Shainin Design of Experiments (DOE)

Training Kit

TUV - Academy

TÜV Rheinland/
Berlin-Brandenburg

TÜV

Contents of the Training Kit

The Training Kit contains the following:

a. **This training material**

b. **A case study material**

c. **Exercise Book**

d. **Problem definition worksheet**

Day – 1 Agenda

Introduction to Shainin Design of Experiments

DMAIC structure used for solving problems

Phase-1 – Definition phase

Phase-2 – Measure and Analyze

- **Paired Comparison**
- **Product/Process Search**

Day – 2 Agenda

Phase –2 – Measure and Analyze

- **Component Search**
- **Modified Component Search**
- **Multi-Vari analysis**

Day – 3 Agenda

Phase –2 – Measure and Analyze

- **Variable Search**
- **B Vs C**
- **Concentration Chart**

Phase – 3 – Improve

Phase – 4 – Control

Test to check knowledge and skill acquired

Table of Contents

Introduction to Shainin DOE

What is DOE ?

- 90% of the Engineering problems are analyzed using "*Atmospheric analysis*"

- Root cause cannot be established just by "thinking"

- Solutions given based on judgment, engineering guesses and Opinions will make the problem recur again

- DOE tools helps to pinpoint the root causes using simple Data collection and analysis techniques

Steps in DOE

- Collect data
- Analyze data
- Conclusion on the cause or sources of variation

Applications of DOE

- Problem solving
- Process redesign
- Process characterization
- Process optimization
- Product design

Why Shainin DOE

- Collect data
  - On-line without disturbing the regular production
- Analyze data
  - Off-line – without fancy mathematics and statistics (To analyze you need to know only how to count, add, subtract, divide and multiply)
- Conclude
  - Either the cause is creating problem or not creating problem (without any ambiguity)

Why Shainin DOE

- Tools selected are to be:-
  - Simple for everyone
    - No complex mathematics, statistics and big jargons
  - Line engineers should be able to analyze the data
  - Should identify the sources of variation clearly
  - Should not allow any ambiguity in the decision making process (Application of Henley's law)
  - Team should get "addicted" to using these tools, day-in, day-out

Why Shainin DOE

- Works on Elimination principle
- Analysis is easy and involves only the following operations
  - Counting
  - Addition
  - Subtraction
  - Division
  - Multiplication

How Shainin DOE Works - Example

- Problem:
  - Non-attainment of Finish in a product
- The suspected sources of variation are
  - Sequence of addition
  - Mixer RPM
  - RPM of Stirrer
  - Vinyl Vagh finish
  - Resin finish

How Shainin DOE Works - Example

- Problem:
  - Frequent Tap breakages in M6 tapping operation
- The suspected sources of variation are
  - Tap shank diameter
  - Tap thread diameter
  - Job hardness
  - Job hole size
  - Machine alignment

How Shainin DOE Works - Example

- Nobody can pinpoint the source of variation.
- Shainin DOE tools works to eliminate these sources of variation one by one using 8 different tools

Organization structure required for effective implementation

- A pool of people skilled in selection of Shainin DOE tools and analysis based on the suspected sources of variation (Generally called as Black Belts)
- This team should work with the following functions (Production,Maintenance,Technical and Standardization) to help them in collecting the data
- Analysis and Conclusion by the pool of people

Cultural change required..

- Strong MANAGEMENT SUPPORT AND ENCOURAGEMENT required to change the mindset of people
- People should change from “I Know” attitude to “Let us do it” attitude
- One strong Champion must to review the status of every project and follow-up

Shainin DOE tools

- Initial DOE tools
  - Multi – Vari analysis
  - Process Parameter Search
  - Paired Comparison
  - Component Search
  - Modified Component Search
  - Concentration Chart
- Process characterization tools
  - Variable Search
  - Full Factorial
- Validation tools
  - B Vs C
- Optimization tools (Not discussed in this training workshop)
  - Scatter Plot
  - EVOP (Evolutionary Operation)

Shainin DOE – A bird's eye view

- Multi – Vari analysis
  - When we know the manufacturing process that creates the problem
- Paired comparison
  - When the sources of variation can be measured on Good and Bad products
- Process Parameter Search
  - When the sources of variation cannot be measured on the Good and Bad products

Tools – Bird’s eye view

- Component Search
  - When the problem is because of assembly and the assembly can be dis-assembled and reassembled without damaging the components
- Concentration chart
  - When the problem can come at any location on the product

Tools – A Bird's eye view

- Variable Search
  - To redesign a formulation/process
  - To characterize a process/formulation
  - To identify the key process parameters that are influencing the outcome
- B Vs C
  - To validate an already established source of variation

Tools – Example of applications

- Multi – Vari analysis
  - To analyse the variations coming in multi-head packing units or from a Grinding machine
- Paired comparison
  - When hardness is suspected as the cause for crack
- Product/Process Search
  - When weld time variation is suspected as the cause for Poor weld

Tools – Examples of applications

- Component Search
  - Setting of dynamic opening pressure is not possible in an Air brake assembly
- Concentration chart
  - Dirt particles on painted surface
- Variable search
  - To identify the application related parameters leading to problem

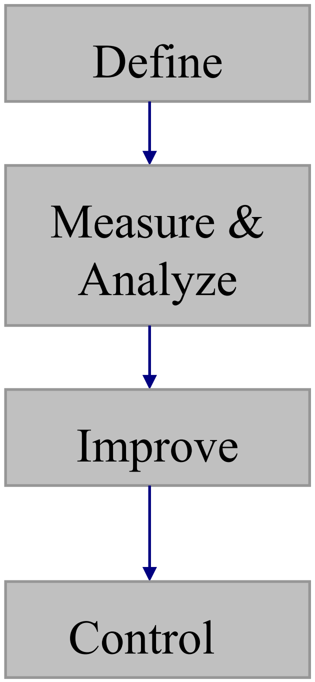
Tools – Examples of applications

- B Vs C
  - To verify whether is surface finish the cause for the vibration in bearing
- Scatter plot
  - To optimize the quantity of a flow additive in the formulation
- EVOP
  - To optimize the quantity of more than one ingredients in the formulation

DMAIC – Problem Solving Phases

DMAIC

- Phase –1 – Definition
- Phase – 2 – Measure and Analyse
- Phase – 3 - Improve
- Phase – 4 - Control
  - This cycle is called as DMAIC



DMAIC – What is done in each phase

- Phase –1 – Definition
  – Problem is clearly defined in this phase. Sources of variation are identified using FMEA or Brainstorming. Instrument capability is verified using R&R
- Phase – 2 – Measure and Analyse
  – This is the key phase of all the four. Shainin DOE tools are used in this phase to pin-point the sources of variation

DMAIC – What is done in each phase

- Phase – 3 – Improve
  - Actions are planned to eliminate the sources of variation.
  - B Vs C tool used to validate the actions
- Phase – 4 – Control
  - Process controls are planned to make sure that the actions implemented in phase-3 is remaining for ever in the Organization

Phase –1 – Definition phase

Phase –1- Definition

- How to select the DOE projects
  - Based on Customer Requirements (CTS)
  - Based on Complaints from users (CTQ)
  - Based on high cost of poor quality (CTQ and CTC)
  - Based on high percentage of scrap (CTQ and CTC)
  - Based on high percentage of rework (CTQ)
  - Cost savings in processes to identify the important and unimportant process parameters (CTC)
  - Based on parameters affecting the customer delivery (CTD)

Phase –1- Definition – Examples

- How to select the project
  - CTS
    - Odometer failure after 20,000 kms in a vehicle
  - CTQ
    - High rejections due to Power piston distortion
  - CTC
    - Energy savings by characterizing the furnace temperature

Phase –1- Definition - Steps

- *Use the format provided to define the problem*
- Problem Statement –Response – Identify the response and also identify whether it is variable or attribute – Identify the Part number/material code that is having the maximum problem
- Instrument used for checking the response
- Specification of response
- Is R&R study required for the measurement system
- Suspected sources of variation (SSV's) for the Problem
  - Use FMEA to identify the sources of variation
  - List down all the possible sources of variation

Phase –1- Definition - Steps

- SSV's should be listed based on the following categories
  - Machine/Process
  - Processing material
  - Person
  - Tooling
  - Input material
  - Work environment
- SSV's should be related to variations only and not due to process/product design

SSV's – Some examples

Category	Example
Machine/Process	Back pressure Pouring temperature Runout of spindle Slide repeatibility Injection speed Quenching time Austenizing temperature Bath content
Processing material	Coolant temperature Coolant viscosity Draw oil property Sand property

SSV's – Some examples

Category	Example
Person	Transfer time of the billet Process setting
Tooling related	Tool wear Mould temperature Shank diameter Tap hardness
Incoming material	Hardness Diameter Finish
Work environment	Ambient temperature

Phase –1- Definition - Example

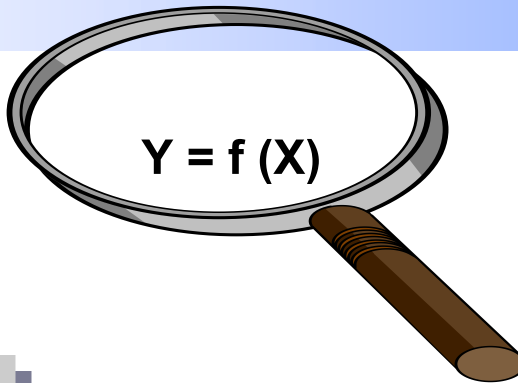
- Problem Statement
  - Non attainment of finish in 1K Taping clear
- Response
  - Finish (Variable)
- Instrument used for checking the response
  - Hegmann gage
- Specification of response
  - 7
- Is R&R study required for the measurement system
  - Yes

Phase –1- Definition - Example

- Suspected sources of variations for the problem
  - Finish of intermediates
  - Stirrer RPM
  - Hygiene of mixer
  - Sequence of addition
  - Wrong addition of Raw materials

“ Do not suspect the product/process design when listing the sources of variations”

Phase –1- Definition - Example



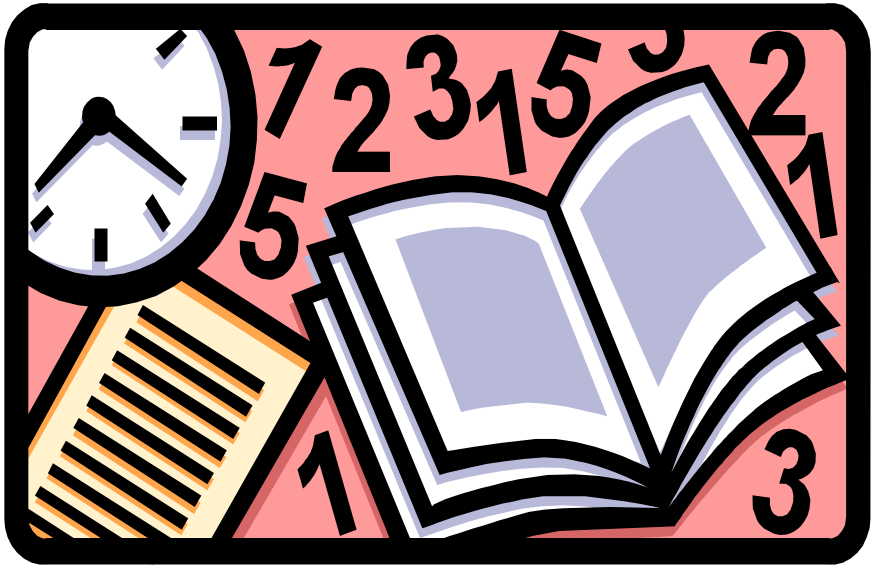
- **Y = Response = Finish**
- **“Is Uncontrollable”**

- **X = Sources of Variations**
- **Stirrer RPM**
- **Wrong addition**
- **Wrong sequence**

“Is Controllable”

Exercise # 1

- Problem definition



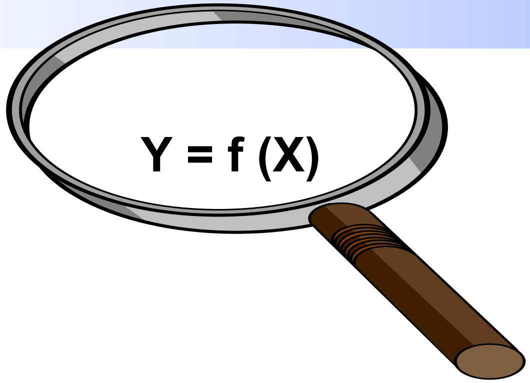
Phase –2 – Measurement and Analysis
Shainin DOE tools

Tool # 1 – Paired Comparison

Application

- Can be used only when the SSV's are measurable on both Good and Bad products
- Good and Bad parts are selected based on the response defined in the Problem definition
- Response can be either attribute or Variable
- SSV's can be either attribute or Variable
- If the SSV's are attribute, then they need to be converted to a scale of at-least 1-5
- Generally this is applicable to input material related SSV's

Application – Paired comparison



X = SSV

- **Y = Response**

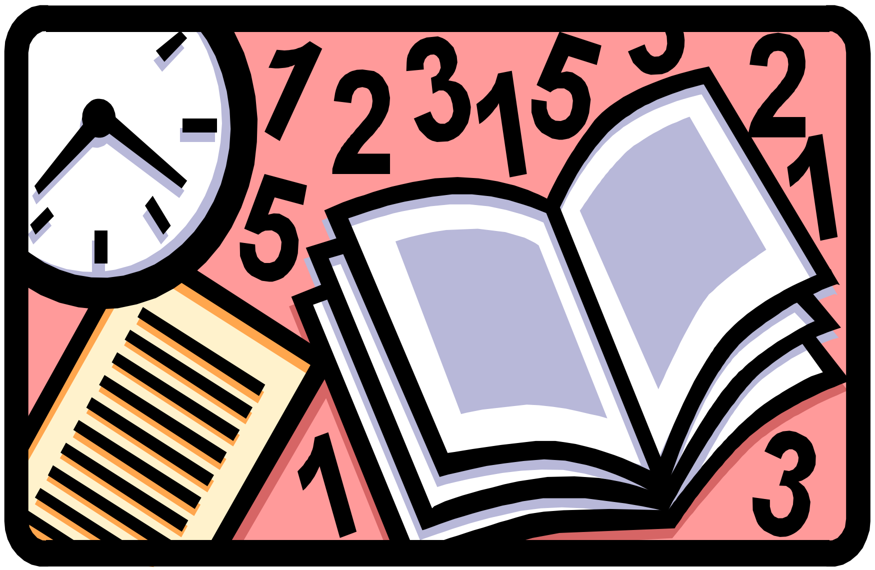
- **Input material parameters**
- **Process parameter values whose data is already available for Bad and good components**

SSV's are measured in this tool

Data Collection

- 8 Good and 8 Bad parts are selected based on RESPONSE ('Y')
- When selecting Good and Bad, Best of Best (BOB) and Worst of Worst (WOW) should be selected
- If 8 Good and 8 Bad cannot be selected, then minimum 6 Good and 6 Bad are required
- Each SSV ('X') is measured on the 16 parts and results are recorded in a table
- If there can be variation that can come due to measurement, it is better to do R&R
- If the SSV is a attribute,judge and record the values on a scale of at-least 1-5

Exercise # 2 – Paired Comparison



- Identification of BOB and WOW responses using the data

Analysis

Data collection → Analyse → Conclusion

- Select one parameter at a time for analysis
- Arrange the values in the ascending order and indicate whether the value has come from a Good or Bad by putting 'G' or 'B' within bracket
- Example

'Y': Opening pressure

SSV: Depth of housing

4.8	G
4.88	G
4.89	G
4.90	G
4.90	G
4.92	G
4.84	B
4.90	B
4.91	B
4.92	B
4.93	B
4.90	B

4.8	G
4.84	B
4.88	G
4.89	G
4.90	G
4.90	B
4.90	G
4.90	B
4.91	B
4.92	B
4.92	G
4.93	B

Analysis

Data collection → Analyse → Conclusion

- If both the Top and the bottom values belong to the same category (either both are good or both are bad), then put the Count as '0'
- If not, then do the following:
  - From the top, check where is the first time either Good is changing to Bad or Bad is changing to Good. Draw a line at the transition point
  - From the bottom, check where is the first time either Good is changing to Bad or Bad is changing to Good. Draw a line at the transition point

