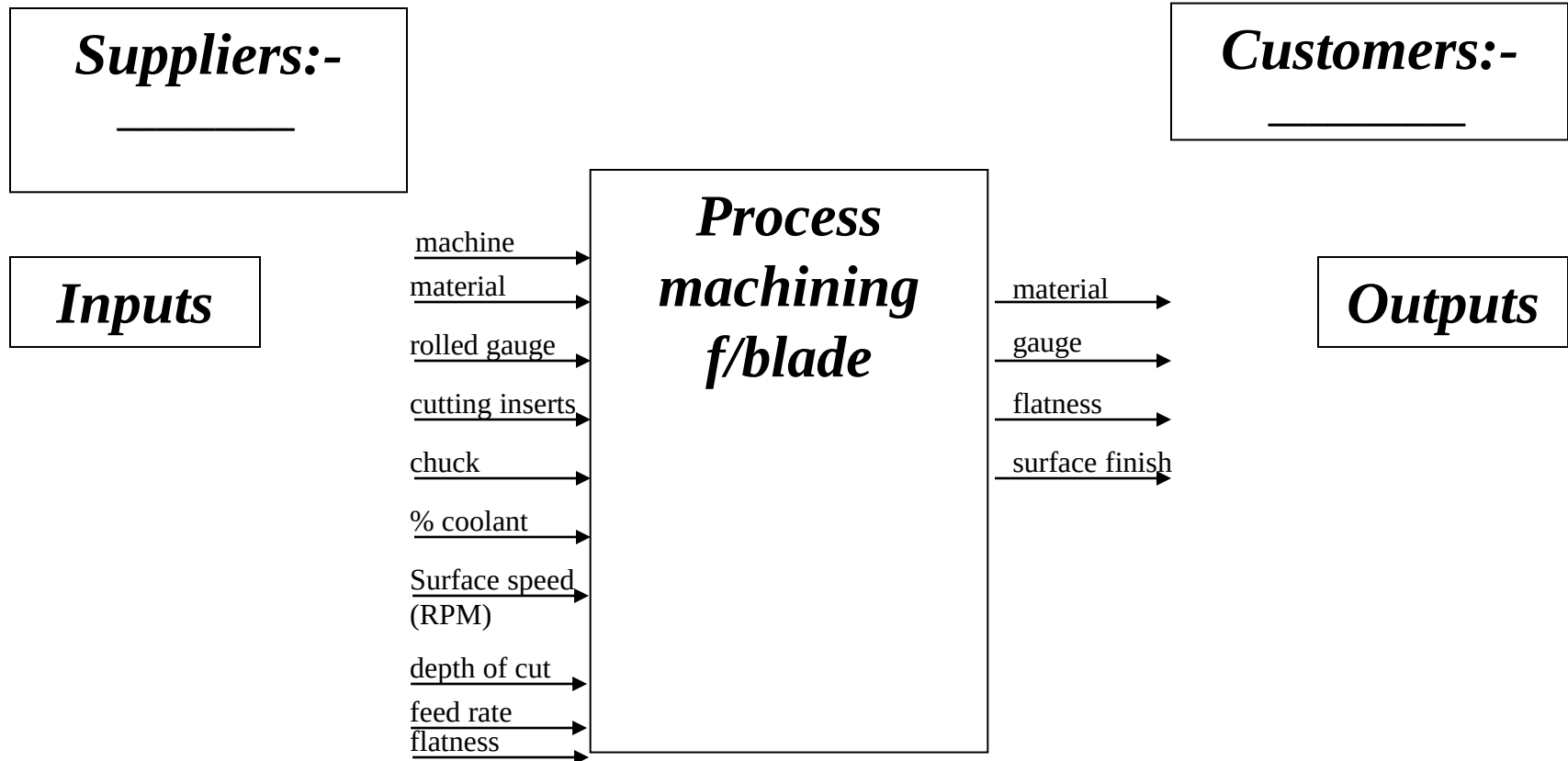
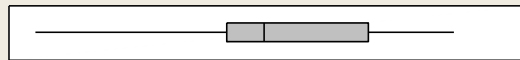
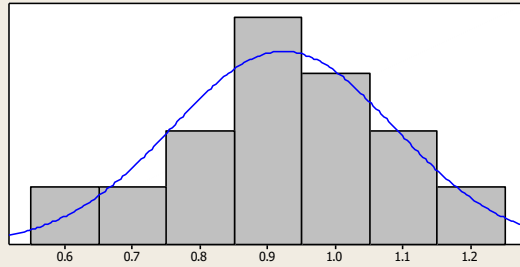


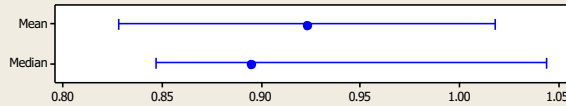
PLATE	FLATNESS PRE M/C	FLATNESS POST M/C
A3D	1.1155	0.5652
A4B	1.0624	0.8599
A3A	1.1755	0.8976
A3C	1.0132	0.758
A4A	0.849	0.6467
A2B	1.033	0.2695
A1D	0.9117	0.3916
A1B	0.8753	0.4134
A3B	0.5567	0.7952
A2C	0.859	0.7914
A2A	0.8773	0.6749
A1C	0.7348	0.6395
A1A	0.8095	0.8219
A2D	1.0431	0.9839

