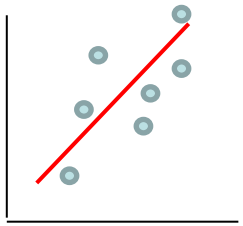
Level 5 – Continuous Improvement with Industry 4.0

Improve 1 – ANOVA
Correlation recap
Process Redesign
Principles,

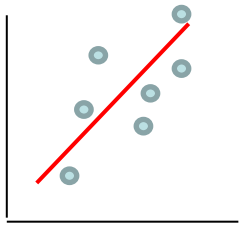
Correlation is used to see if there is a relationship between different sets (x, y) of data

- Machining speed and surface finish
- Hours revised and exam results
- Car milage and second-hand value

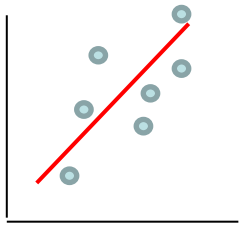


These may be classed in three ways:-

- Positive correlation where one value rises, so does the other
- Negative correlation where one value rises, the other descreases
- No correlation between either

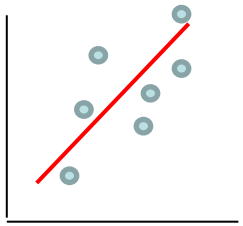


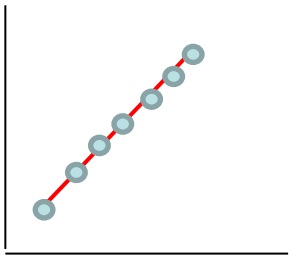
The relationship is expressed as 'r' and is known as the 'Pearson correlation coefficient'



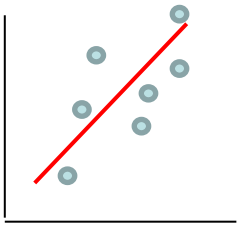
Analyse – Correlation and Regression

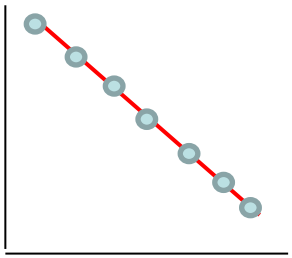
$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$



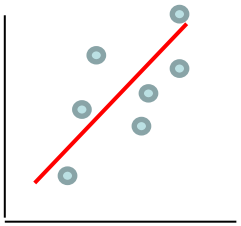


Perfect positive correlation r = 1

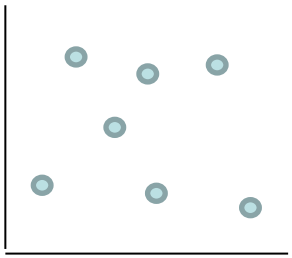




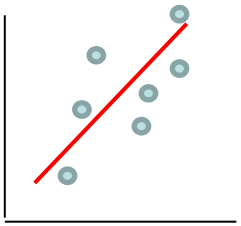
Perfect negative correlation r = -1



Analyse – Correlation and Regression



No correlation r = 0



Analyse – Correlation and Regression

Here is some data I have collected about my car (the one I use on my journey to work!)

value	milage	servicing
32000	5000	300
29000	10000	400
27000	15000	450
26500	20000	610
26000	25000	400
25000	30000	700
24000	35000	700
22000	40000	610
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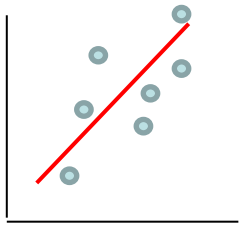

Analyse – Correlation and Regression

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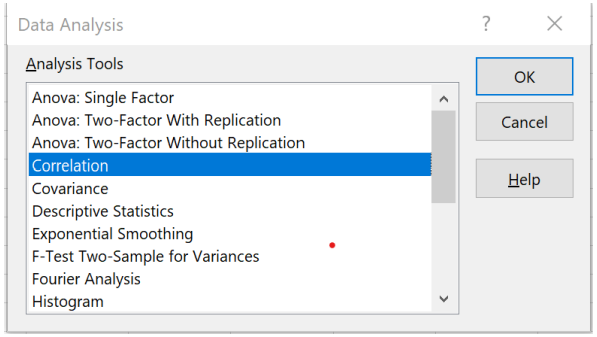