'Y': Opening pressure

SSV: Depth of housing

4.8	G
4.84	B
4.88	G
4.89	G
4.90	G
4.90	B
4.90	G
4.90	B
4.91	B
4.92	B
4.92	G
4.93	B

Data collection → Analyse → Conclusion

Analysis

- Check whether at the transition line, the values of the SSV are same.
- If they are same, check whether only 2 values are same or more than 2 values are same.
- If two values are same, do the following:
  - Arrange the Bad or Good in the same trend and then redraw the line if required

'Y': Opening pressure

SSV: Depth of housing

4.8	G
4.84	B
4.88	G
4.89	G
4.90	G
4.90	B
4.90	G
4.90	B
4.91	B
4.92	B
4.92	G
4.93	B

4.8	G
4.84	B
4.88	G
4.89	G
4.90	G
4.90	B
4.90	G
4.90	B
4.91	B
4.92	G
4.92	B
4.93	B

Redrawn line

Data collection
Analyse
Conclusion

Analysis

- If more than 2 values are same, do the following
  - Treat the entire block as one data and draw the transition line
- Example

'Y': Opening pressure

SSV: Runout

0.07	G
0.09	G
0.10	G
0.10	G
0.12	G
0.12	G
0.1	B
0.13	B
0.14	B
0.14	B
0.21	B
0.18	B

0.07	G
0.09	G
0.1	G
0.1	G
0.1	B
0.12	G
0.12	G
0.13	B
0.14	B
0.14	B
0.18	B
0.21	B

Treat the entire block as one data and line is drawn

Data collection → Analyse → Conclusion

Analysis

- Count the number of data above the line
- Count the number of data below the line
- If we are having 2 values same in the transition line reduce ½ count
- Add both
- This count is called the Total Count

4.8	G
4.84	B
4.88	G
4.89	G
4.90	G
4.90	B
4.90	G
4.90	B
4.91	B
4.92	G
4.92	B
4.93	B

1

1 1/2

Count = 2 1/2

0.07	G
0.09	G
0.1	G
0.1	G
0.1	B
0.12	G
0.12	G
0.13	B
0.14	B
0.14	B
0.18	B
0.21	B

2

5

Count = 7

Conclusion

Data collection → Analyse → Conclusion

- If the total count is >=6, then the parameter is concluded as the reason for the problem.
- Otherwise, the parameter is not creating the problem

'Y': Opening pressure

SSV: Depth

Count: 2 1/2

4.8	G
4.84	B
4.88	G
4.89	G
4.90	G
4.90	B
4.90	G
4.90	B
4.91	B
4.92	G
4.92	B
4.93	B

1

1 1/2

0.07	G
0.09	G
0.1	G
0.1	G
0.1	B
0.12	G
0.12	G
0.13	B
0.14	B
0.14	B
0.18	B
0.21	B

2

'Y': Opening pressure

SSV: Runout

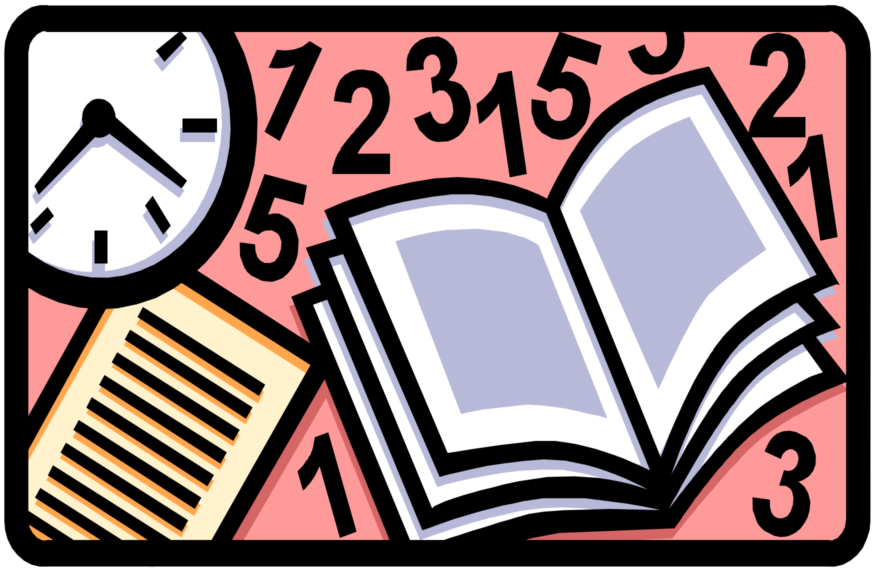
Count: 7

5

Count and Confidence level

Count	CL (%)
6	90%
7	95%
10	99%
13	99.9%

Exercise # 3 – Paired Comparison



- Finding out the root cause of a problem using Paired comparison

Deciding the Specs for SSV's having count >=6

Data collection → Analyse → Conclusion

- For the SSV's with count >=6, decide the spec based on the band in which the Good is lying

0.07	G
0.09	G
0.1	G
0.1	G
0.1	B
0.12	G
0.12	G
0.13	B
0.14	B
0.14	B
0.18	B
0.21	B

2

'Y': Opening pressure

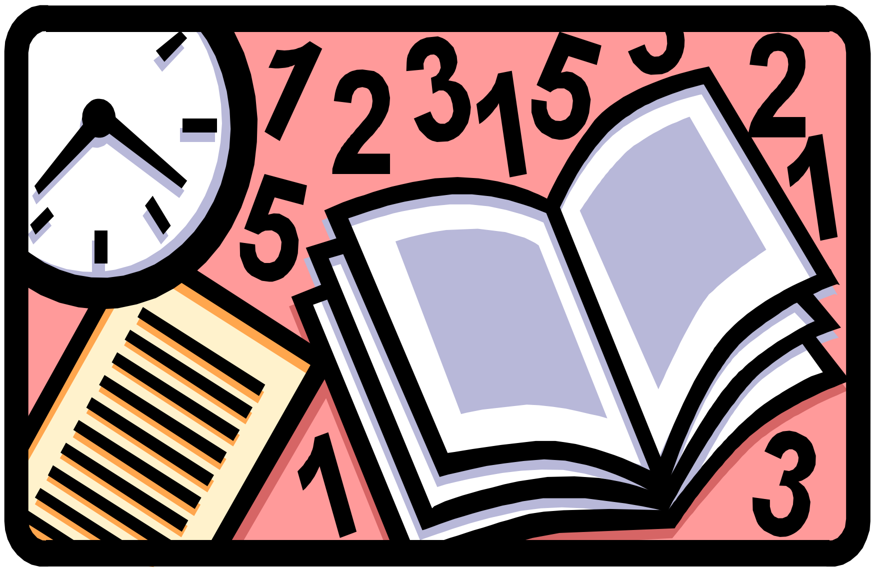
SSV: Runout

Count: 7

5

Tolerance should be <= 0.09mm

Exercise # 4 – Paired Comparison



- Establishing the specifications for the SSV's which are significant

Data collection
Analyse
Conclusion

Handling other situations

- If we get a SSV where the count is '0', and the Bad responses having SSV values outside tolerances, we have to eliminate the bad values and then do the analysis

Status	OD
Bad	96.36
Bad	96.4
Good	96.45
Good	96.45
Bad	96.45
Bad	96.45
Good	96.46
Good	96.47
Good	96.47
Good	96.49
Good	96.49
Good	96.5
Bad	96.52
Bad	96.52
Bad	96.52
Bad	96.53

Parameter: Housing cover dia

Spec: 96.44/96.5 mm

Here we have a situation where the count is zero, and all the Bad responses are having the cover diameter values outside tolerance

Data collection → Analyse → Conclusion

Handling other situations

- Here, we have to remove the Bad values and then do the count.

Status	OD
Bad	96.36
Bad	96.4
Good	96.45
Good	96.45
Bad	96.45
Bad	96.45
Good	96.46
Good	96.47
Good	96.47
Good	96.49
Good	96.49
Good	96.5

Parameter: Housing cover dia

Spec: 96.44/96.5 mm

Top count =

Bottom count =

Total count =

Proceeding further ..

- After we have established the specification for SSV, we now have to find out why the variation is coming in the SSV
- For further investigation, we may have to either do another Paired Comparison or Product/Process search
- Sometimes, we can modify the process to control the SSV to the specification established

Proceeding further ..

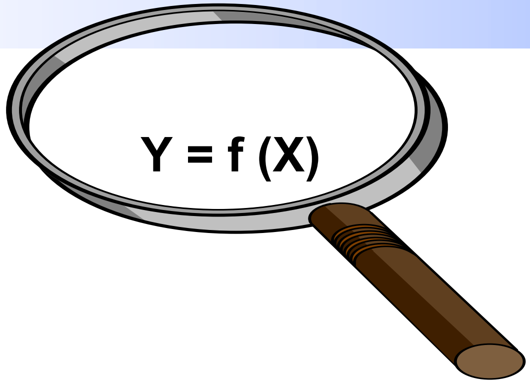
- Based on the conclusions done in exercise 4, find out what is the band of variation for the following parameters
  - Inner ring L3
  - Outer ring Wt
  - Outer ring Ra

Tool # 2 – Product/Process search

Application

- Is used to identify the SSV related to the Process parameter
- Is used when the SSV’s are process parameter variations like temperature, pressure, pouring time
- Is also used when the SSV’s are related to input material dimensions, but the dimensions will get changed during processing preventing the application of Paired comparison
- SSV’s can be either attribute or variable
- Response can be either attribute or variable

Application – Product/Process search



X = SSV

- **Y = Response**

- **Input material parameters that gets changed during processing**
- **Process parameter variation**
- **Machine behaviour**

SSV's are measured in this tool

Data Collection

Data collection
Analysis
Conclusion

- Data collection will be different from Paired comparison
- There are two methods for data collection
  - Method #1 – Collect data till we get 8 BOB parts and 8 WOW parts
  - Method #2 - Fix the number of parts that will be made, collect data and then pick up 8 BOB parts and 8 WOW parts based on the data
- Method #2 is more practical and easy way of collecting data

Data Collection – Method #1

Data collection → Analysis → Conclusion

- List down the SSV's that has to be measured
- Do R&R if there can be variation due to method of measurement
- If the SSV is relating to input material, measure the parameter and then process the part
- If the SSV is relating to the process parameter measure the actual value of the parameter when the part is getting processed (Actual value and not the Set value)
- Measure the response after the part is processed
- Based on the response decide whether the part that has come out is BOB or WOW
- Continue this till you get 8 BOB and 8 WOW responses (parts)

Data Collection – Method #2

- Decide on the parts that will be processed (say 70 nos)
- Measure the Input material SSV for all the parts
- Measure the Process parameter SSV for all the parts when the parts is getting processed
- Measure the Response for all the parts
- Arrange the responses in the ascending or descending order and pick up the 8 BOB and 8 WOW responses

- Caution!! – Ensure that the Worst and Best responses are coming in the parts that are processed. If not, we have to continue with more parts

Data collection
Analysis
Conclusion

Data Collection – Method #2 - Example

As Collected data

No	Before honing Groove form	After honing Groove form
1	3.48	2.84
2	2.93	1.34
3	3.19	0.94
4	5.03	1.75
5	5.02	2.8
6	4.93	2.77
7	6.2	2.38
8	6.76	2.05
9	5.74	1.47
10	6.27	2.1
11	5.42	1.87
13	5.43	1.61
14	3.21	1.62
15	4.88	2.09
16	3.86	1.31
17	2.35	1.32
18	1.95	0.86
19	2.51	1.71
20	2.79	1.87
21	2.72	1.17
22	3.53	2.03
23	2.79	1.53
24	2.83	1.77
25	2.72	1.4
26	3.93	2.36
27	2.64	2.02
28	2.47	1.4
29	2.3	0.89
30	3.69	1.27
31	1.89	1.39
32	3.38	1.32
33	3.9	1.55
34	2.72	1.15
35	2.51	0.64
36	3.5	1.21
37	3.33	1.9
38	3.73	1.95
39	3.69	0.93
41	5.69	2.04
42	5.37	1.84
43	6.07	2.68
44	3.23	1.61
45	5.46	1.34
46	3.89	0.8
47	3.45	1.25
48	4.38	1.52
49	4.57	1.53
50	2.53	1.11
51	4.09	1.88
52	4.17	2.24
53	4.28	1.16
54	2.89	1.46
55	4.19	1.72
56	4.03	1.96
57	3.48	2.74
58	5.3	1.54
59	3.65	1.61
60	4.14	1.1
61	4.19	2.76
62	3.49	1.5
63	4.49	1.72
64	3.29	2.1
65	2.35	1.32
66	6.26	2.12
68	6.19	2.77
69	6.58	3.04
70	6.4	2.1
71	6.23	1.67

Data collection
Analysis
Conclusion

Data Collection – Method #2 - Example

After picking up 8 BOB and 8 WOW

No	Groove form (SSV)	Groove form (Response)	
35	2.51	0.64	BOB
46	3.89	0.8	BOB
18	1.95	0.86	BOB
29	2.3	0.89	BOB
39	3.69	0.93	BOB
3	3.19	0.94	BOB
60	4.14	1.1	BOB
50	2.53	1.11	BOB
43	6.07	2.68	WOW
57	3.48	2.74	WOW
61	4.19	2.76	WOW
6	4.93	2.77	WOW
68	6.19	2.77	WOW
5	5.02	2.8	WOW
1	3.48	2.84	WOW
69	6.58	3.04	WOW

Data collection
Analyse
Conclusion

Analysis

- Same as Paired Comparison

No	Groove form (SSV)	Response
18	1.95	BOB
29	2.3	BOB
35	2.51	BOB
50	2.53	BOB
3	3.19	BOB
57	3.48	WOW
1	3.48	WOW
39	3.69	BOB
46	3.89	BOB
60	4.14	BOB
61	4.19	WOW
6	4.93	WOW
5	5.02	WOW
43	6.07	WOW
68	6.19	WOW
69	6.58	WOW

What is the total count?

Conclusion

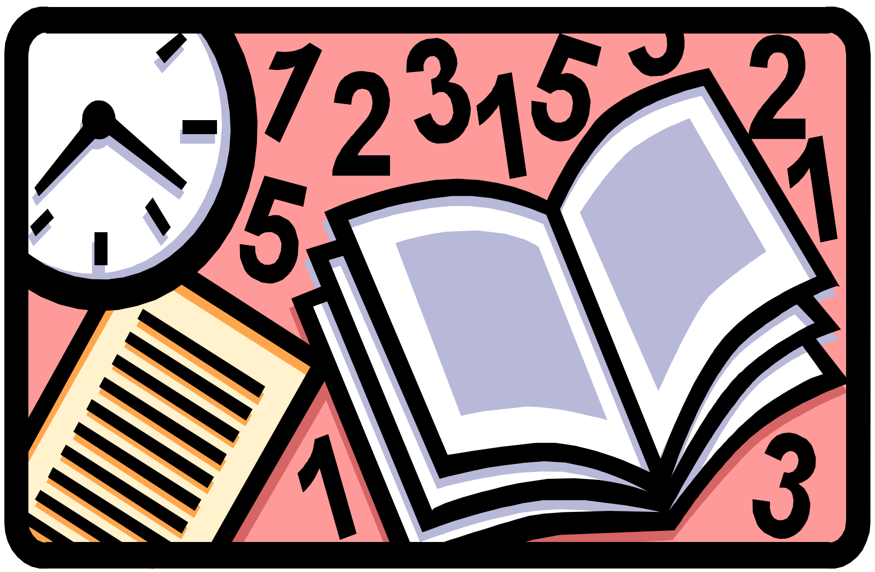
- Same as Paired Comparison

No	Groove form (SSV)	Response
18	1.95	BOB
29	2.3	BOB
35	2.51	BOB
50	2.53	BOB
3	3.19	BOB
57	3.48	WOW
1	3.48	WOW
39	3.69	BOB
46	3.89	BOB
60	4.14	BOB
61	4.19	WOW
6	4.93	WOW
5	5.02	WOW
43	6.07	WOW
68	6.19	WOW
69	6.58	WOW

What is the conclusion ?

What should be the specification of the groove form after grinding

Exercise # 5 – Product/Process Search



- Identification of the root cause using Product/Process search and establishing the specification for the Process parameter

Proceeding further ..