Single Pass Machining – Analysis of Std _____ Fan Blade – normal data

Summary for FLATNESS PRE M/C



95% Confidence Intervals



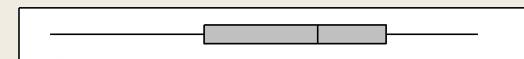
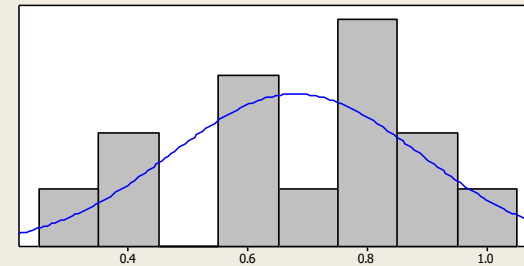
Anderson-Darling Normality Test
A-Squared 0.28
P-Value 0.595

Mean 0.92257
StDev 0.16442
Variance 0.02703
Skewness -0.564506
Kurtosis 0.457118
N 14

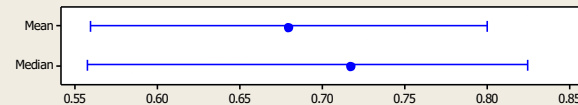
Minimum 0.55670
1st Quartile 0.83912
Median 0.89450
3rd Quartile 1.04793
Maximum 1.17550

95% Confidence Interval for Mean
0.82764 1.01750
95% Confidence Interval for Median
0.84697 1.04409
95% Confidence Interval for StDev
0.11920 0.26489

Summary for FLATNESS POST M/C



95% Confidence Intervals



Anderson-Darling Normality Test
A-Squared 0.33
P-Value 0.467

Mean 0.67919
StDev 0.20804
Variance 0.04328
Skewness -0.617193
Kurtosis -0.383147
N 14

Minimum 0.26950
1st Quartile 0.52725
Median 0.71645
3rd Quartile 0.83140
Maximum 0.98390

95% Confidence Interval for Mean
0.55907 0.79931
95% Confidence Interval for Median
0.55739 0.82386
95% Confidence Interval for StDev
0.15082 0.33517

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 = μ (FLATNESS PRE M/C) - μ (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

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:-

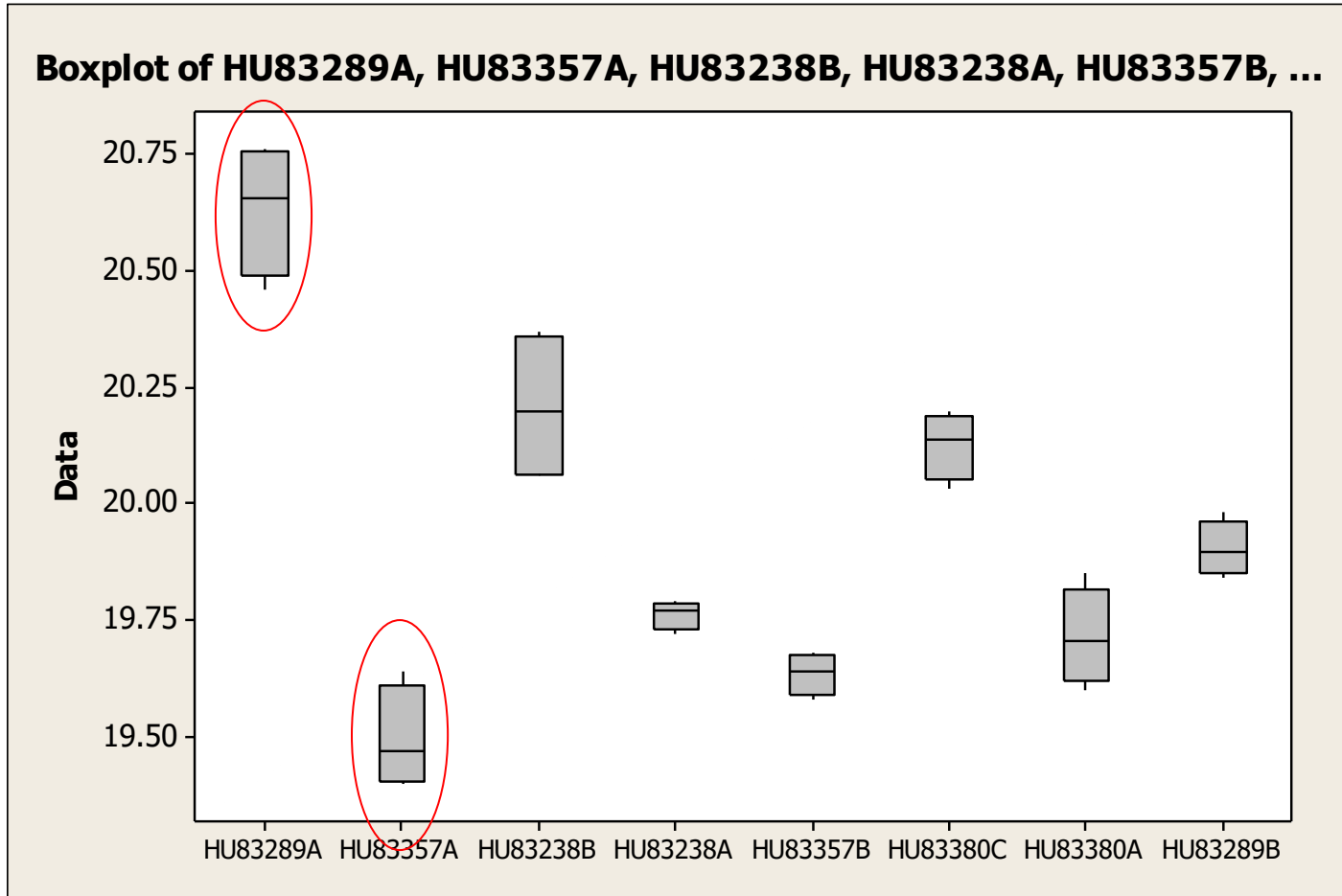
- **Depth of Cut – top end of rolling tolerance / bottom end of rolling tolerance**
- **Insert wear on cutting tool – new inserts / used inserts (after __ passes – changed after __)**
- **RPM – __ / __ (__ rpm current roughing – __rpm current finishing)**
- **Feed/insert – __mm/min and __mm/min (currently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