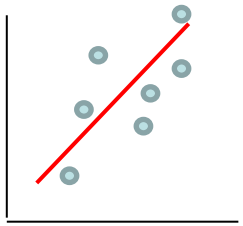

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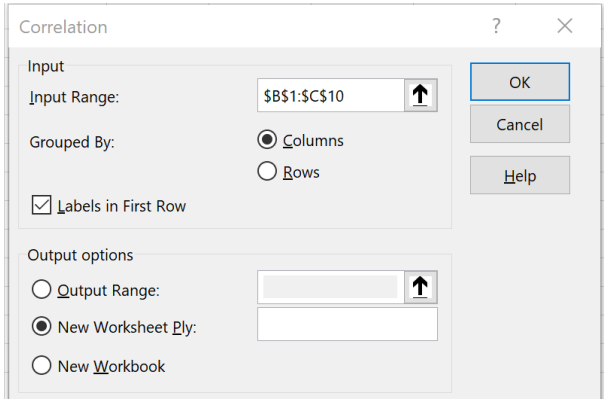
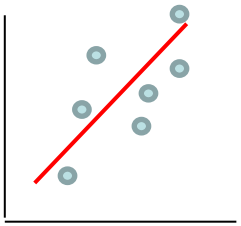
Paint in first two columns





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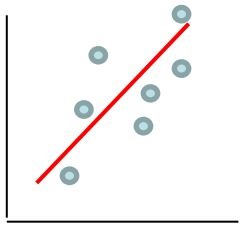
	value	milage
value	1	
milage	-0.96957	1

There is a strong (negative) correlation between value and milage



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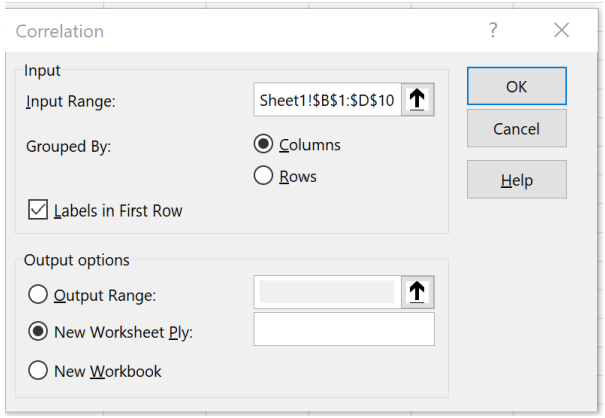
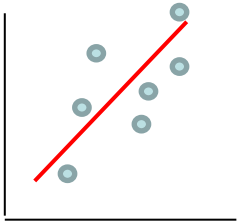
Paint in all columns





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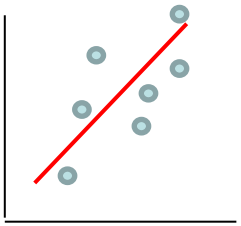
	value	milage	servicing
value	1		
milage	-0.96957	1	
servicing	-0.83992	0.8516	1

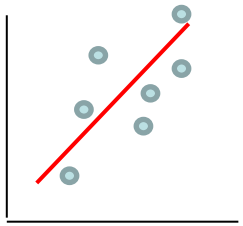
There is a strong (negative) correlation between value and servicing. Strong (positive) correlation between milage and servicing



Analyse – Correlation and Regression

Machine shop collected data to see if there was any correlation between size and finish (outputs and other parameters

size off machine	surface finish	chuck speed	temperature	motor amps
10.94	2	448	18	18
10.82	1	447	21	18
10.78	1	446	21	17
10.62	1	441	20	17
10.58	1	440	20	17
10.58	1	435	21	17
10.57	1	434	22	17
10.56	1	432	21	16
10.54	2	428	20	16
10.52	2	428	22	16
10.52	2	426	22	16
10.48	3	423	21	16
10.47	3	421	22	16
10.45	3	417	20	15
10.42	3	416	21	15
10.41	4	415	22	15
10.40	4	415	22	15
10.39	5	408	21	15
10.39	5	405	21	15
10.38	5	401	18	15