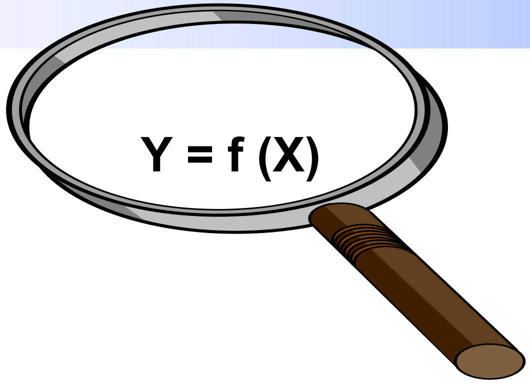
- If the root cause established is the input material variation, we have to continue further with Paired comparison or Product/Process search for the processes generating this variation
- If the root cause established is process parameter variation, we need to introduce controls in the machine to control the variation or modify the process to control the parameter to the established specification
- If the root cause established is not the input material and there are no process parameters that can vary in the process, we have to do Variable Search to redesign the process or study the machine for variations

Tool # 3 – Component Search
Applicable for assemblies that will not get damaged during disassembly

Application

- Used for assembly related problems (functional failures of assembly like leakage, Opening pressure , current drawn, noise, torque)
- Will help to find out whether the problem is generated due to the process of assembly or due to the components in the assembly
- SSV’s are either assembly process or the components
- Response can be variable or attribute. If it is attribute convert it to a scale of 1-5

Application – Component search



X = SSV

- Y = Response

- Process of assembling
- Component(s) in the assembly

Response is measured in this tool

Application

- Three stages of Data collection , analysis and conclusion
  - Stage – 1 – To identify whether the assembly process is the cause or not
  - Stage – 2 – To identify which component(s) are the causes for the problem
  - Stage – 3 – To validate the findings of Stage –2
- We can proceed to Stage 2 and 3 only if in Stage-1, the conclusion is assembly process is not the reason for the problem

Data collection
Analysis
Conclusion

Stage #1 - Data Collection

- One BOB assembly and One WOW assembly is selected based on the response
- If the response is attribute, then try to scale the response on 1-5 (Eg: gear shifting smoothness can be scaled on 1-5)
- If the response is attribute, and cannot be scaled just select One assembly that is working and another one that is not working (Eg: Seizure of the vacuum pump during testing)

Stage#1 - Data Collection

Data collection
Analysis
Conclusion

- Actual values of the responses as selected is entered in a table as given in the next slide
- Disassemble and Reassemble the BOB & WOW assembly *TWICE* , measure and enter the responses (Same disassembled parts should be used in reassembly every time)
- If the required torque needs to be maintained, same needs to be done everytime. Fasteners can be replaced for this, if required

Stage#1 - Data Collection- Example

Response: End Torque Unit of measurement: mm, Spec : 0.3 mm

	Good (BOB)	Bad (WOW)
Initial value (As selected)	0.1	0.3
First disassembly and reassembly	0.1	0.3
Second disassembly and reassembly	0.1	0.28

Stage#1 - Analysis

Data collection
Analysis
Conclusion

Calculate the D/d ratio

	Good	Bad
Initial value	0.1	0.3
First disassembly & reassembly	0.1	0.3
Second disassembly& reassly	0.1	0.28
Median	0.1	0.3
Range	0	0.02
D	0.2	
d	0.01	
D/d ratio	20	

Stage#1 - Conclusion

Data collection → Analysis → Conclusion

	Good	Bad
Initial value	0.1	0.3
First disassembly & reassembly	0.1	0.3
Second disassembly& reassly	0.1	0.28
Median	0.1	0.3
Range	0	0.02
D	0.2	
d	0.01	
D/d ratio	20	

If D/d ratio is < 3, then assembly process is the reason for the problem

If D/d ratio is >=3, then the component(s) in the assembly are the reason for the problem

CAUTION!! – D/d ratio can be <3, due to BOB and WOW not selected properly

Stage#1 - Conclusion

Data collection
Analysis
Conclusion

- This indicates the estimated variation in the responses of the Good and Bad assembly at 99.5% CL
- For the data discussed earlier, the control limits are
  - UCL (+) = 0.11
  - LCL (+) = 0.09
  - UCL (-) = 0.31
  - LCL (-) = 0.29

Data collection
Analysis
Conclusion

Stage#1 – Conclusion – Attribute response

- If the response is attribute and cannot be scaled on a scale, following are the conclusions
- If Good remains good and Bad remains bad during both the disassembly and reassembly,then the components in the assembly are creating the problem
- If Good turn Bad or Bad turns Good during the disassembly/reassembly, then the assembly process is the reason for the problem

Stage # 2 - Data Collection

Data collection
Analysis
Conclusion

- List down the components suspected in the order or suspect level.
- List down the component most suspected first and proceed in the same way
- Name the components as A,B,C etc..

- For the steering gear problem, the following components in the same order were selected
  - A – Housing
  - B – Housing Cover

Stage # 2 - Data Collection

- Start with the first component. Disassemble the first component from Good and assemble it in Bad and disassemble the component from Bad and assemble it in Good (Interchange or swapping)
- If the component is represented as ‘A’, this interchange is called as A+R- and A-R+ (R - Stands for remaining components or the assembly in which component ‘A’ is assembled)
- + -> Indicates Good assembly
- - -> Indicates Bad assembly
- After the swapping, measure the response and note down in the table as shown in the next slide

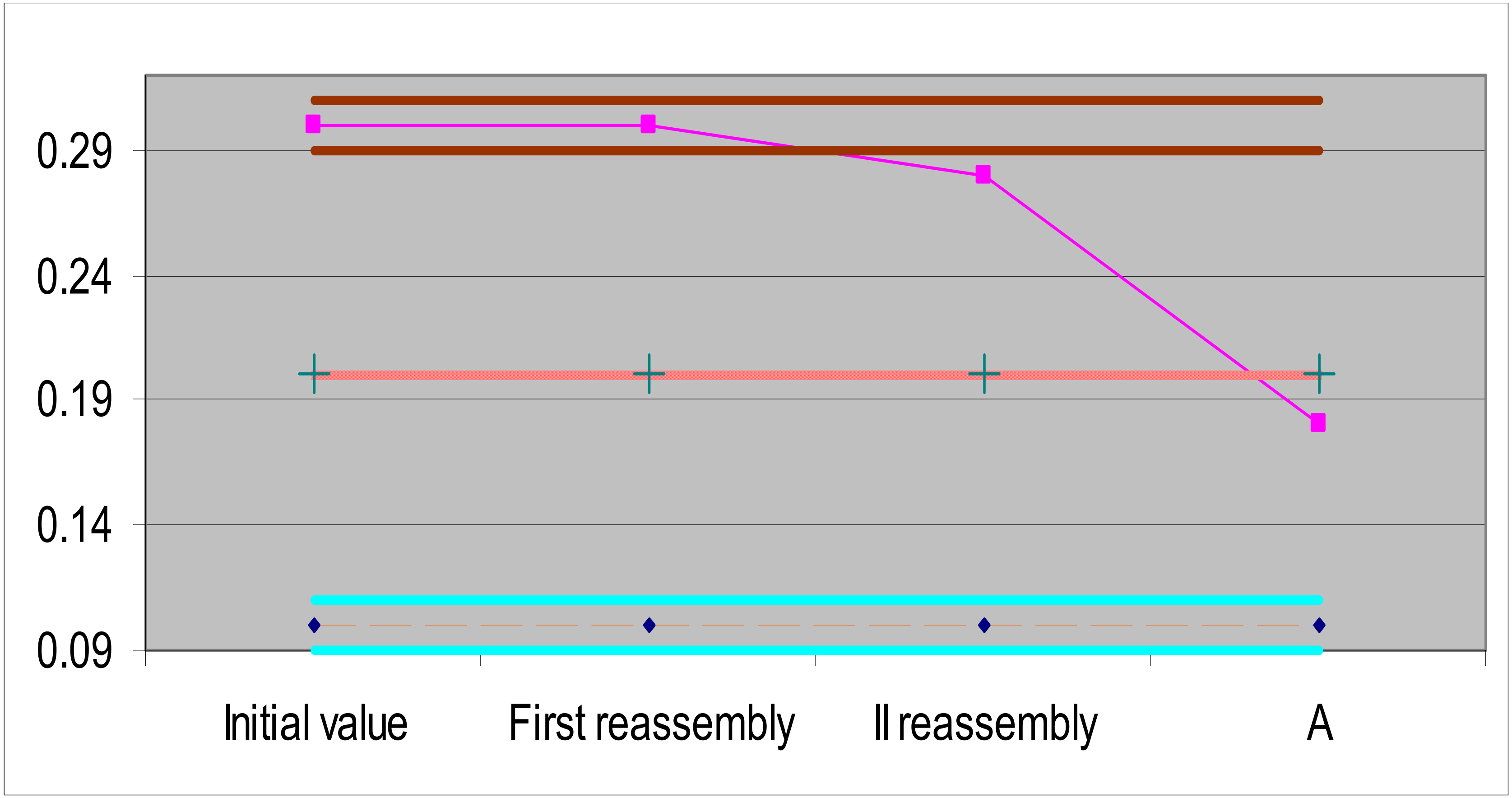
Stage # 2 - Data Collection

Data collection
Analysis
Conclusion

Good assembly (+)	Response	Bad Assembly (-)	Response
A-R+	0.1	A+R-	0.18

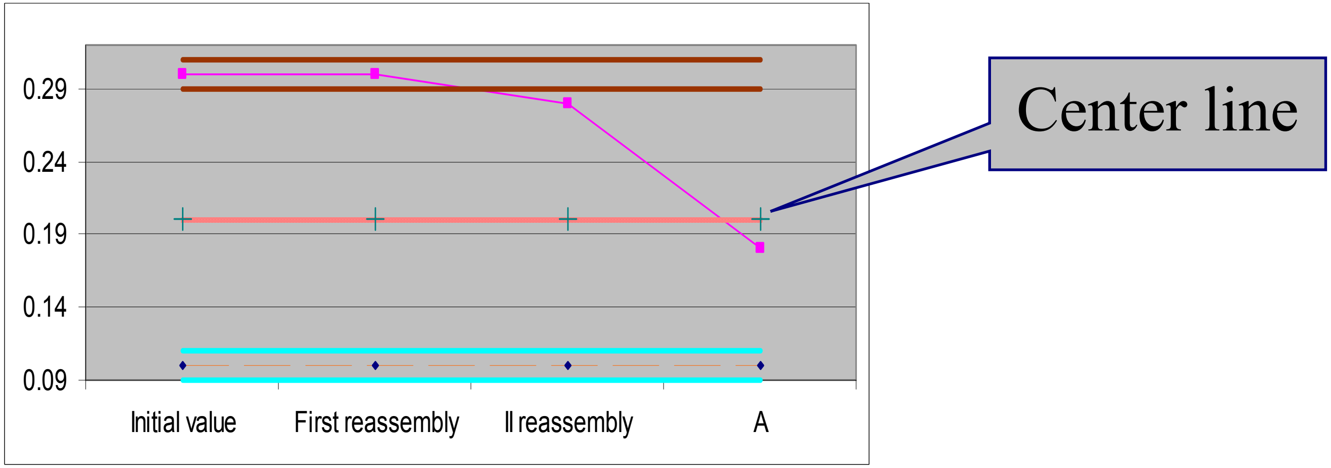
Plot the values in the graph as shown in the next slide along with the Decision limits calculated for + and – in Stage # 1

Stage # 2 - Data Collection



Stage # 2 - Conclusion

Data collection
Analysis
Conclusion



Following are the three conclusions possible:

a) If the value remains within the + band and – band after swapping, then conclusion is ‘A’ is not the reason for the problem

b) If both the values cross the Center line, then ‘A’ is the only component creating the problem (Complete reversal)

c) If one value remains within the band and the other value goes outside or crosses the center line, then ‘A’ is one of the components creating the problem (Partial reversal)

Stage # 2 - Conclusion

Data collection
Analysis
Conclusion

Complete reversal	Both the values are crossing the center line
Partial reversal	One value is crossing the center line and the other one is not crossing
No reversal	Both the values are not crossing the center line

Stage # 2 - Conclusion

Data collection
Analysis
Conclusion

If we get a complete reversal (Values crossing the center line), then Stage # 2 is over and we have to go to Stage #3

If we get a partial reversal, then we need to continue with the next suspected component, as this is only one of the components creating the problem

If we get no reversal, then we need to continue with the next suspected component

CAUTION!! Before we proceed with the next component, we need to put the component interchanged back to the original assemblies

Stage # 2 - Data Collection

Data collection
Analysis
Conclusion

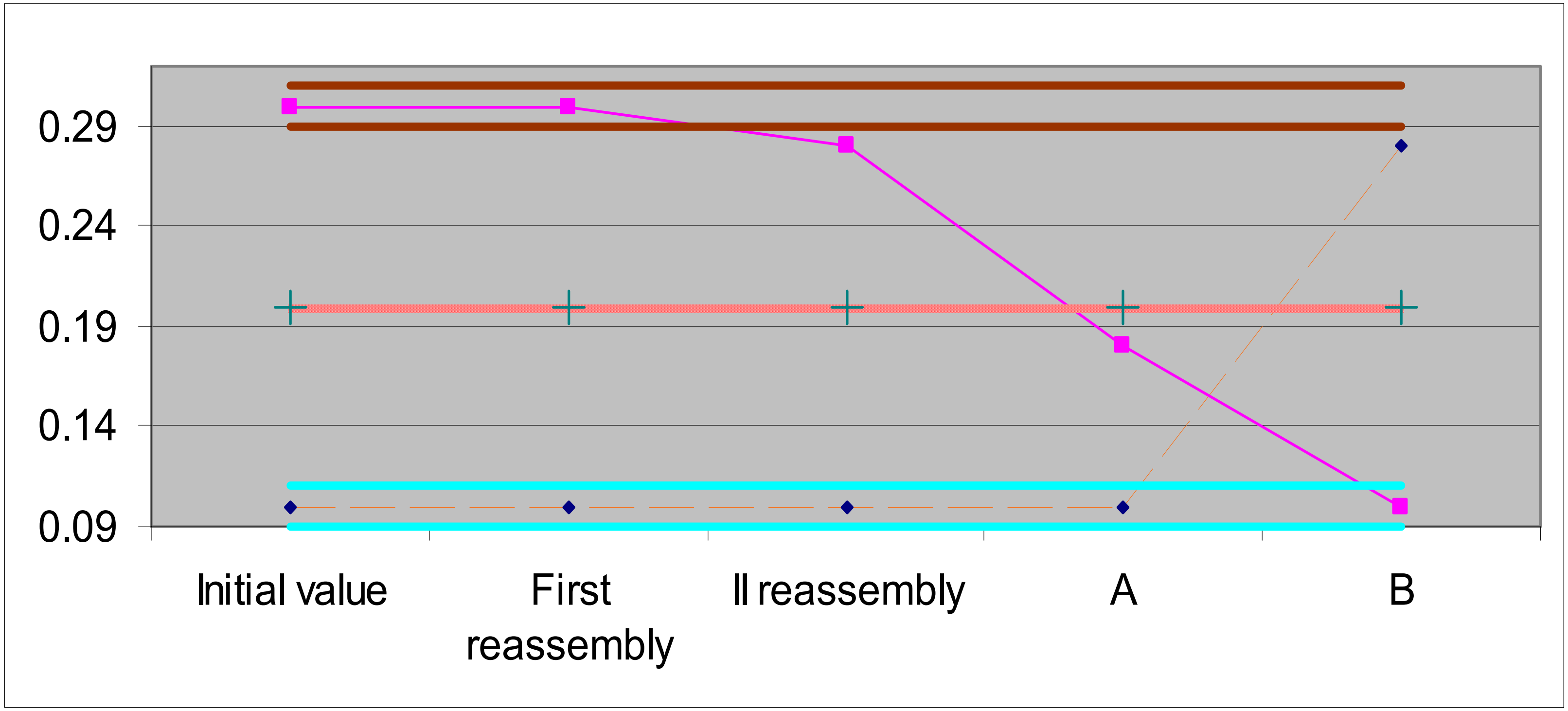
Good assembly (+)	Response	Bad Assembly (-)	Response
A-R+	0.1	A+R-	0.18
B-R+	0.28	B-R+	0.10

Plot the values in the graph as shown in the next slide

Stage # 2 - Data Collection

Data collection
Analysis
Conclusion

Graph after interchanging component 'B'



What is your conclusion ??

Stage # 2 - Conclusion

Data collection

Analysis

Conclusion

If we get a complete reversal, then component swapped is the only component creating the problem

If we get no reversal, then component swapped is not the component along with the previous creating the problem

If we get partial reversal, then component swapped is one of the components along with the previous creating the problem

Stage # 2 - Conclusion

Data collection

Analysis

Conclusion

Now, if we get a partial reversal after interchanging component 'B', before we proceed with component 'C', we need to swap A & B together

This is indicated as A+B+R- and A-B-R+

After this if we get a complete reversal, then component A & B are the causes for the problem

After this if we get partial reversal, then A & B again are one of the components creating the problem. There is one or more components along with this.