**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.

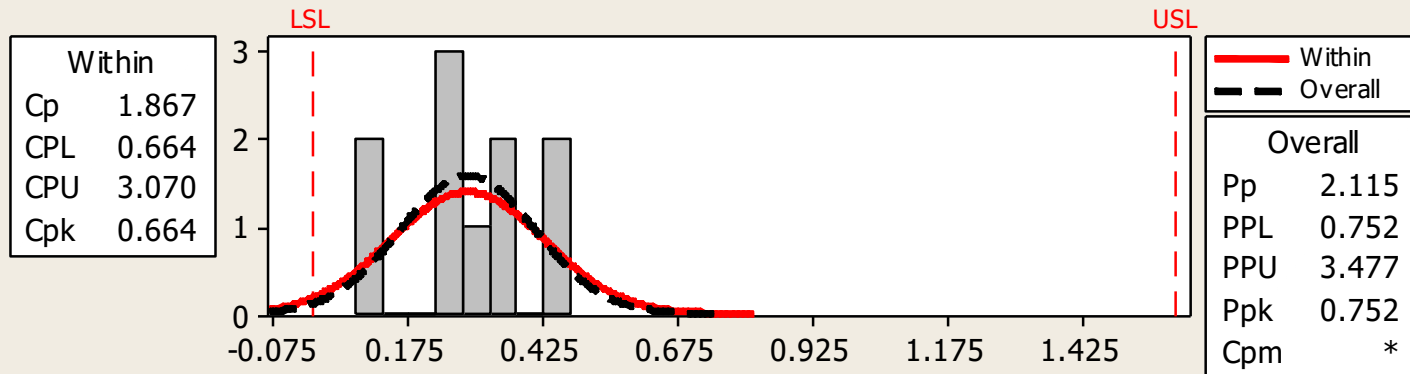
Gauge = 2 batches from sample which is at each end of rolling gauge tolerance.

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

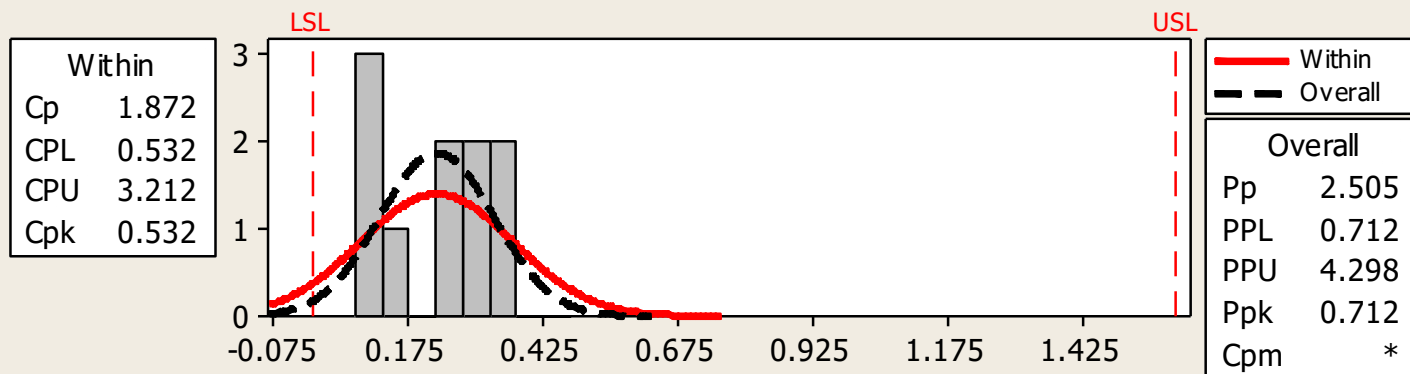
Coolant concentration to be controlled at 5% - nominal between 4% and 6%. Checked throughout trial.

Capability Histograms of Flatness Pre, Flatness after m/c

Flatness Pre



Flatness after m/c



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

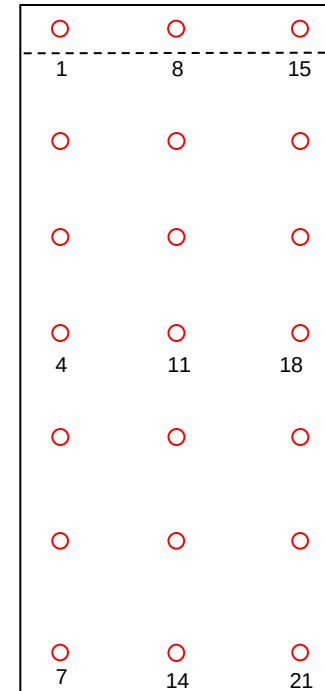
95% CI for mean difference: (0.0027, 0.1115)