Analyse – Correlation and Regression

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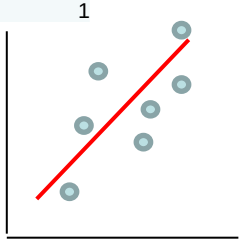
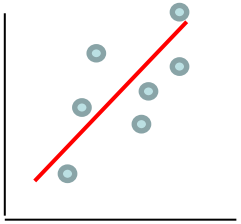
	size off machine	surface finish	chuck speed	temperature	motor amps
size off machine	1				
surface finish	-0.701728373	1			
chuck speed	0.908005172	-0.911895623	1		
temperature	-0.314750053	-0.059889904	-0.089815367	1	
motor amps	0.918230007	-0.807241187	0.937190844	-0.198216948	1



Analyse – Correlation and Regression

Linear Regression is used with correlation to see if we can predict future performance

It defines the relationship between x and y more accurately than correlation alone



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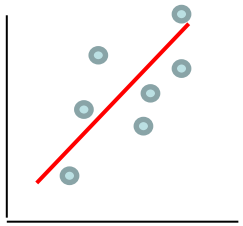

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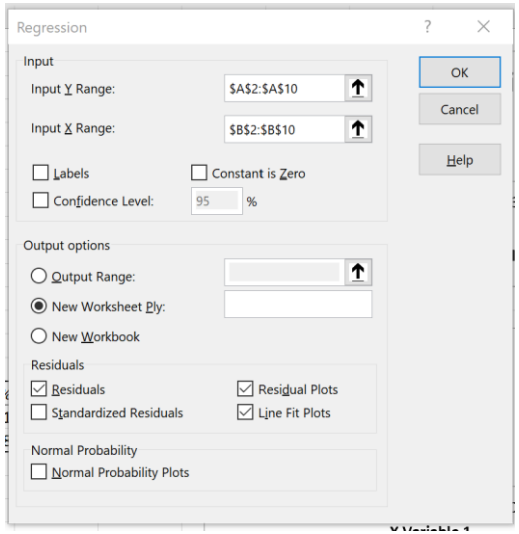

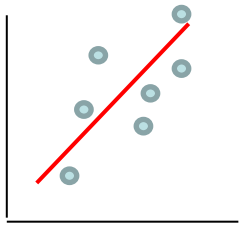

Analyse – Correlation and Regression

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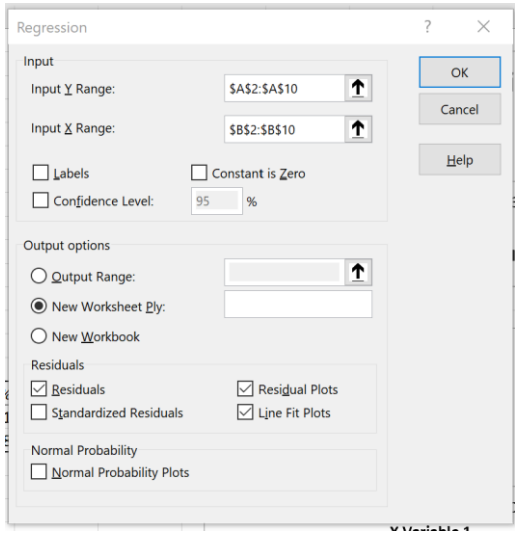
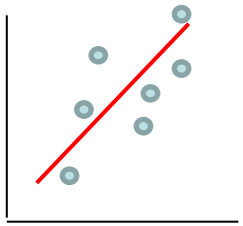




Analyse – Correlation and Regression

SUMMARY OUTPUT

This is the correlation same as found earlier

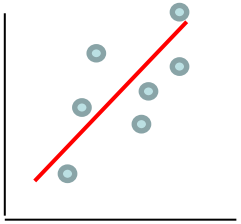
This is the correlation squared

Regression Statistics	
Multiple R	0.969575
R Square	0.940075
Adjusted R Square	0.931514
Standard Error	991.7317
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	1	1.08E+08	1.08E+08	109.8126	1.57E-05
Residual	7	6884722	983531.7		
Total	8	1.15E+08			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	32319.44	720.4764	44.85844	7.15E-10	30615.79	34023.1	30615.79	34023.10034
X Variable 1	-0.26833	0.0256006	-10.4792	1.57E-05	-0.32888	-0.20778	-0.32888	-0.207783814