Do Stage # 2 , till we get a complete reversal

Stage # 3 - Data Collection

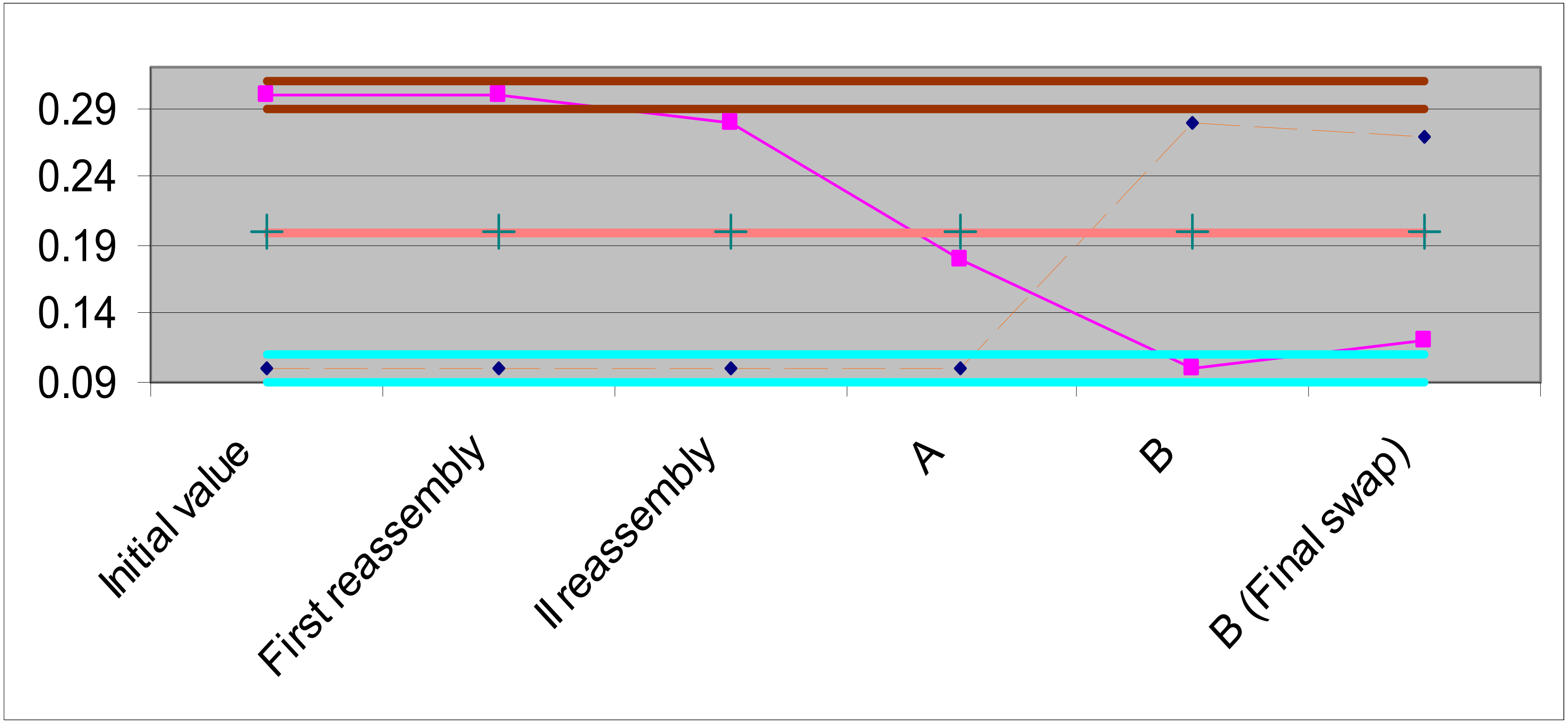
Data collection
Analysis
Conclusion

- This is a validation stage
- Swap the components identified in Stage #2 back to the original assemblies and again swap them
- There should be complete reversal happening strengthening our root cause identification in Stage #2
- If not, redo from Stage #1
- The results of this step are also plotted on the graph

Stage # 3 - Data Collection

Data collection
Analysis
Conclusion

Graph after interchanging component 'B' (Final swap)



What is your conclusion ??

Proceeding further ..

- Component Search ends here, the objective being to identify the component creating the problem
- Use **Paired Comparison** to identify which parameters in the component are leading to the problem
- If you are interested in analyzing the contribution of each component to the problem, we have to do an analysis called "FACTORIAL ANALYSIS", which is the Stage # 4 of Component search. This is required, only if one is interested in quantifying the contribution of each component to the problem

Stage#4 – Factorial Analysis

- Used to quantify the influence in response for each component
- Used to quantify the influence in response due to interaction among components
- Analysis is done based on Factorial table

Data collection
Analysis
Conclusion

Stage#4 – Factorial Analysis

- **<u>What is Interaction?</u>**
- **Catapult – Response is 'Distance'. Let us consider two parameters influencing Distance, 'Angle' and 'Tension-1'. We will call them 'A' and 'T-1'**
- **Let us have two levels for each parameter. Let us call them as '-' and '+'**
- **A- -> 4"   A+ -> 6"**
- **T1- -> 3   T1+ ->1**

Stage#4 – Factorial Analysis

Data collection
Analysis
Conclusion

Parameter	Level	Distance	Level	Distance	Increase	Remark
Angle	- (4”)	15”	+ (6”)	65”		Tension-1 fixed at 3 (-)
Tension-1	- (3)	15”	+ (1)	40”		Angle fixed at 4” (-)

If we increase both Angle and Tension-1 from the ‘-’ level to ‘+’ level together, how much increase in distance will we get ??

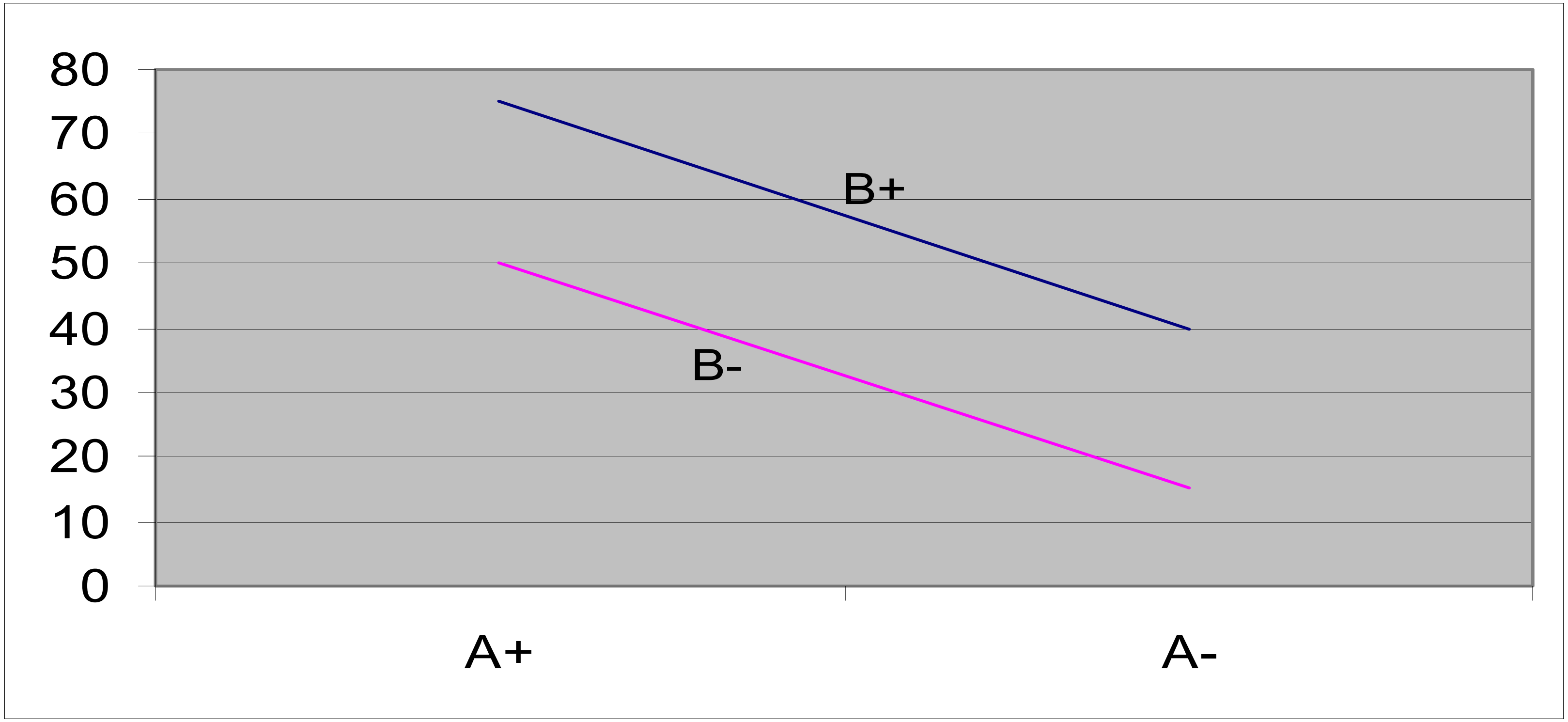
Stage#4 – Factorial Analysis

Data collection
Analysis
Conclusion

Parameter	Level	Distance	Level	Distance	Increase	Remark
Angle (A)	- (4”)	15”	+ (6”)	65”	50”	Tension-1 fixed at 3 (-)
Tension-1 (B)	- (3)	15”	+ (1)	40”	25”	Angle fixed at 4” (-)

If we increase Angle and Tension-1 from “-” to “+” level together, we get an increase of 75”, distance is 90”, is there any interaction between Angle and Tension-1 ??

Stage#4 – Factorial Analysis



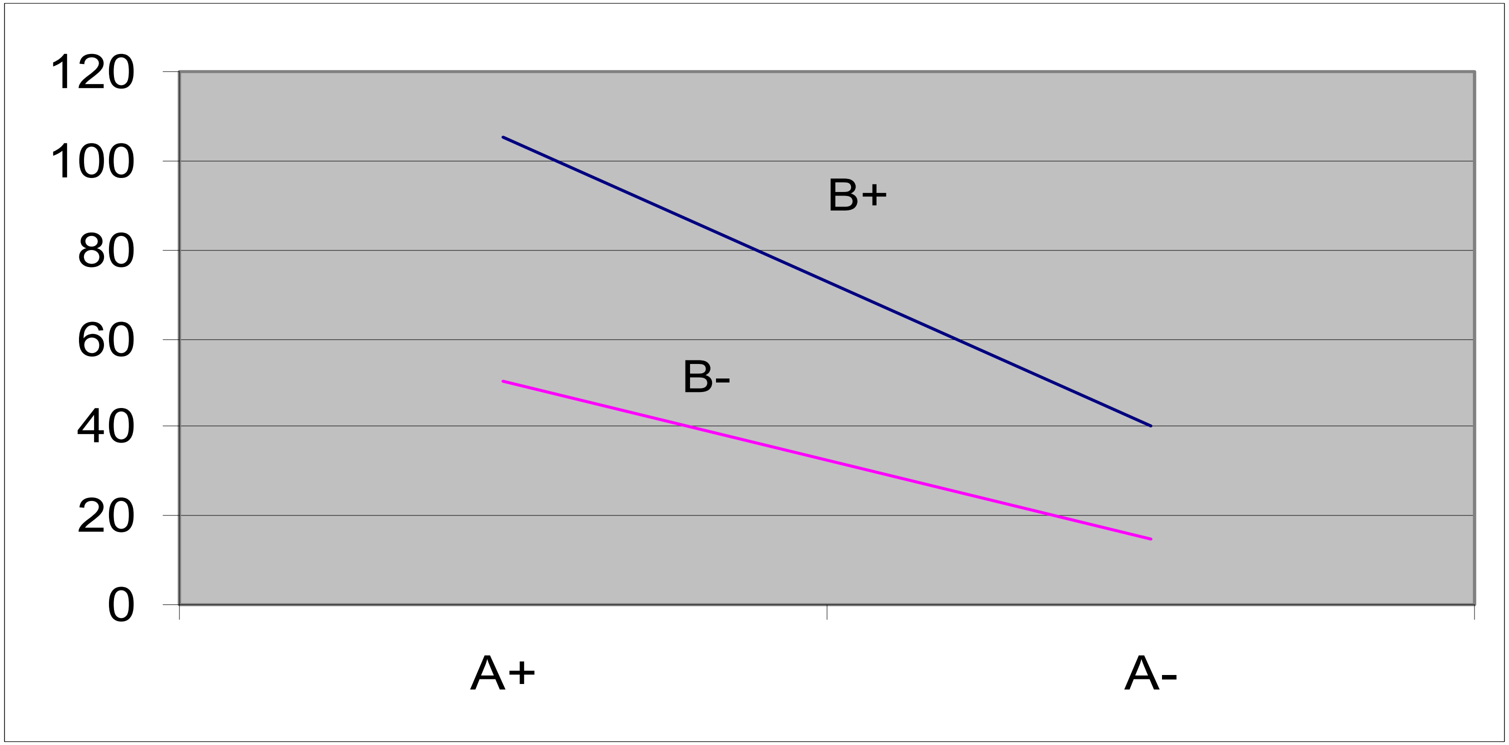
If we get two parallel lines, there is no interaction

Stage#4 – Factorial Analysis

Data collection

Analysis

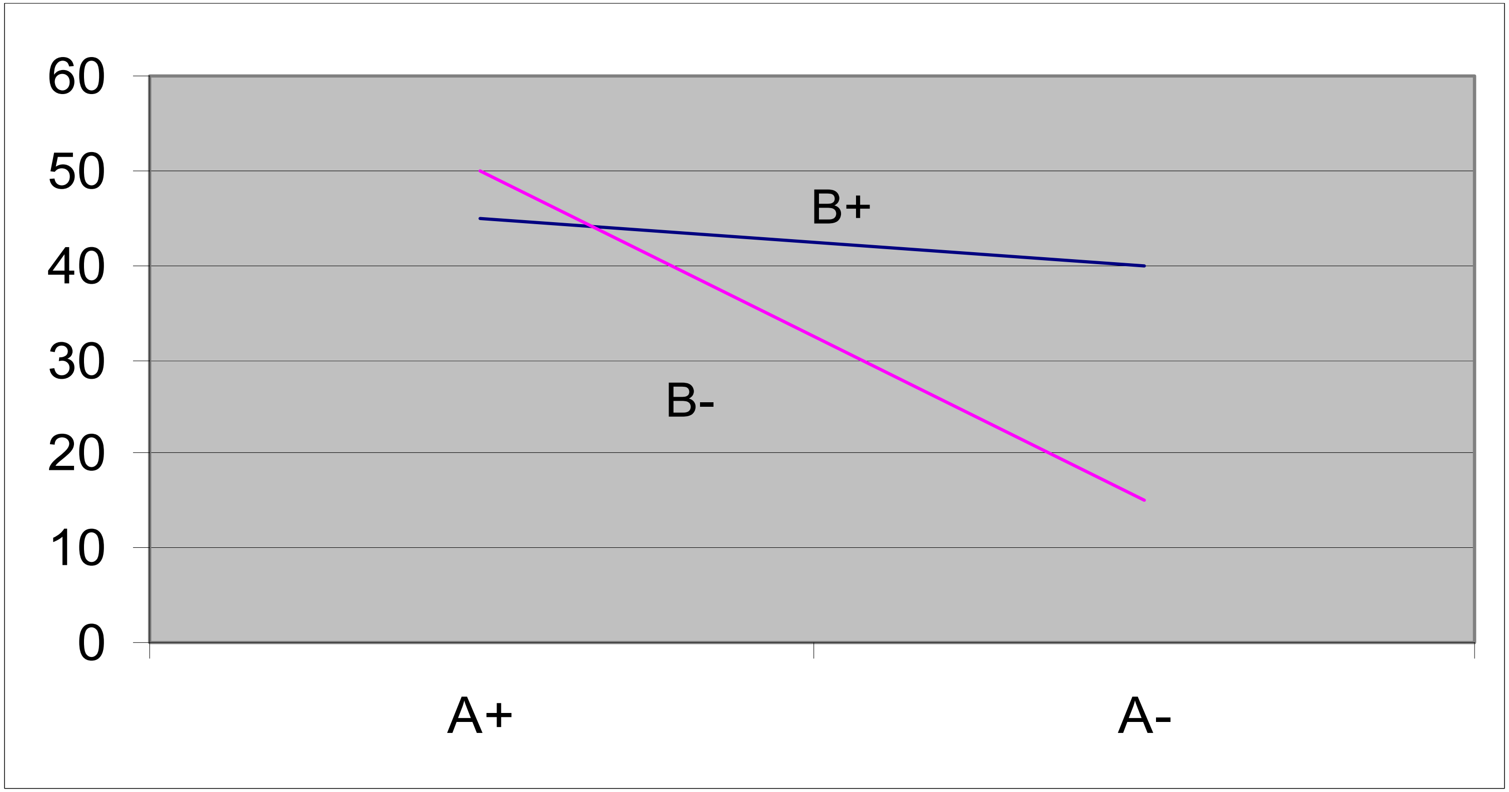
Conclusion



Positive interaction – Interaction improves the response

Stage#4 – Factorial Analysis

Data collection
Analysis
Conclusion



Negative interaction – Interaction pulls down the response

Stage#4 – Factorial Analysis

Data collection
Analysis
Conclusion

Table for 3 parameters

A	B	C
-	-	-
+	-	-
-	+	-
+	+	-
-	-	+
+	-	+
-	+	+
+	+	+

Stage#4 – Factorial Analysis

Data collection
Analysis
Conclusion

- Constructing the factorial table. Rules
  - Number of rows = 2^n (n – Number of parameters)
  - Number of columns = Number of rows – 1
  - Hence, if there are 4 parameters, number of rows are 16 and number of columns are 15. Four column will be taken for the 4 parameters, the remaining 11 parameters are the interactions