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	

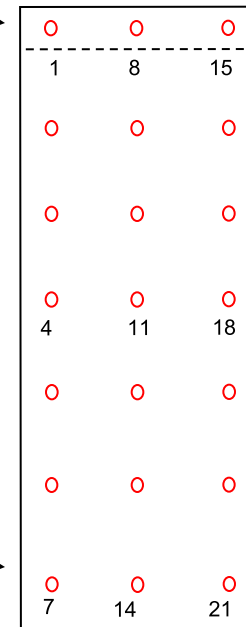
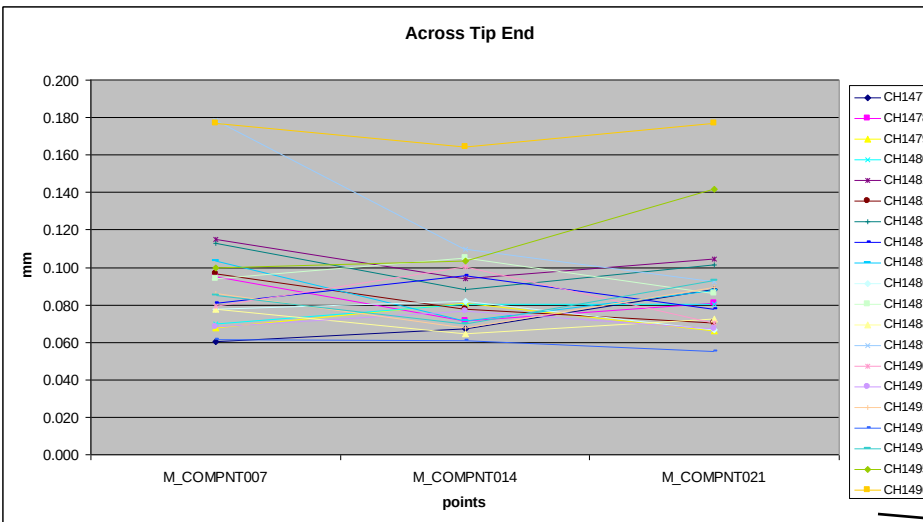
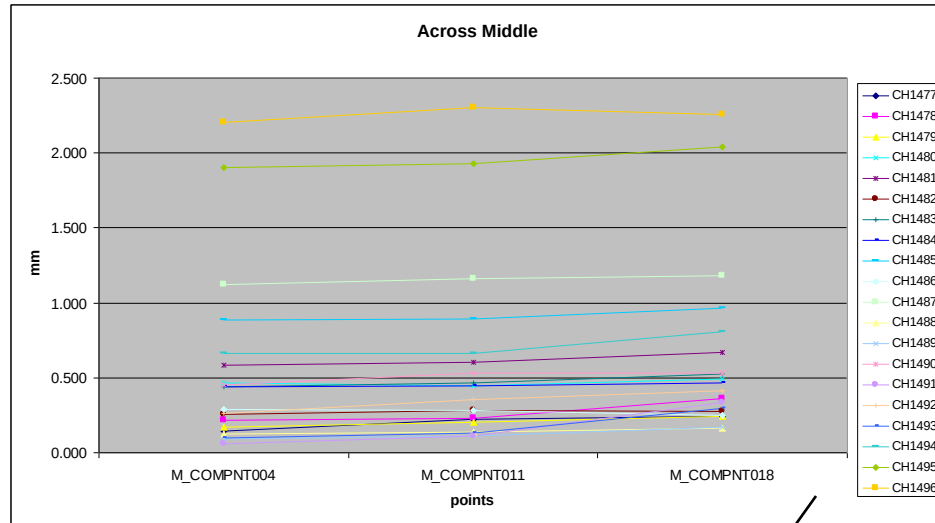
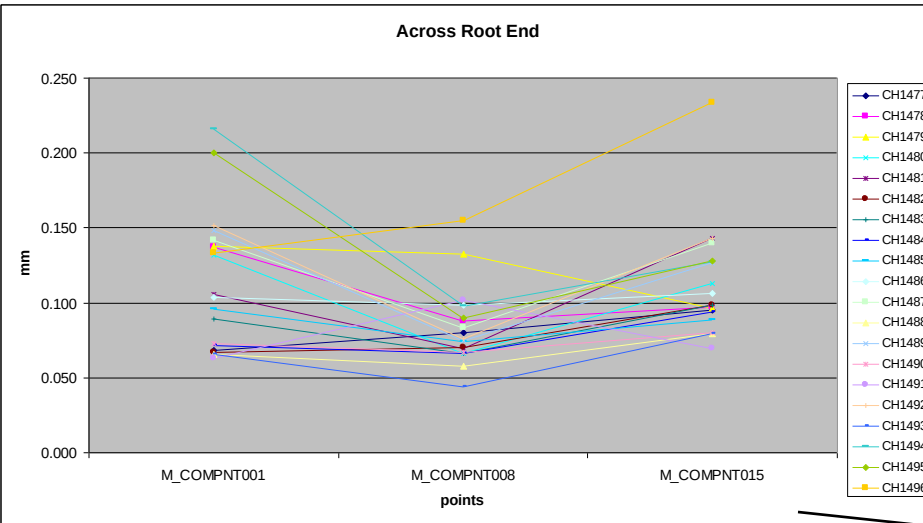