From straight line graph *y=mx+c*

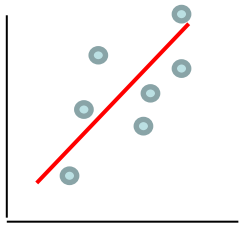
From straight line graph

Y = predicted value

M = slope

X = independent variable

C = intercept



Whats my car value at 100,000 miles?

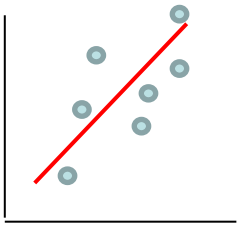
$$y = mx+c$$

$$value = 100{,}000*-0.2683+32319$$

$$value = £5{,}489$$

$$value = 45{,}000*-0.2683+32319$$

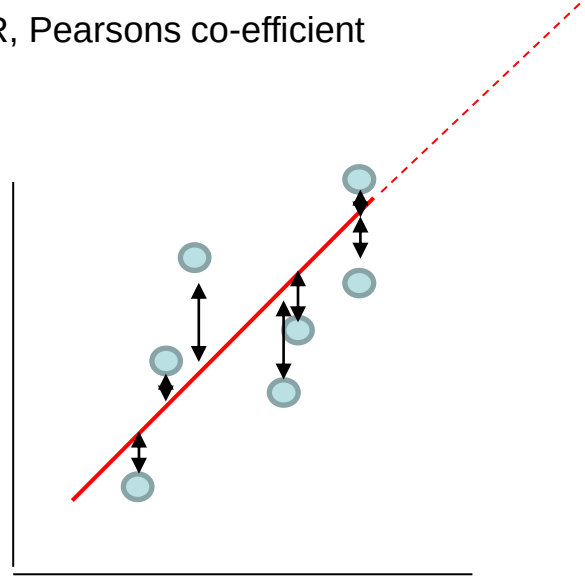
value = £20,245



Scatter plots

R, Pearsons co-efficient

Y=mx+c

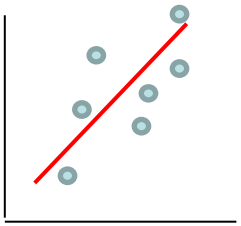


residuals

Analyse – Correlation and Regression

Residuals - how much do results vary from the predicted values

RESIDUAL OUTPUT		
Observation	Predicted Y	Residuals
1	30977.78	1022.222
2	29636.11	-636.111
3	28294.44	-1294.44
4	26952.78	-452.778
5	25611.11	388.8889
6	24269.44	730.5556
7	22927.78	1072.222
8	21586.11	413.8889
9	20244.44	-1244.44



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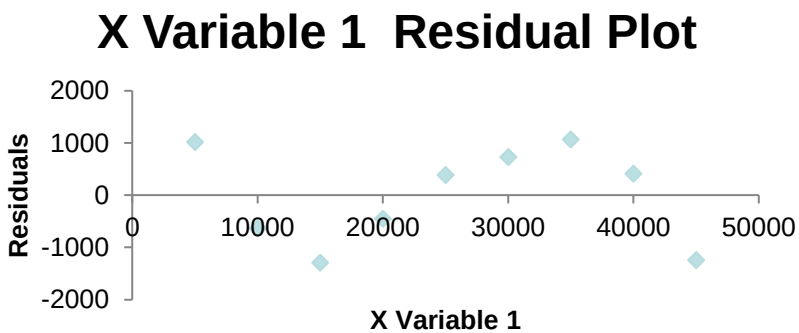
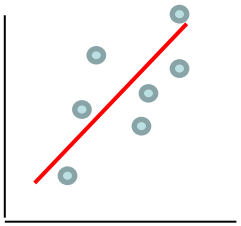


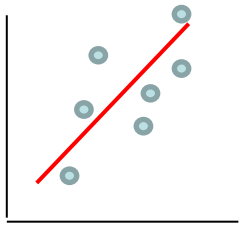
We want the residuals to be evenly spaced around zero, some positive, some negative



Analyse – Correlation and Regression

I have been collecting some data on my farm!