Data collection

Analysis

Conclusion

Stage#4 – Factorial Analysis

• For the Steering gear data we are analyzing, suppose if we want to find out the contribution of Component A and B, we need to construct a two factor table and write the responses from all the three stages

	A	B	Response	Median
	-	-		
	+	-		
	-	+		
	+	+		
Total				
Contribution				

Stage#4 – Factorial Analysis

Data collection
Analysis
Conclusion

- To find out the total contribution of ‘A’, add all the medians where A is at ‘-’ level and add all the median where A is at ‘+’ level and then subtract the two
- Put whichever higher number sign on the top
- To find out the Contribution, divide the total by “half the number of rows”

Stage#4 – Factorial Analysis - Conclusions

Data collection
Analysis
Conclusion

- How to read the contributions
- Example:
    - If we get the contribution of ‘A’ as 0.15mm, with a ‘+’ sign on top, means that when A is moved from ‘-’ level to ‘+’ level, the response INCREASES by 0.15mm

Stage#4 – Factorial Analysis

Building table for interactions

A	B	A*B
-	-	+
+	-	-
-	+	-
+	+	+

Multiply the signs of the parameters and put the sign for the interaction

Stage#4 – Factorial Analysis

Data collection → Analysis → Conclusion

• For the Steering gear data we are analyzing, suppose if we want to find out the contribution of Component A and B, we need to construct a two factor table and write the responses from all the three stages

	A	B	A*B	Median
	-	-	+	
	+	-	-	
	-	+	-	
	+	+	+	
Total				
Contribution				

Stage#4 – Factorial Analysis

Data collection → Analysis → Conclusion

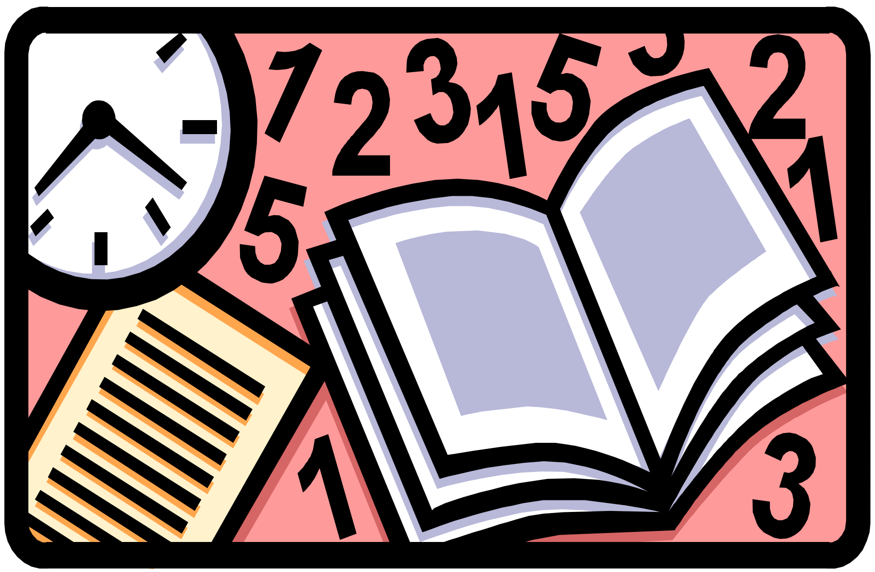
Based on the factorial analysis done for the data summarize your conclusions in the table below

Parameter	Contribution	When the parameter is moved from '-' to '+', response increases/decreases
A		
B		
A*B		

When both A & B are moved from '-' level to '+' level, the response increases/decreases ?

By How much ?

Exercise # 6 – Component Search



- Analyze the data of various stages and conclude the root cause

Tool # 3 – Modified Component Search
Applicable for assemblies where parts will get damaged during disassembly/reassembly

Application

- Is a modified form of Component search if the some parts in the assembly gets damaged during disassembly/reassembly
- Data collection is same as Component search. Only conclusions are different

Stage #1 - Data Collection and conclusion

Data collection → Analysis → Conclusion

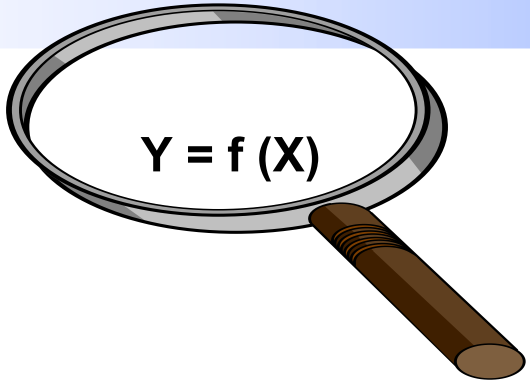
- During the disassembly/reassembly twice, replace the parts that are getting damaged with new parts in both the good and bad assemblies
- If D/d ratio is >= 3, conclusion is the parts that are replaced and the assembly process are not the causes for the problem. Proceed to Stage #2
- If D/d ration is <3, conclusion is either the parts replaced or the assembly process is creating the problem

Tool # 4 – Multi-Vari analysis

Application

- Used to find out what sources of variation is the highest in a process
- Is applied only after the process creating the problem is established using the other tools
- Any Process will have the following types of variation
  - Part to Part
  - Time to Time
  - Stream to Stream (If the process has multiple streams)
- Multi-vari analysis identifies which type of variation is the highest

Application – Multi-Vari analysis



X = SSV

- **Y = Response**

- **Part to Part variation**
- **Time to Time variation**
- **Stream to Stream variation**

Response is measured in this tool

Application

- Part to Part variation
  - Variation in the response from one part to the immediate next part (Example: Diameter variation from one part to another part, Finish variation from one part to another part)
- Time to Time variation
  - Variation in the response from one “Time block” to another “Time block” (Example: Diameter variation from 09:00 am to 11:00 am to 01:00 pm)
- Stream to Stream variation
  - Cavity to Cavity variation in a die
  - Maximum diameter to Minimum diameter variation within a part (Runout)
  - Diameter variation across the length of the part (Taper)

Application

- Sources for Part to Part variation
  - –
  - –
  - –
- Sources for Time to Time variation
  - –
  - –
- Sources for Stream to Stream variation
  - –
  - –

Data Collection

Data collection
Analysis
Conclusion

- First step in data collection is we have to identify whether are there any streams in the process
- If there are streams in the process then we have to find out how many types are there and in how many levels
- Make a stream table for collecting the data
- If there are no streams in the process, then there are only two types of variations , Part to Part and Time to Time

Data collection
Analysis
Conclusion

Data Collection

Stream to Stream

Product

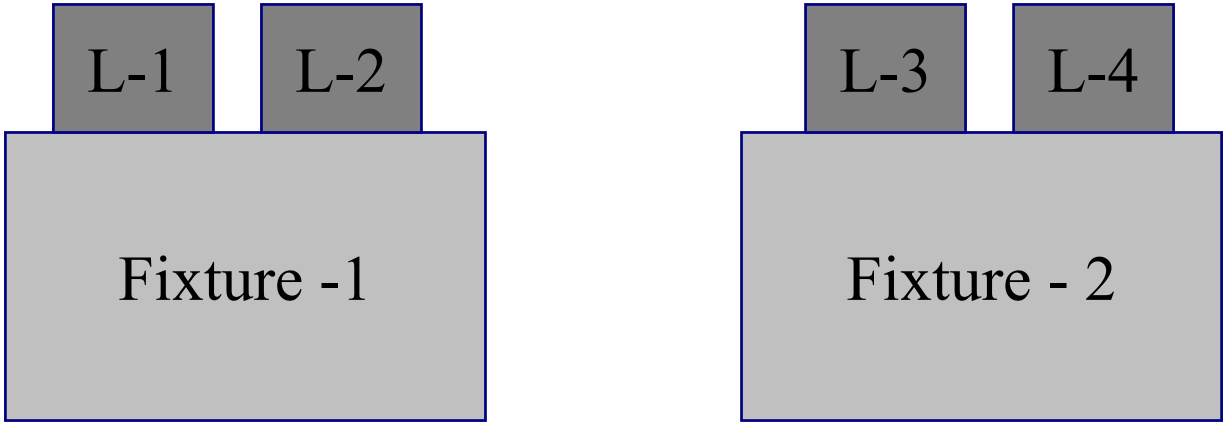
• Runout
•Taper
•Journal to Journal on a crankshaft
•Pin to Pin on a crankshaft

Process

• Spindle to Spindle
•Cavity to Cavity
•Fixture to Fixture
•Line to Line

Data Collection

- Example:



How many streams are there:

How many types are there:

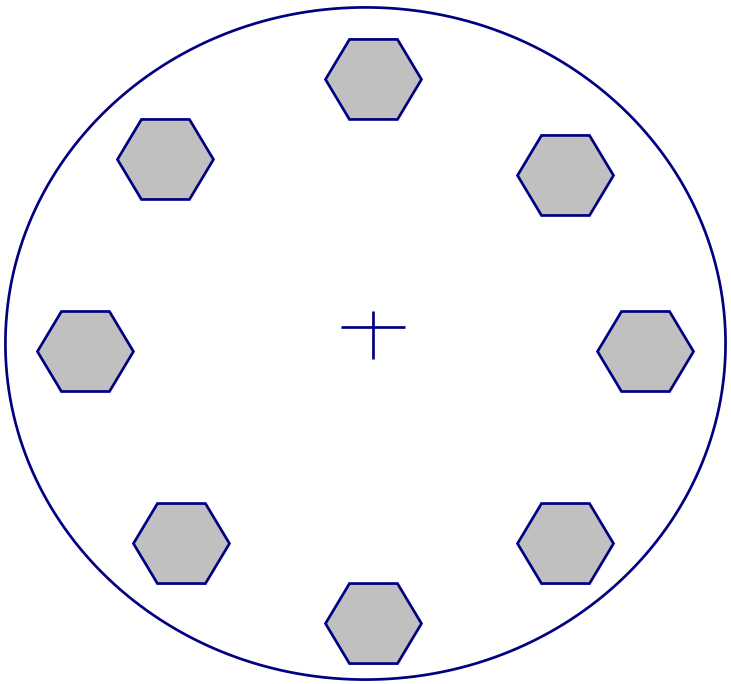
How many levels are there:

Is this a process or product stream:

Data collection
Analysis
Conclusion

Data Collection

- Example:



How many streams are there:

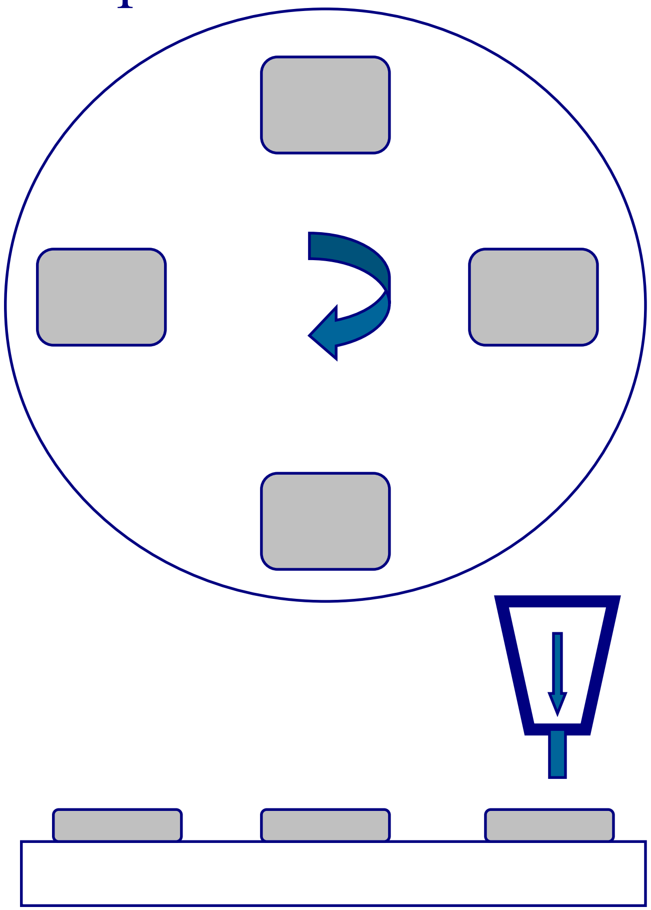
How many types are there:

How many levels are there:

Is this a process or product stream:

Data Collection

- Example:



How many streams are there:

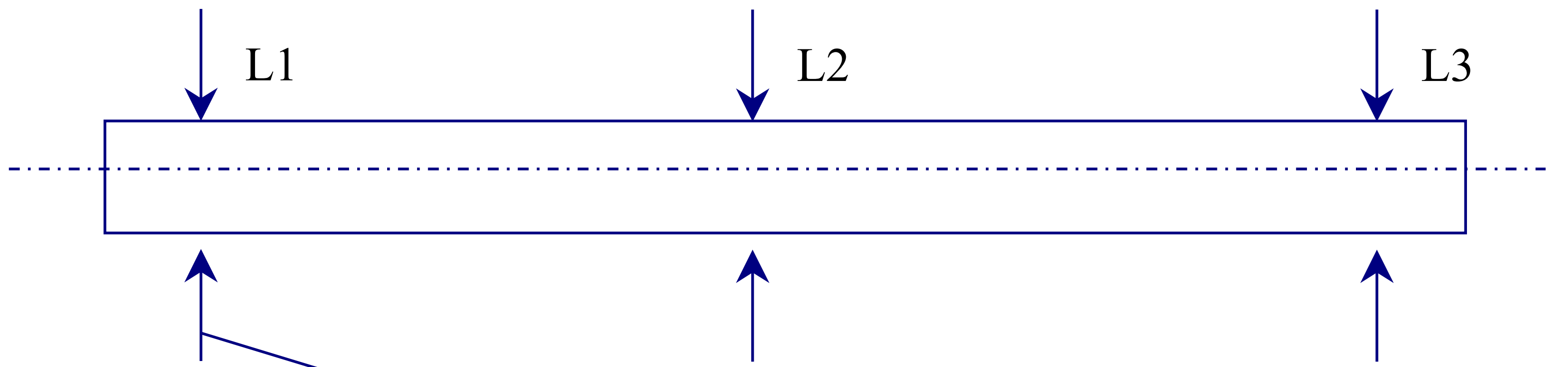
How many types are there:

How many levels are there:

Is this a process or product stream:

Data Collection

- Example:



At each place max, min values are obtained

How many streams are there:

How many types are there:

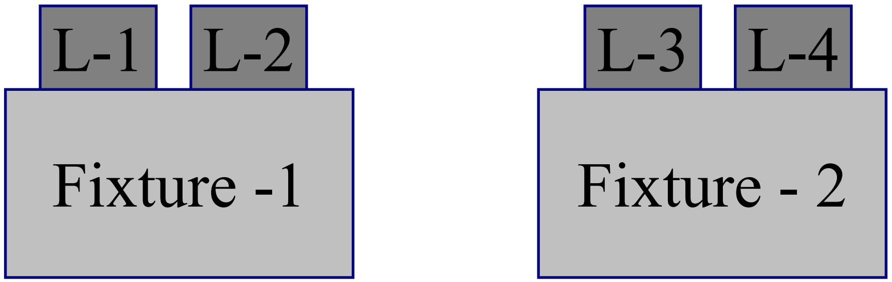
How many levels are there:

Is this a process or product stream:

Data collection
Analysis
Conclusion

Data Collection

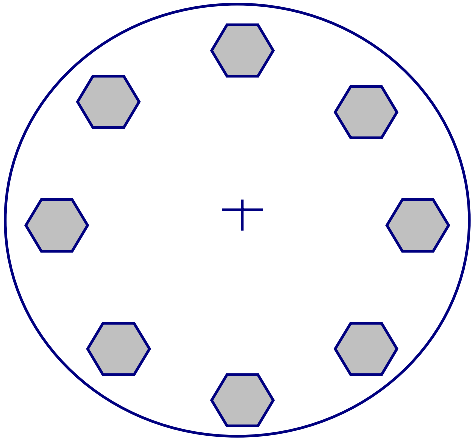
- Example: Constructing the Stream table



	Fixture-1		Fixture-2	
	L1	L2	L3	L4
1				
2				
3				

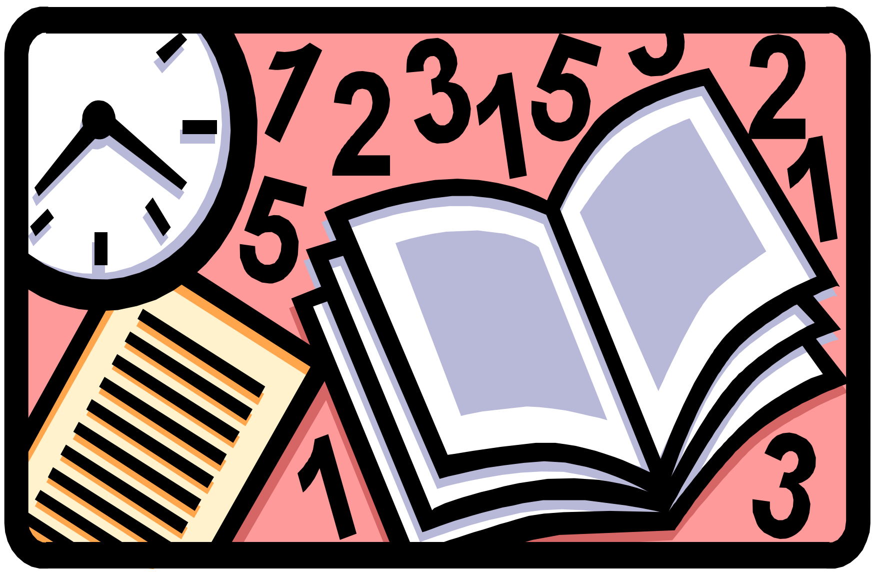
Data Collection

- Example:



	A	B	C	D	E	F	G	H
1								
2								
3								

Exercise # 7 – Multi-Vari analysis



- Identify the number of streams and construct the stream table for collecting data

Data Collection – Method #1

Data collection
Analysis
Conclusion

- Collect 3-5 parts or Units (in case of streams) continuously (This will be at time block T1)
- Check whether 80% of the historic rejection is captured in this data. If the answer is yes, stop collecting the data
- If the answer is NO, leave some time interval and collect 3-5 parts or units continuously at another time block T2
- Check whether 80% of historic rejection is captured in the data for T1 and T2. If yes, stop, otherwise continue to collect data
- Continue to collect till 80% of the rejection is captured

Data Collection – Method #2

Data collection
Analysis
Conclusion

- Fix time to collect data. Generally done for one shift
- Collect 3-5 units continuously.
- Leave some time block and collect another 3-5
- Continue like this for the entire time fixed
- If the rejection % is less (say <=0.5%), collect data continuously without leaving time interval between two time blocks

Data Collection

Process: Multispindle turning, Two sets of toolings

Response: Outer diameter, Spec: 42.38 +/- 0.070 mm , Tolerance: 140 microns

Readings are deviation from 42.38 in microns

	SP1		SP2		SP3		SP4		SP5		SP6	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
T1	-9	7	6	-5	-3	-6	1	-3	-15	-3	0	5
	-5	7	2	4	-4	-6	2	-5	-3	-5	6	2
	4	11	-1	5	-1	0	-8	-1	-3	2	-3	5
T2	8	-3	3	7	-3	0	-3	-5	6	-5	4	2
	-5	8	2	-4	-10	-7	-7	-5	-5	2	3	8
	-3	2	-1	-9	-3	-3	2	1	0	-1	5	4
T3	-6	-5	-10	-10	-8	-7	-7	-8	-3	-5	1	4
	-3	-2	-1	-7	-6	-14	3	-8	1	5	5	4
	3	-10	-8	-5	-1	-10	-3	-5	-2	-10	4	2
T4	-3	-5	-8	-5	-4	-2	1	-1	2	6	3	-5
	-6	-2	-7	-5	-10	-5	-6	-4	-10	-6	-4	3
	-5	3	-7	-1	-3	-2	-8	-3	-10	-5	0	6

Analysis

Data collection
Analysis
Conclusion

Finding out Part to Part variation

	SP1		SP2		SP3		SP4		SP5		SP6	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
T1	-9	7	6	-5	-3	-6	1	-3	-15	-3	0	5
	-5	7	2	4	-4	-6	2	-5	-3	-5	6	2
	4	11	-1	5	-1	0	-8	-1	-3	2	-3	5
Range	13	4	7	10	3	6	10	4	12	7	9	3
T2	8	-3	3	7	-3	0	-3	-5	6	-5	4	2
	-5	8	2	-4	-10	-7	-7	-5	-5	2	3	8
	-3	2	-1	-9	-3	-3	2	1	0	-1	5	4
Range	13	11	4	16	7	7	9	6	11	7	2	6
T3	-6	-5	-10	-10	-8	-7	-7	-8	-3	-5	1	4
	-3	-2	-1	-7	-6	-14	3	-8	1	5	5	4
	3	-10	-8	-5	-1	-10	-3	-5	-2	-10	4	2
Range	9	8	9	5	7	7	10	3	4	15	4	2
T4	-3	-5	-8	-5	-4	-2	1	-1	2	6	3	-5
	-6	-2	-7	-5	-10	-5	-6	-4	-10	-6	-4	3
	-5	3	-7	-1	-3	-2	-8	-3	-10	-5	0	6
Range	3	8	1	4	7	3	9	3	12	12	7	11

Maximum value = 16 microns

Data collection

Analysis

Conclusion

Analysis

Finding out Stream to Stream variation for T1 – T2

	SP1		SP2		SP3		SP4		SP5		SP6	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
T1	-9	7	6	-5	-3	-6	1	-3	-15	-3	0	5
	-5	7	2	4	-4	-6	2	-5	-3	-5	6	2
	4	11	-1	5	-1	0	-8	-1	-3	2	-3	5
	-3.3333	8.33333	2.33333	1.33333	-2.6667	-4	-1.6667	-3	-7	-2	1	4
	11.6667		1		1.33333		1.33333		5		3	
T2	8	-3	3	7	-3	0	-3	-5	6	-5	4	2
	-5	8	2	-4	-10	-7	-7	-5	-5	2	3	8
	-3	2	-1	-9	-3	-3	2	1	0	-1	5	4
	0	2.33333	1.33333	-2	-5.3333	-3.3333	-2.6667	-3	0.33333	-1.3333	4	4.66667
	2.33333		3.33333		2		0.33333		1.66667		0.66667	
T3	-6	-5	-10	-10	-8	-7	-7	-8	-3	-5	1	4
	-3	-2	-1	-7	-6	-14	3	-8	1	5	5	4
	3	-10	-8	-5	-1	-10	-3	-5	-2	-10	4	2
	-2	-5.6667	-6.3333	-7.3333	-5	-10.333	-2.3333	-7	-1.3333	-3.3333	3.33333	3.33333
	3.66667		1		5.33333		4.66667		2		0	
T4	-3	-5	-8	-5	-4	-2	1	-1	2	6	3	-5
	-6	-2	-7	-5	-10	-5	-6	-4	-10	-6	-4	3
	-5	3	-7	-1	-3	-2	-8	-3	-10	-5	0	6
	-4.6667	-1.3333	-7.3333	-3.6667	-5.6667	-3	-4.3333	-2.6667	-6	-1.6667	-0.3333	1.33333
	3.33333		3.66667		2.66667		1.66667		4.33333		1.66667	

Maximum = 11.6

Analysis

Data collection
Analysis
Conclusion

Finding out Stream to Stream variation for Spindle to Spindle

	SP1		SP2		SP3		SP4		SP5		SP6		
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	
T1	-9	7	6	-5	-3	-6	1	-3	-15	-3	0	5	
	-5	7	2	4	-4	-6	2	-5	-3	-5	6	2	
	4	11	-1	5	-1	0	-8	-1	-3	2	-3	5	
	2.50		1.83		-3.33		-2.33		-4.50		2.50		7.00
T2	8	-3	3	7	-3	0	-3	-5	6	-5	4	2	
	-5	8	2	-4	-10	-7	-7	-5	-5	2	3	8	
	-3	2	-1	-9	-3	-3	2	1	0	-1	5	4	
	1.17		-0.33		-4.33		-2.83		-0.50		4.33		8.67
T3	-6	-5	-10	-10	-8	-7	-7	-8	-3	-5	1	4	
	-3	-2	-1	-7	-6	-14	3	-8	1	5	5	4	
	3	-10	-8	-5	-1	-10	-3	-5	-2	-10	4	2	
	-3.83		-6.83		-7.67		-4.67		-2.33		3.33		11.00
T4	-3	-5	-8	-5	-4	-2	1	-1	2	6	3	-5	
	-6	-2	-7	-5	-10	-5	-6	-4	-10	-6	-4	3	
	-5	3	-7	-1	-3	-2	-8	-3	-10	-5	0	6	
	-3.00		-5.50		-4.33		-3.50		-3.83		0.50		6.00

Maximum = 11

Analysis

Data collection
Analysis
Conclusion

Finding out Time to Time variation

	SP1		SP2		SP3		SP4		SP5		SP6		
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	
T1	-9	7	6	-5	-3	-6	1	-3	-15	-3	0	5	
	-5	7	2	4	-4	-6	2	-5	-3	-5	6	2	-0.55556
	4	11	-1	5	-1	0	-8	-1	-3	2	-3	5	
T2	8	-3	3	7	-3	0	-3	-5	6	-5	4	2	
	-5	8	2	-4	-10	-7	-7	-5	-5	2	3	8	-0.41667
	-3	2	-1	-9	-3	-3	2	1	0	-1	5	4	
T3	-6	-5	-10	-10	-8	-7	-7	-8	-3	-5	1	4	
	-3	-2	-1	-7	-6	-14	3	-8	1	5	5	4	-3.66667
	3	-10	-8	-5	-1	-10	-3	-5	-2	-10	4	2	
T4	-3	-5	-8	-5	-4	-2	1	-1	2	6	3	-5	
	-6	-2	-7	-5	-10	-5	-6	-4	-10	-6	-4	3	-3.27778
	-5	3	-7	-1	-3	-2	-8	-3	-10	-5	0	6	
													3.25

3.25 microns

Analysis - Summary

- Part to Part variation = 16 microns
- Tooling 1 to Tooling 2 variation = 11.6 microns
- Spindle to Spindle variation = 11 microns
- Time to Time variation = 3.25 microns

Conclusion

Data collection
Analysis
Conclusion

- Part to Part variation is the highest
- Since, Part to Part variation is the highest, it could be due to the following sources of variation
    - Machine
    - Process design
- To further zero down, Variable search should be done

Proceeding further ..

- If part to part variation is high
  - Source of variation is either machine or Process design. Do “Variable Search” or TPM
- If Stream to Stream variation is high
  - Plan action based on which stream is having an undesirable value
- If Time to Time variation is high
  - Identify the event that has lead to this variation and take action to control the quality of the event

Graphical Analysis (ANOM)

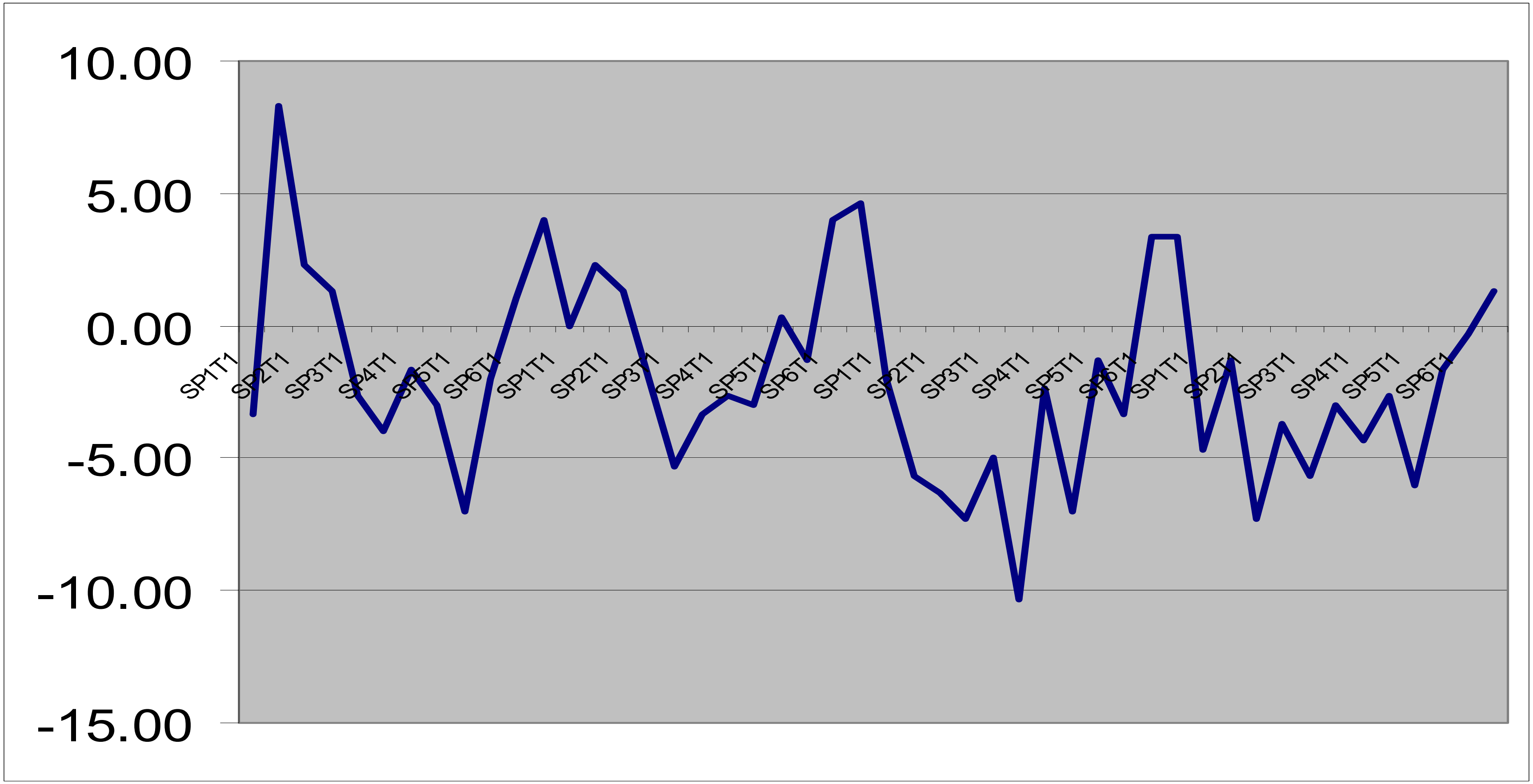
Data collection → Analysis → Conclusion

- ‘Y’ axis is the average values
- Decide on in what pattern ‘X’ axis should be made
- ‘X’ axis can be grouped Stream wise or Time wise depending on the objective of the analysis
- Stream wise grouping will give an indication in the shift in the averages between the streams
- Time wise grouping will give an indication in the shift in the average over a period of time

Graphical Analysis (ANOM)