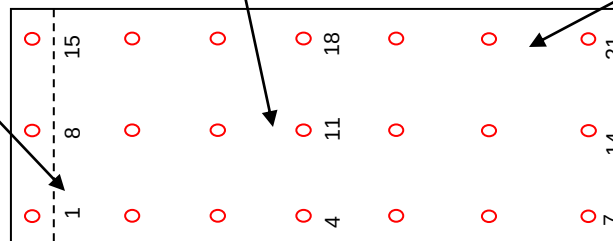
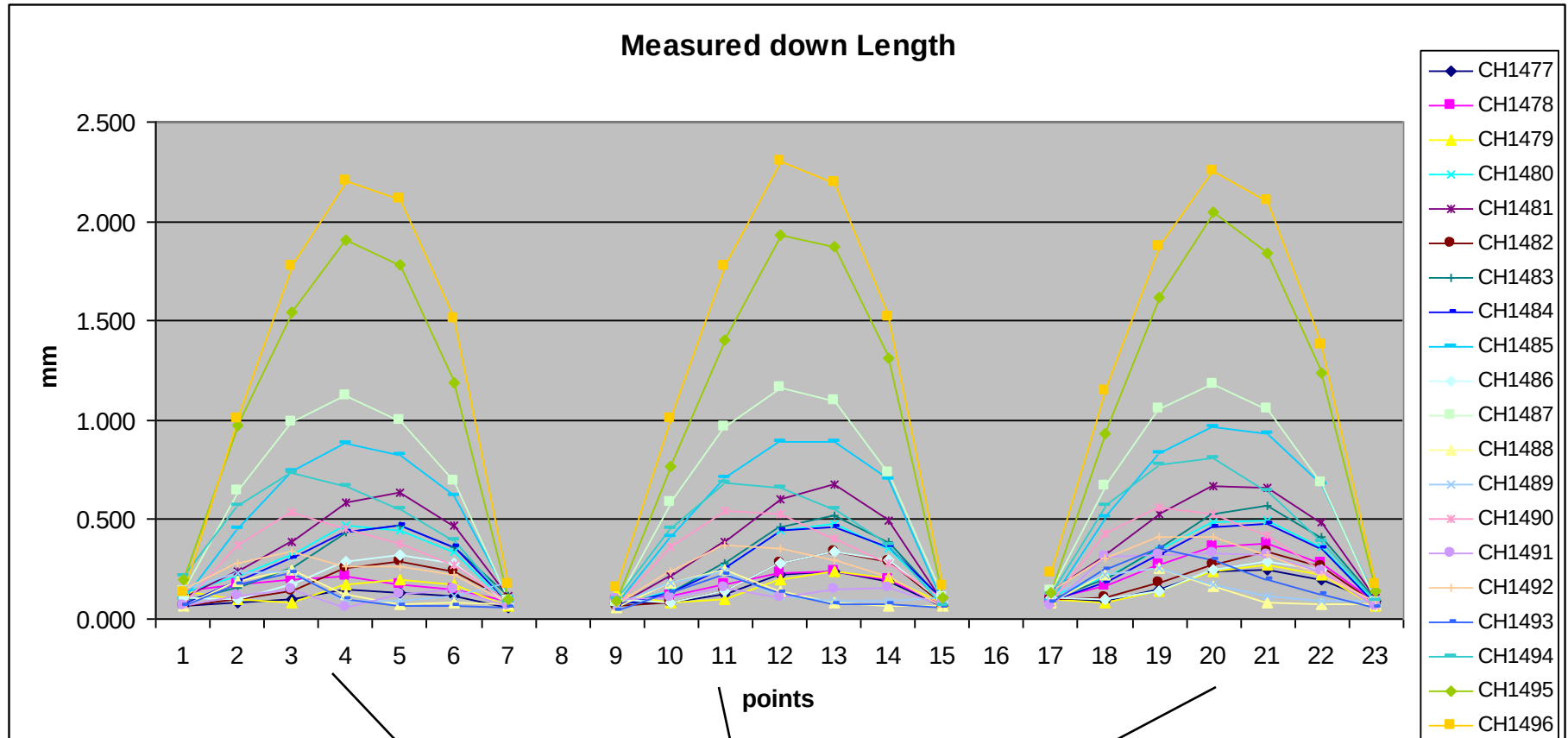
Single Pass Machining – Results after Slotting/Splitting and m/c



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	1 blade 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.																			

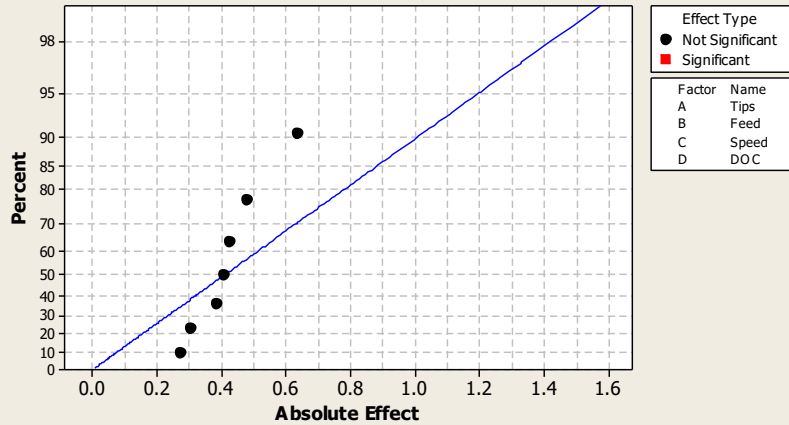
Single Pass Machining – Data Across Blade Widths