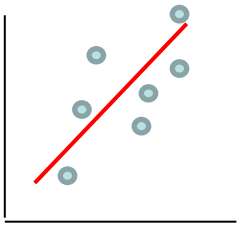
field size (Ha)	pH value	N applied Kg/Ha)	Diesel (L/Ha)	Barley Yield (t)	water content (%)	Distance from Shed (m)	cost of harvesting (Ha)
4.2	5.3	1025	13.02	14.03	14.2	285	£92.50
3.7	5.3	875	11.53	13.07	13.9	470	£83.00
5.6	5.7	1367	18.05	23.04	14.3	560	£125.00
5.2	6.1	1282	15.46	24.5	12.7	325	£115.00
3.8	5.9	1100	10.07	16.89	13.5	678	£88.00
4.7	5.8	1203	16.02	22.07	14.1	528	£103.00
6.2	5.6	1485	18.51	24.5	17.5	457	£130.00
3.4	5.5	970	9.07	13.25	16.2	365	£75.00
5.6	5.9	1501	17.53	25.97	16.8	210	£125.00
7.2	5.8	1846	26.07	31.8	16.5	25	£160.00



Analyse – Correlation and Regression

Here are the results:-

	field size (Ha)	pH value	N applied Kg/Ha)	Diesel (L/Ha)	Barley Yield (t)	water content (%)	Distance from Shed (m)	cost of harvesting (Ha)
field size (Ha)	1							
pH value	0.407844974	1						
N applied Kg/Ha)	0.968382691	0.516683173	1					
Diesel (L/Ha)	0.972421431	0.33510267	0.940619794	1				
Barley Yield (t)	0.945441392	0.659042576	0.964319103	0.920129478	1			
water content (%)	0.486194283	-0.137580716	0.534526785	0.432697789	0.373504003	1		
Distance from Shed (m)	-0.531712427	-0.041624799	-0.554110119	-0.584015357	-0.484899409	-0.454969135	1	
cost of harvesting (Ha)	0.994859797	0.444188691	0.97639778	0.976507576	0.955440095	0.44549946	-0.540498829	1



Analyse – the tools

- Normality Testing – Mean, Median, Mode
- Process Capability Cp and Cpk
- Two Sample T Testing
- ANOVA
- Correlation
- Regression