Data collection
Analysis
Conclusion

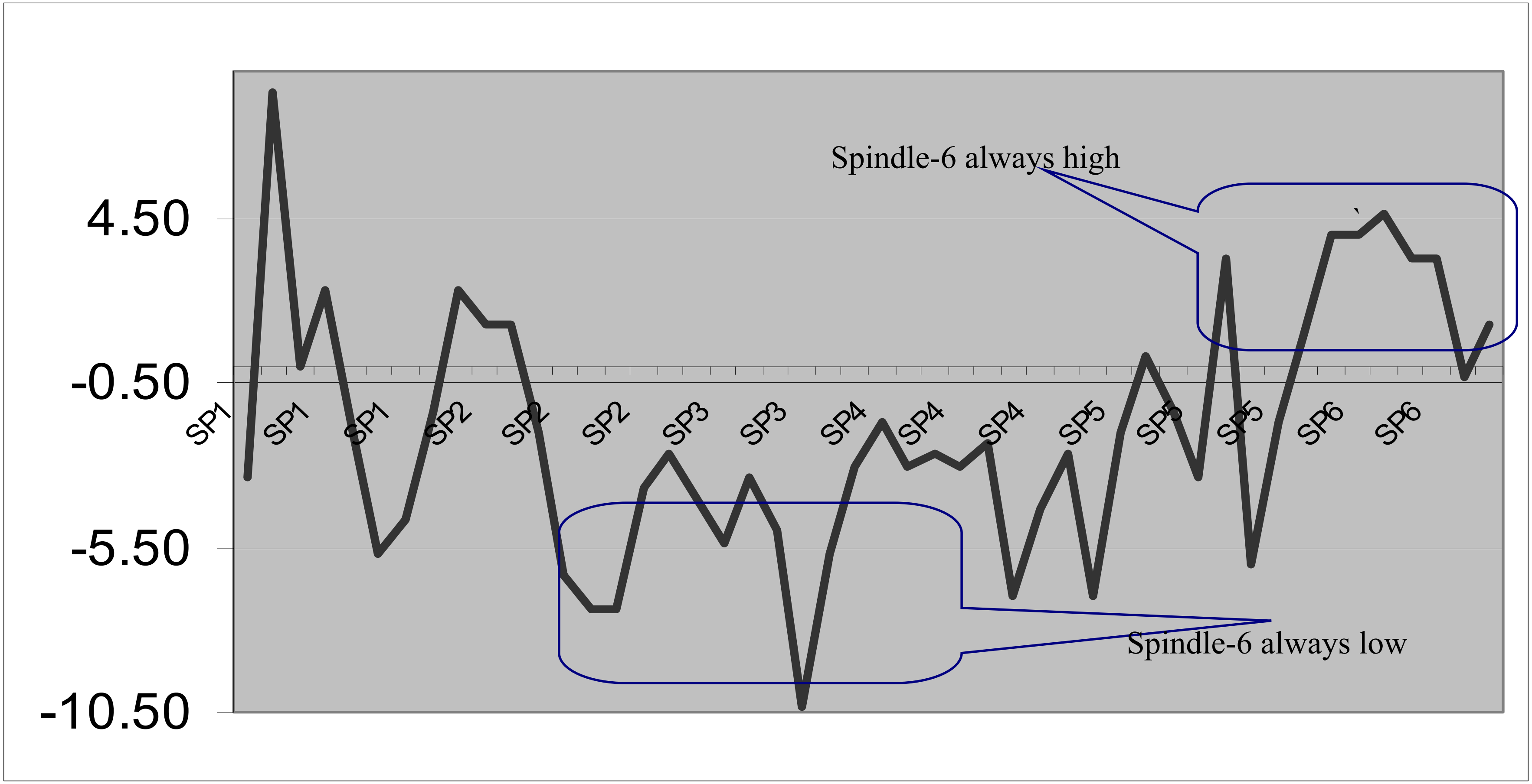
Graph with x-axis over the time period



Graphical Analysis (ANOM)

Data collection
Analysis
Conclusion

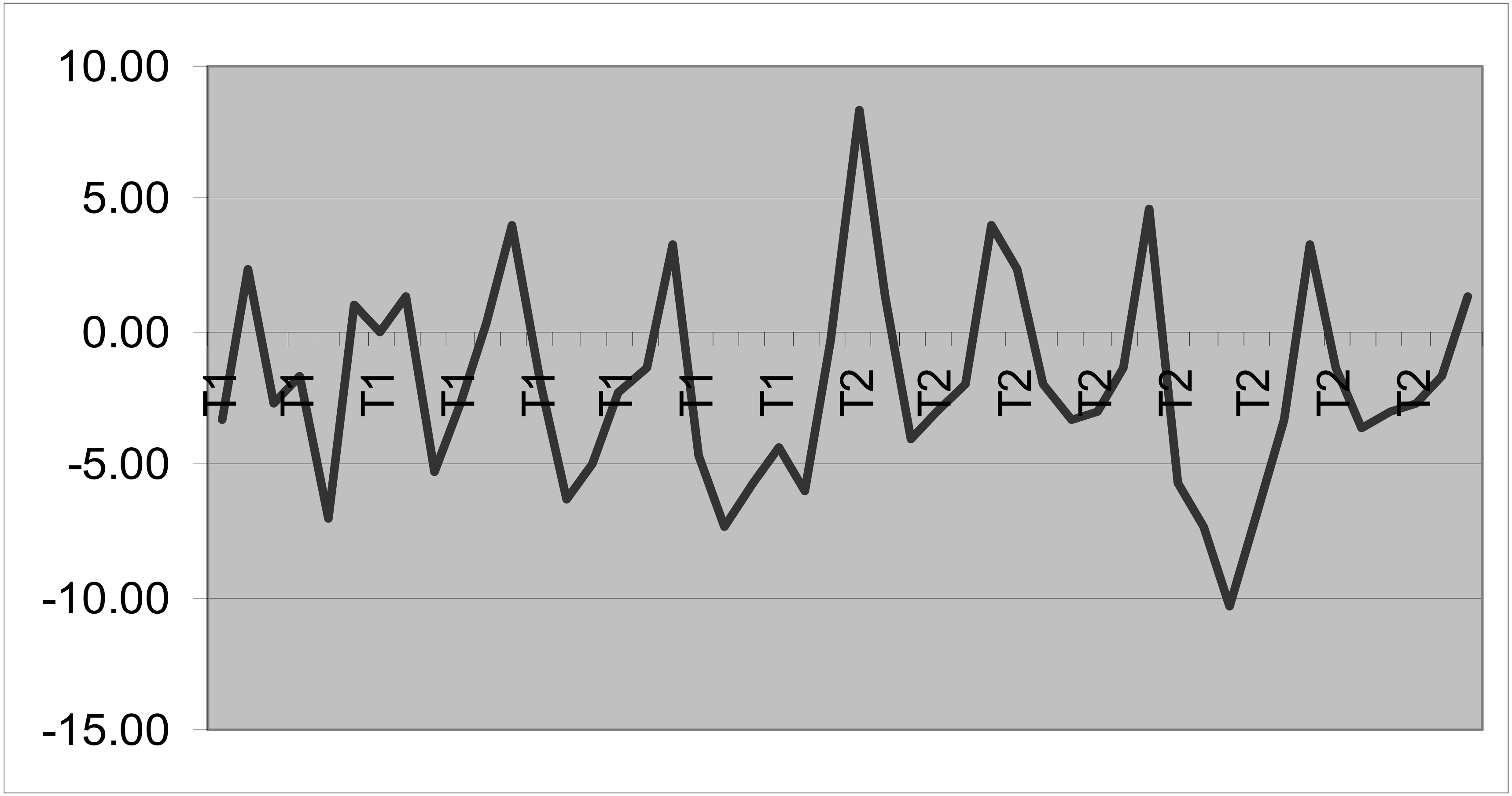
Graph with x-axis grouped Spindle wise



Graphical Analysis (ANOM)

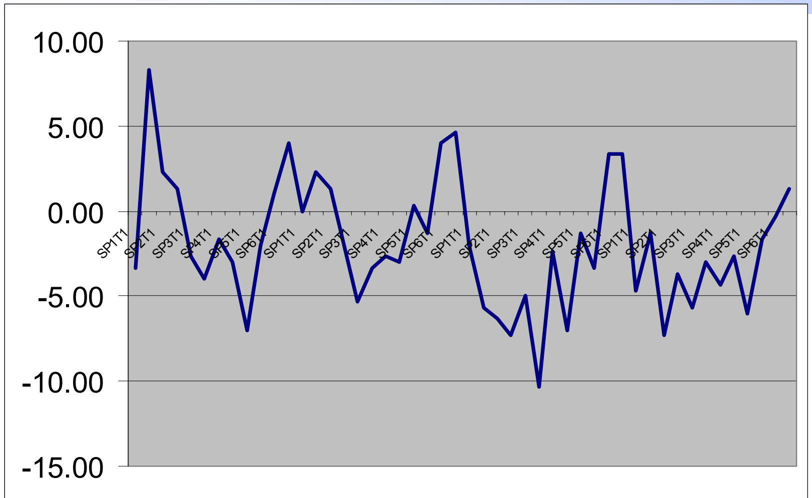
Data collection
Analysis
Conclusion

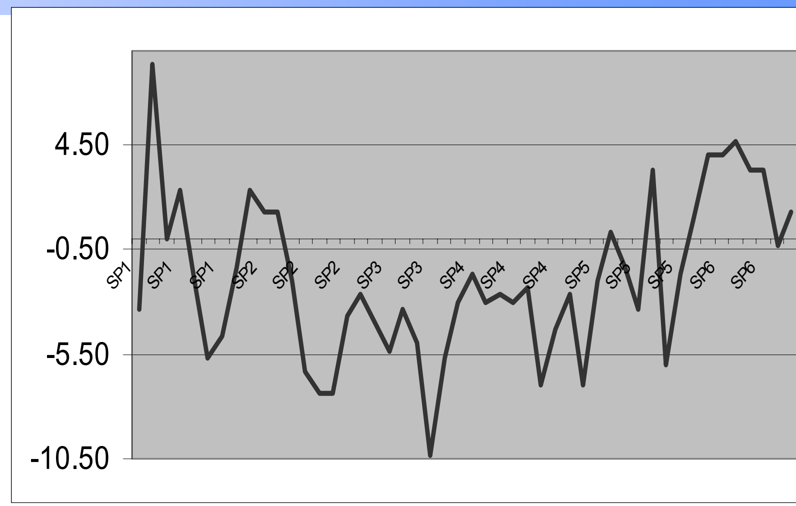
Graph with x-axis grouped Tooling wise

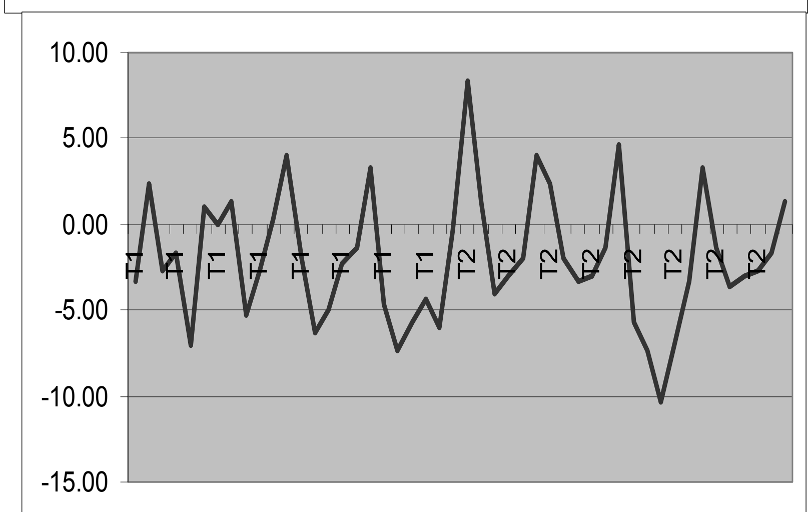


Graphical Analysis (ANOM) - Summary

Data collection → Analysis → Conclusion



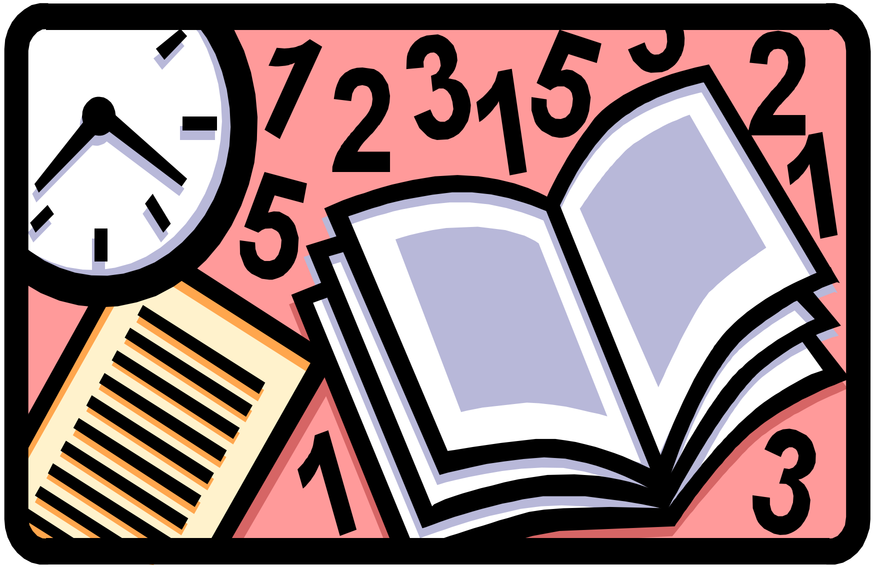




Proceeding further ..

- Based on the average position in the graph (grouped based on Time), setting has to be adjusted in the process
- Based on the average position in the graph (grouped based on streams), sources of some streams having high average to be determined

Exercise # 8 – Multi-Vari analysis



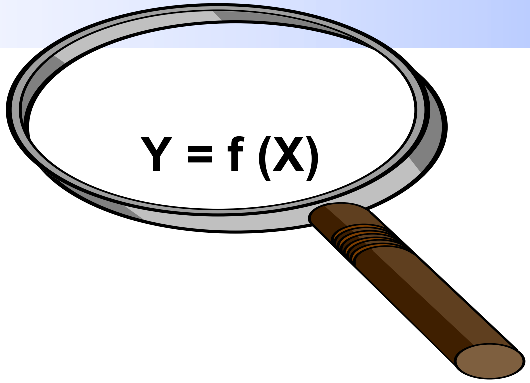
- Do Multi-vari analysis and tell the causes

Tool # 5 – Concentration Chart

Application

- Used to find out whether the problem/defects is concentrated in a particular region of a product or in a process
- Is used when the defect can come at multiple locations of the product (eg: blow holes, pinholes, dirt)
- Is used when the defect can get generated at multiple streams from the process and the streams are too high to apply Multi-vari (eg: Batch type Heat treatment)