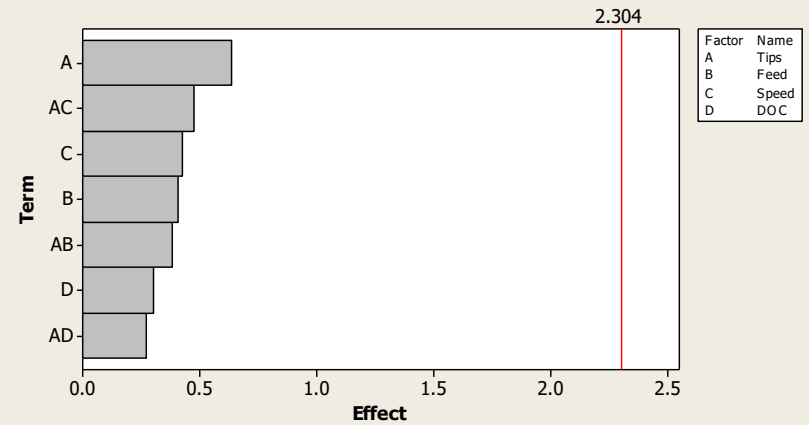
Single Pass Machining – Factors – little significance

Half Normal Plot of the Effects
(response is result, Alpha = 0.05)



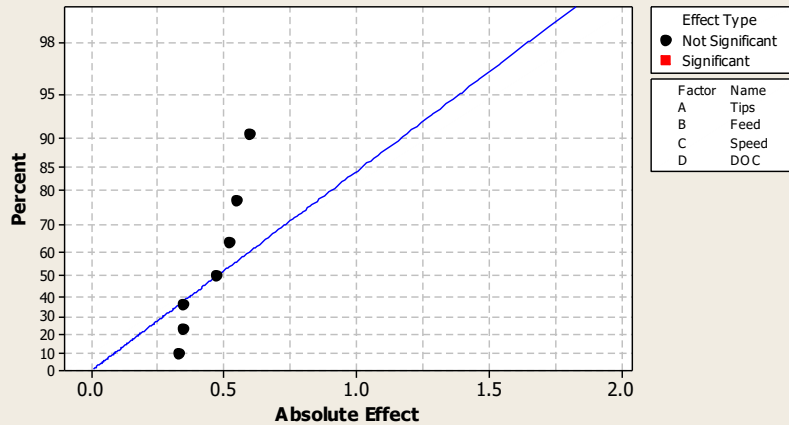
Lenth's PSE = 0.612

Pareto Chart of the Effects
(response is result, Alpha = 0.05)



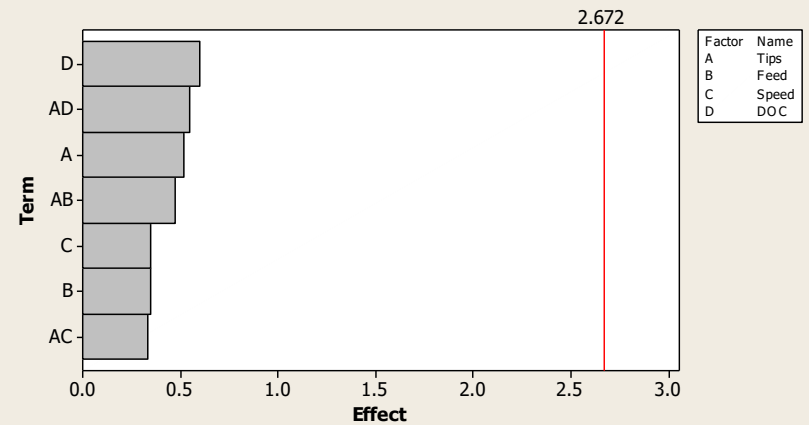
Lenth's PSE = 0.612

Half Normal Plot of the Effects
(response is result 2, Alpha = 0.05)



Lenth's PSE = 0.709875

Pareto Chart of the Effects
(response is result 2, Alpha = 0.05)



Lenth's PSE = 0.709875

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				

- **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**

Level 5 – Continuous Improvement with Industry 4.0

Improve 8 – Process Flow



- Try to build Quality control into each step of the process
- Minimise defects
- Prevent adding value to products which are already non-conforming
- Balance workflow to avoid overloading bottleneck constraints
- Try to smooth customer demand
- Process by FIFO (first in first out)

- Reduce the size of batches
 - Operate 'finish job, move job'
 - Detect errors sooner, if possible immediately after that characteristic is changed
-
- Design process to handle the routine not the exceptions
 - Use specialists to handle exceptions
 - Problem solve root causes of the exceptions to minimise and fix

We have previously learnt about the 'Voice of the Customer' (Kano model, House of Quality etc), now we need to understand how we relate this and adapt into our day to day activities to streamline manufacturing products and delivering more efficient services

Also, the VSM can identify the different elements of Value Added, Non-Value Added and the 8 wastes (TIM WOODS)

- Demand Smoothing - Heijunka
- Takt Time
- Work Place Layout – Standard Work Combination Tables
- Theory of Constraints

- Production smoothing - Heijunka

Process for levelling customer demand so waste is reduced:-

- Removes the peaks and troughs of customer demand
- Minimises waste
- More efficient to plan materials, manning machines etc.
- Reduce batch sizes to actual customer demand