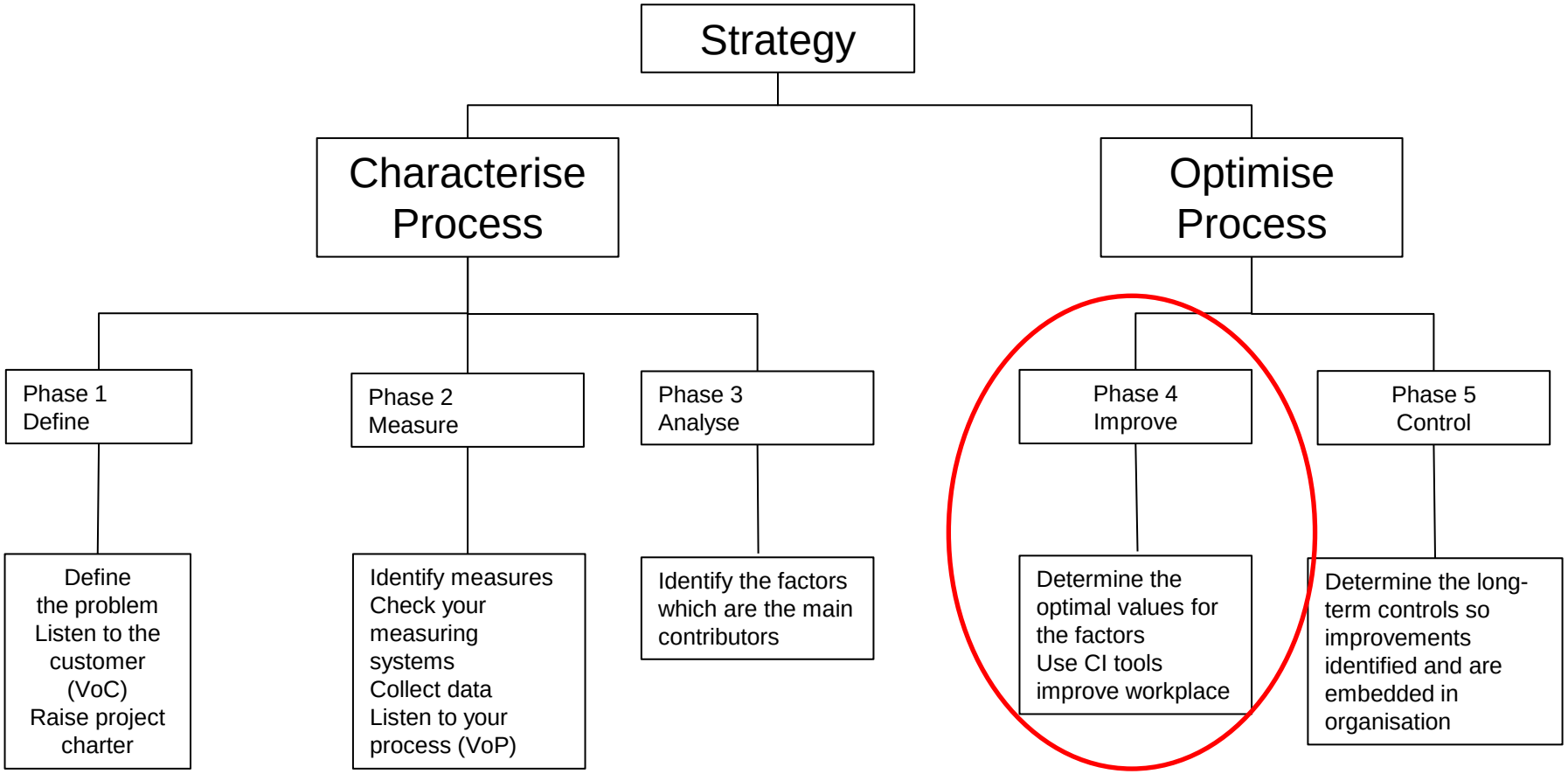
Analyse – the tools

- No data or experience – all we can offer is an opinion
- No data – we use our experience to get through
- Some data - data collected we just look at the numbers
- Grouped data - basic charts and diagrams
- Descriptive statistics - mean, median, mode, Std Dev etc
- Characterising statistics - Cp, Cpk,
- Control statistics - SPC charts (Mr Shewhart!)
- Inferential statistics - normality, correlation, regression, etc

Level 5 – Continuous Improvement with Industry 4.0

Improve 1 – Process Redesign Principles

The Road Map


Strategy
Characterise Process
Optimise Process
Phase 1 Define
Phase 2 Measure
Phase 3 Analyse
Phase 4 Improve
Phase 5 Control
Define the problem Listen to the customer (VoC) Raise project charter
Identify measures Check your measuring systems Collect data Listen to your process (VoP)
Identify the factors which are the main contributors
Determine the optimal values for the factors Use CI tools improve workplace
Determine the long-term controls so improvements identified and are embedded in organisation

Improve - Process Redesign Principles

- Minimise approvals
- Try to build in controls
- Reduce repetitive decisions by defining policy to all stakeholders
- Police these policies through audit processes

- Minimise responsibility movement
- Reduce the work-flow across departmental boundaries if possible
- Minimise number of personnel required
- Let customer facing employees be empowered to make decisions

Improve - Process Redesign Principles

- 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)

Improve - Process Redesign Principles

- 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

Improve - Process Redesign Principles

- 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

Improve - Process Redesign Principles

- Use problem solving techniques, 5 why, Is/Is Not, 8D, fishbone diagrams

- Brain storm solutions

Improve – Some Tools

- 5 ‘S’
- TPM
- SMED
- Design of Experiments
- FMEA
- Control Plans