- Production smoothing - Heijunka

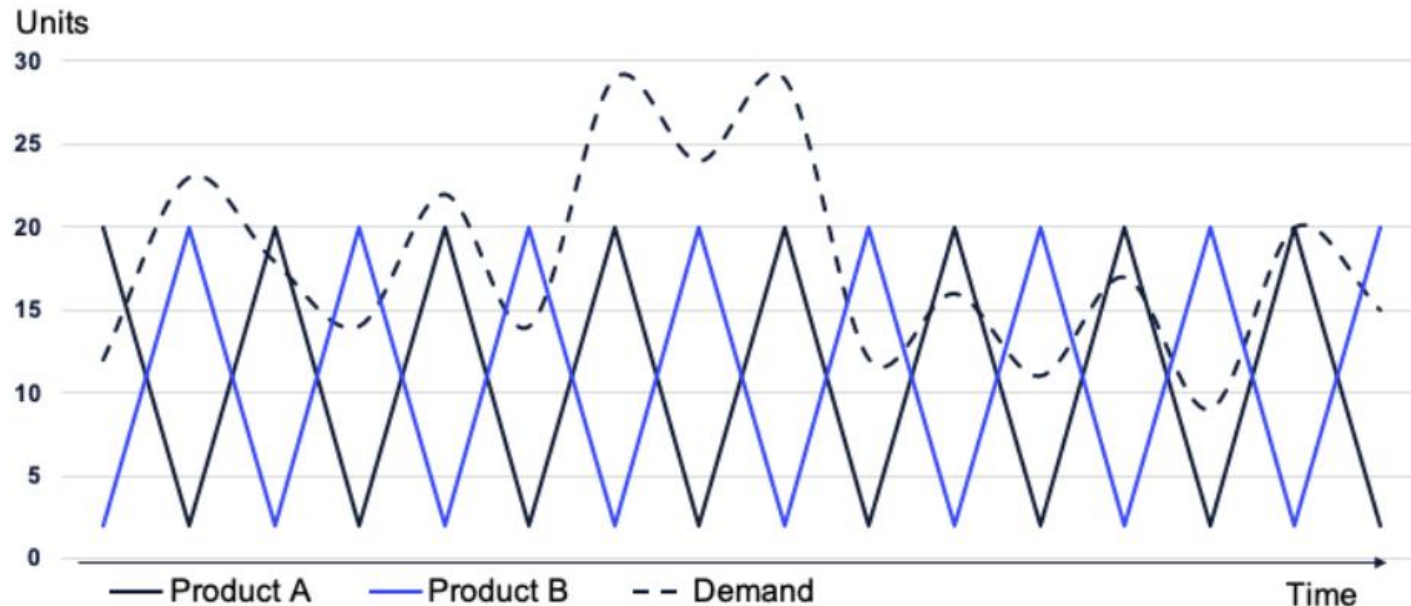


Figure 3: Shopfloor operations after applying production leveling

- Production smoothing - Heijunka
- Dialogue with customer to understand their specific needs
- Will need certain CI tools to help achieve this – SMED activity for faster changeovers, line balancing
- May not be able to achieve in certain scenarios i.e. jobbing shops

- Takt Time

Takt time is the drum beat of the flow of products. It is the metronome (from German origins of the word).

It is worked out by the available time (i.e. day – breaks, planned stoppages) divided by that days demand.

i.e

7.5 hr av./day (7.5 x 60) = 450 minutes / (600 units/day)

=

0.75 minute = 45s

- Takt Time = 45 seconds

If any of our individual processes are longer than 45 seconds within a production line we have a bottleneck within our process and cannot meet customer demands!

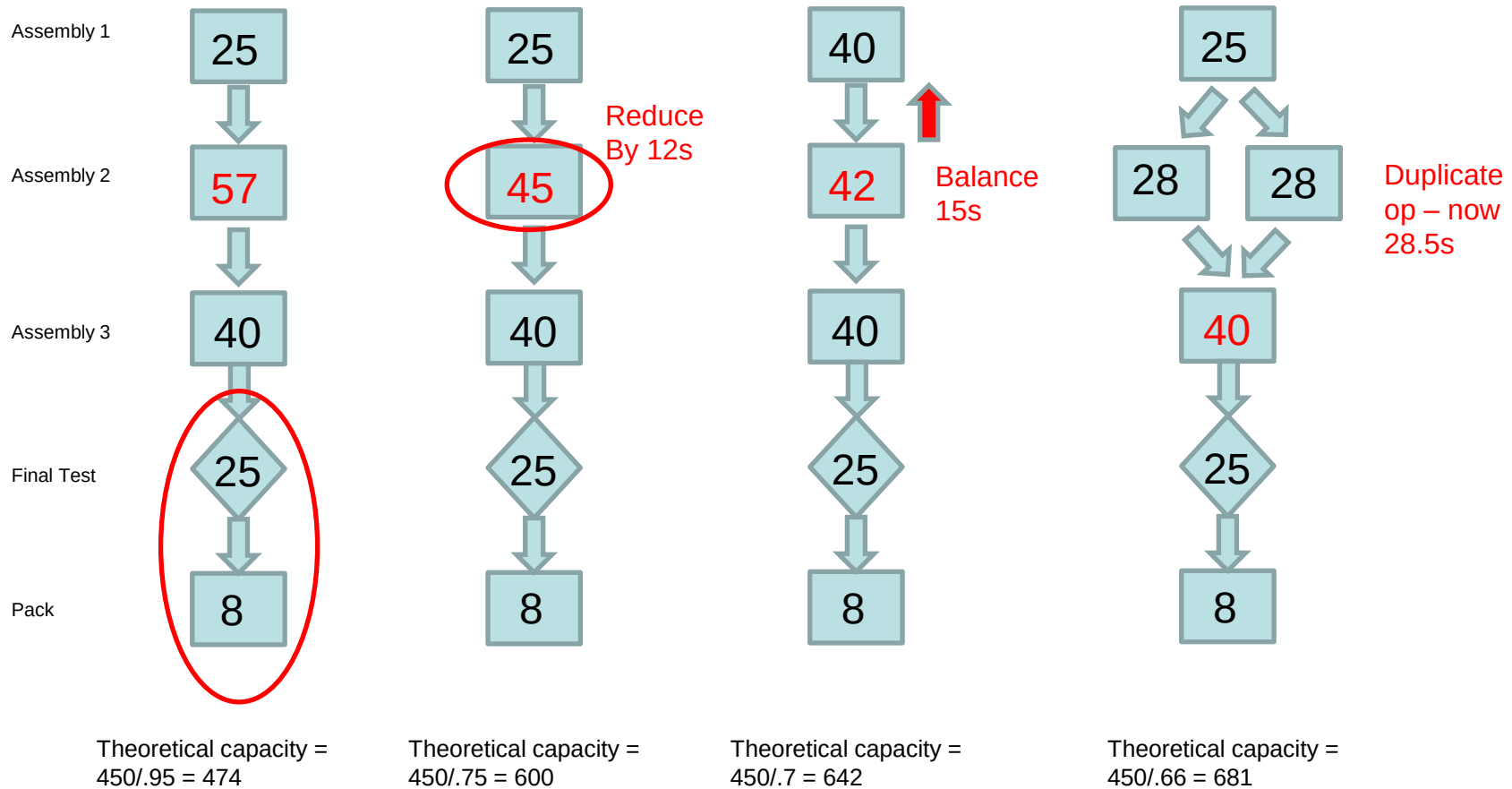
What can we do???



- Takt Time = 45 seconds
- Reduce our cycle time to equal or less than 45s
- Redistribute the work – balance the line
- Duplicate operation so we increase capacity
- Expand work time (overtime)
- Reduce demand

Improve - Process Flow

- Takt Time = 45 seconds



- Workplace Layout – traditional

Traditionally factories were laid out by process function:-

- Press shop
- Welding bay
- Assembly area
- Test area

- Workplace Layout - traditional

Some disadvantages of this type of layout:-

- Increased inventory
- Longer lead-time
- Quality issues not being identified until component being used
- Encouraged 'Silo' mentality within organisation.

- Workplace Layout – Cell

Most factories now laid out as cells:-

- One piece flow through process possible
- Optimum inventory levels
- Quality issues can be highlighted straight away and acted upon
- Job rotation of operators
- Can be manned according to demand

- Standard Work Combination Table/Sheet

Standard format for understanding the detailed work of a process, each element and their interactions:-

- Itemises each element of the work
- Shows if each element is a manual, automatic or walking operation – this can also be classed as VA/NVA or waste activity
- Shows time taken for each element and total cycle time
- Basis for on-going improvements

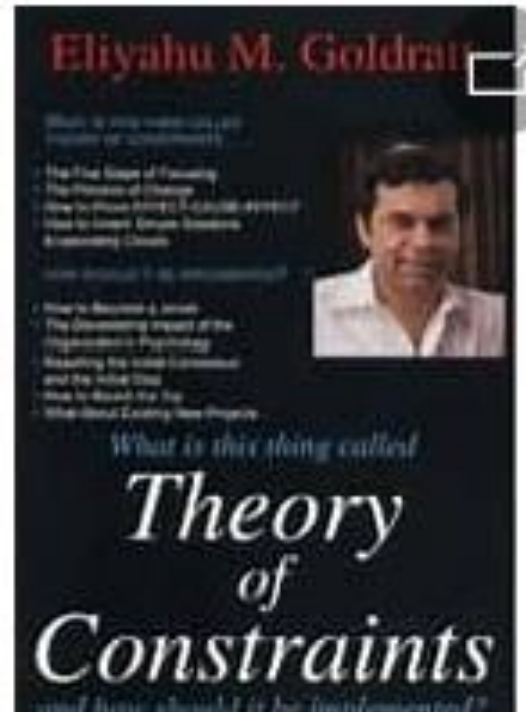
MADE

The Lean Toolbox 2016, John Bicheno/Matthias Holweg

Standardized Work 2: Standardized Work Combination Table

Standardized Work Combination Table		From:		Date:										Required Units per Shift:				Hand Walk Auto									
		To:		Area:										Takt Time:													
Work Elements		Time (sec.)			Seconds																						
		Hand	Auto	Walk	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100			
1																											
2																											
3																											
4																											
5																											
6																											
7																											
8																											
9																											
10																											
11																											
12																											
13																											
14																											
15																											
Totals			Waiting		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100			
					Seconds																						

- Theory of Constraints



- Theory of Constraints

‘The Goal’ written by Eli Goldratt in 1984

- Every process has a limiting factor ‘the constraint’ – bottleneck – which constrains that process to improve
- Focuses on the limiting factor until it is no longer the constraint

- Theory of Constraints

5 distinctive steps

- Identify the constraint
- Decide how to exploit the constraint
- Subordinate all other resources to the constraint
- Elevate the constraint
- When constraint has been broken go back to step 1

- Theory of Constraints

Identify the constraint

- Company KPI's may identify this
- Largest maintenance issues
- Low OEE measure – if being used
- Often identified by large amount of inventory in front of constraint
- Down stream processes starved of material/inventory

- Theory of Constraints

Decide how to exploit the constraint

- Don't rework defects on it
- Ensure maintenance focus and attention
- Ensure products being manufactured meet quality requirements
- Make sure products being manufactured are actually required by customer

- Theory of Constraints

Subordinate all other resources to the constraint

- Encourage flow to the constraint
- Regular material and uninterrupted
- Make everyone aware of the constraints importance
- Minimise batch sizes

- Theory of Constraints

Elevate the constraint

- Break constraint by undertaking the previous two steps
- Additional machine
- Additional overtime
- When constraint is broken it will move

- Theory of Constraints

Back to identify constraint

- Note constraint will move around the process
- A constraint is precious – spend time understanding it
- Acts as a break within the process

Further reading ‘The Lean Toolbox’ p228