Application – Concentration chart



- **Y = Response**

X = SSV

- **Material**
- **Process design**
- **Machine/Equipment**

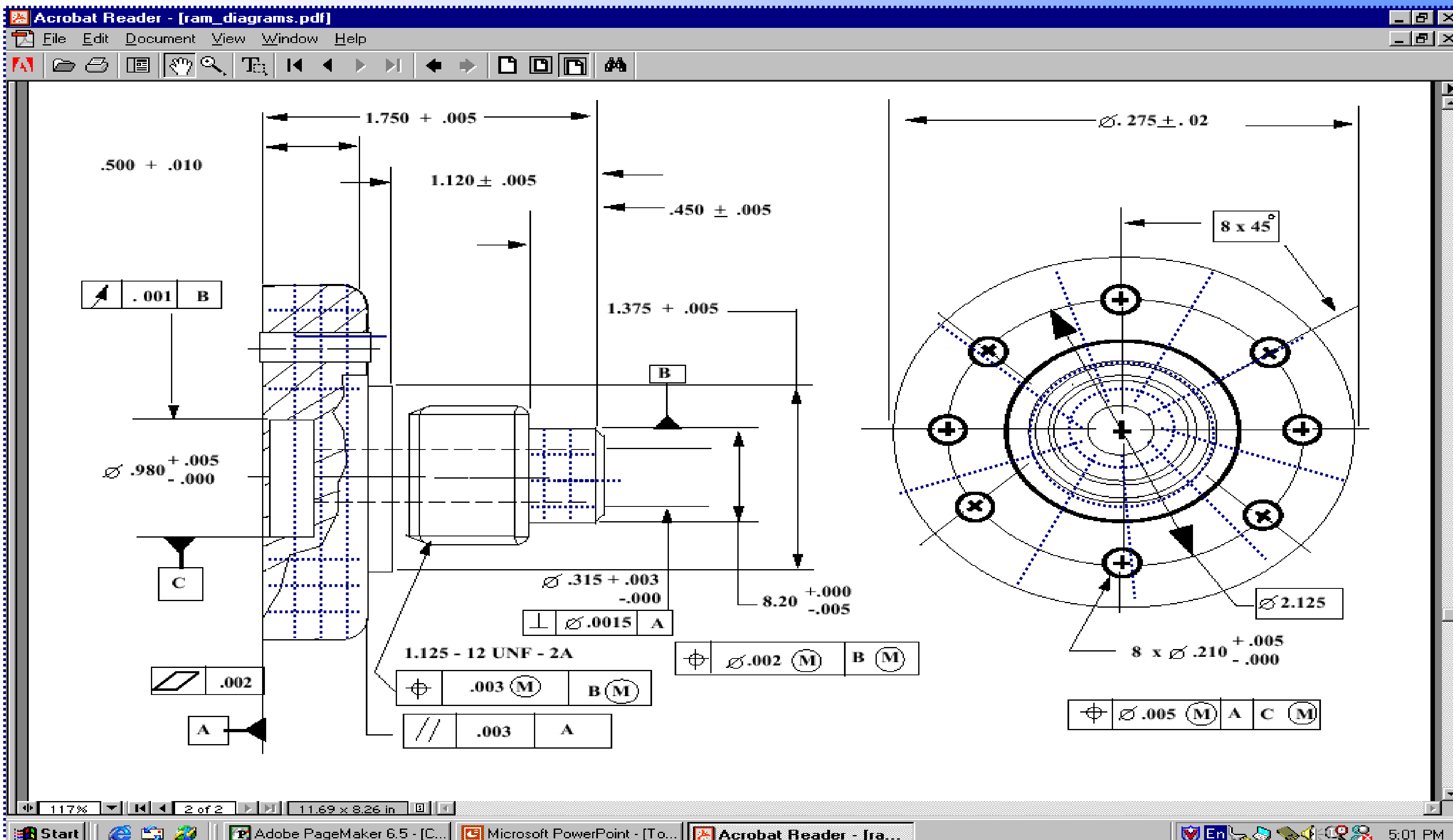
Response is measured in this tool

Data Collection – Product stream

- Make a sketch of the part and divide into different zones (grids)
- Quantify the response on a scale of 1-5
- Collect parts continuously from the process and if there are defects, find out the location and judge the severity and mark the appropriate number in the grid
- Continue to do this till 80% of historic rejection is captured

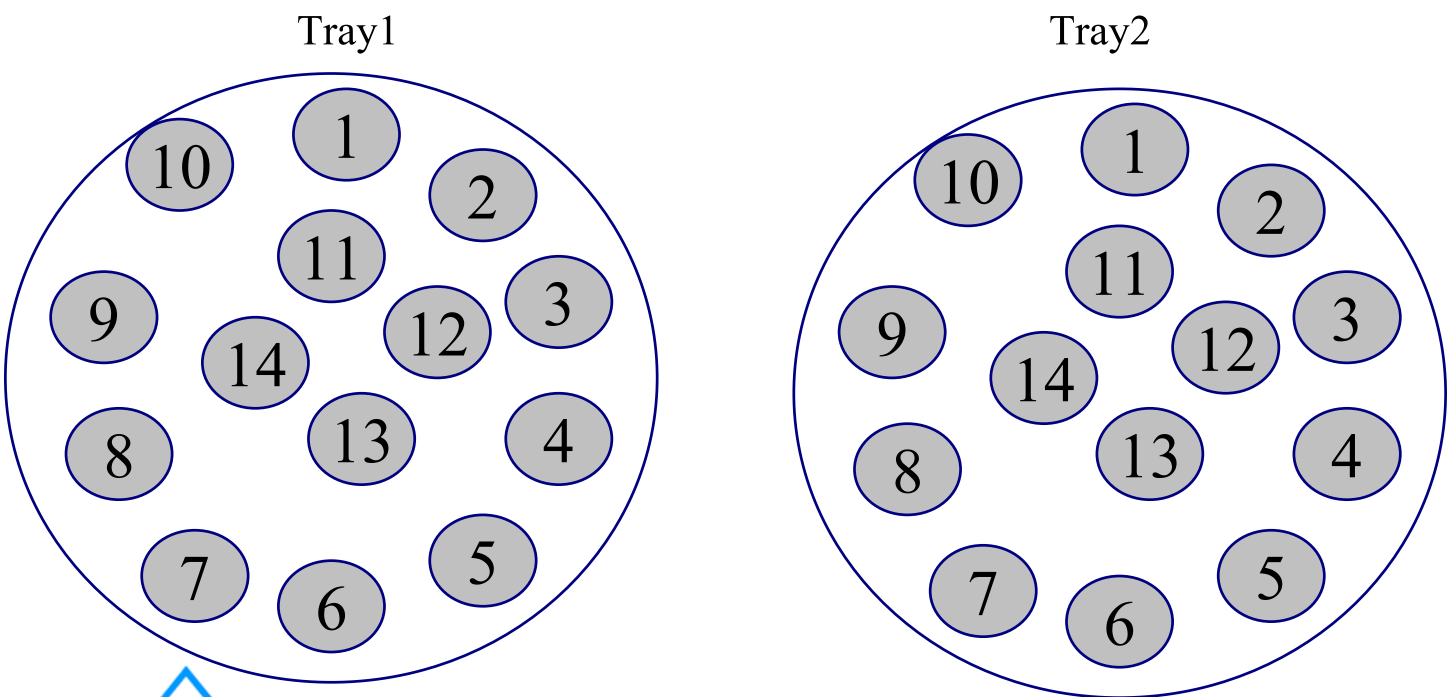
Data Collection – Product stream

Data collection
Analysis
Conclusion



Data Collection – Process stream

- Make a sketch of the jig/fixture with all the streams
- Process the parts and measure the response
- Record on the sketch the defects on a scale of 1-5



Analysis & Conclusion

Data collection
Analysis
Conclusion

• Only a visual analysis done

• Look for any concentration of the defect in a particular region of the product/process

•If the defect is concentrated in a process stream, then the source of variation is from the process (eg: Variation in temp across the furnace)

•If the defect is not concentrated in a process stream, then the source of variation is the material spec

•If the defect is concentrated in a product stream, it is a deficiency in the process

•If the defect is not concentrated in a product stream, it is a process design/material issue.

Tool # 6 – Variable Search Process/Product design and Characterization tool

TUV - Academy

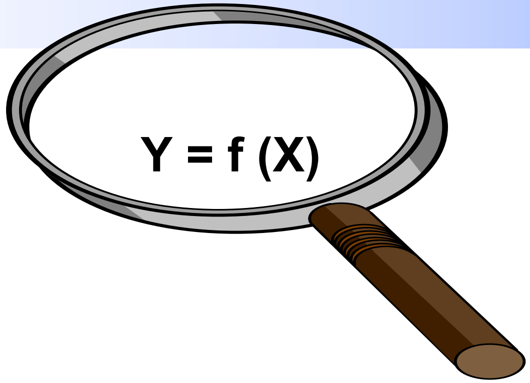
TÜV Rheinland/
Berlin-Brandenburg

TÜV

Application

- The application of this tool is not based on the difference between good and bad parts
- Can be used for following
  - Process/Product design
  - Process/Product characterization
- Stages involved are similar to Component Search

Application – Variable search



X = SSV

- Y = Response

- Process parameters
- Product characteristics

Response is measured in this tool

Application

- Stage # 0 , where the parameters and the levels are decided (Experimental design)
- Three stages of Data collection , analysis and conclusion
  - Stage – 1 – To find out whether the parameters and the levels are identified correctly (To validate Stage # 0)
  - Stage – 2 – To identify which of the process/product parameters are significant [Characterization]
  - Stage – 3 – To validate the findings of Stage –2
- We can proceed to Stage 2 and 3 only if in Stage-1, the conclusion is, the parameters and levels are identified correctly (Stage # 0 is done correctly)

Application

- Stage # 4 of Variable search is factorial analysis
- This analysis is used to build a Linear model between the Response ('Y') and the Characterized parameters ('X') in Stage #2
- Future Process design can be done once this Linear model is built
- Will save time in Process design and can be done accurately

Data collection
Analysis
Conclusion

Stage # 0 – Experimental design

- The design of the process parameters and the levels are done in this stage
- The levels depends on the objective of using the variable search
  - If we are applying Variable search for a process which is creating problems, then Method # 1 design discussed should be followed
  - If we are applying to characterize a new process design then Method # 2 design discussed should be followed

Stage # 0 – Experimental design Method #1

Data collection

Analysis

Conclusion

- List down all the Process parameters involved in the process affecting the response
- We need to identify the ‘+’ (BOB) level and ‘-’ (WOW) level for each parameter
- Which should be the BOB level -------------------
- Which should be the WOW level ----------------------

Stage # 0 – Experimental design Method #2

Data collection → Analysis → Conclusion

- List down all the Process parameters involved in the process affecting the response that needs to be characterized
- We need to identify the ‘+’ (BOB) level and ‘-’ (WOW) level for each parameter
- Which should be the BOB level -----------------
- Which should be the WOW level ---------------------

Stage # 0 – Experimental design Example

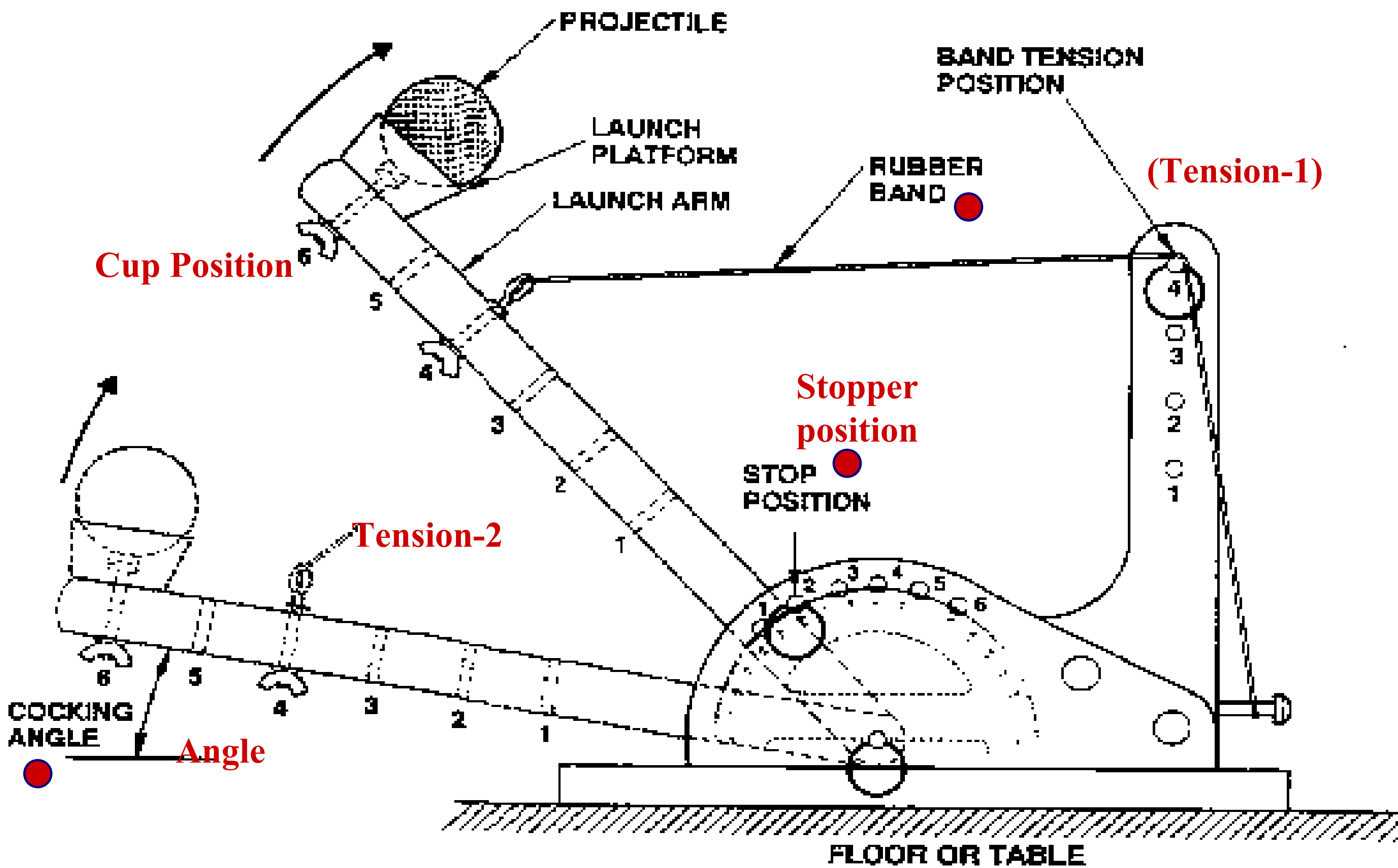
Data collection
Analysis
Conclusion

Response: Finish, Method #1 design

Parameter	-	+
a.Stirrer design	Cowl disc	Paddle type
b.Sequence of addition	R6710-RS5901-VV	VV-RS5901-R6710
c.Mixing time	15	120
d.Stirrer RPM	400	800

Stage # 0 – Experimental design Catapult

Data collection
Analysis
Conclusion



Stage # 0 – Experimental design Catapult

Data collection → Analysis → Conclusion

Response: Distance

Parameter	-	+
a.Angle		
b.Tension-1		
c.Tension-2		
d.Stopper position		
e. Cup position		

Stage # 1 – Data Collection

Data collection
Analysis
Conclusion

- Set the process at the '-' level and make one part/batch and measure the response
- Set the process at the '+' level and make one part/batch and measure the response
- Do like this two more time alternating between '-' level and '+' level
- Totally we will have 3 responses in '-' level and 3 responses in '+' level

Stage # 1 – Data collection Catapult

Data collection

Analysis

Conclusion

Response: Distance in inches

	-	+
First run		
Second run		
Third run		

Calculate D/d ratio:

What is your conclusion:

Stage # 2 – Data Collection

Data collection
Analysis
Conclusion

- List down the parameters in the order in which we think that it will affect the response
- Take one parameter at a time
- Set the parameter at '-' level and all other parameters at '+' level. Make one part and note down the response (A-R+)
- Set the parameter at '+' level and all other parameters at '-' level. Make one part and note down the response (A+R-)
- Conclusion is same as we did in 'Component Search'

Stage # 2 – Data collection Catapult

- List down the parameters in the order it will affect the response for Catapult
  - A.
  - B.
  - C.
  - D.
  - E.

Stage # 2 – Data collection Catapult

Data collection
Analysis
Conclusion

	Response		Response	Conclusion

Stage # 3 – Data collection Catapult

Data collection
Analysis
Conclusion

Validation of the characterized parameters in Stage #2

	Response		Response	Conclusion

Stage # 4 – Factorial analysis Catapult

Data collection
Analysis
Conclusion

Do factorial analysis for the parameters characterized in Stage #2 and identify the contribution

			Responses	Median

Stage # 4 – Factorial analysis Catapult

Data collection
Analysis
Conclusion

Find out the contribution of the interactions between the parameters

				Median

Stage # 4 – Factorial analysis Catapult

Data collection

Analysis

Conclusion

Write your conclusions of the Factorial analysis here

Data collection

Analysis

Conclusion

Stage # 4 – Factorial analysis
Building Linear model

- Mathematical model for the process is given by the general equation
  - Y = (Average of all medians) (+/-) ½ * (A's contribution)*A (+/-) ½ * (B's contribution) *B (+/-) ……. (+/-) ½ * (AB's interactions contribution) *A*B (+/-) …..

Data collection
Analysis
Conclusion

Stage # 4 – Factorial analysis
Catapult- Building Linear model

- Write the Catapult's Linear model here

Data collection

Analysis

Conclusion

Stage # 4 – Factorial analysis
Process design using Linear model

Your distance is (Y) =

Design the process and prove the design

Proceeding further ..

- If we are applying variable search for problem solving, then do the following
  - If there is no difference achieved through the design, then the cause is the machine and we have to analyze the machine mechanisms in detail
- Generally the problem solving process will culminate with Variable Search

Tool # 7 – B vs C
(Better Vs Current)

Application

- This is not a root cause identification tool
- This is a tool to validate the causes already found by applying the other 6 tools
- Other than validation of the cause, there are many other applications
- There are two applications
  - To find out whether one choice is better than other
  - To find out how much it is better in terms of response

Application

- Following are the applications for B Vs C
  - To validate the cause
  - To validate the Process/Product changes
  - To validate the improvement actions
  - To compare between two entities (eg: two suppliers, two machines, two departments, two assembly lines etc..)
  - Process qualification

Application

- What is B and C for different situations
  - To validate the cause
    - With the cause is ‘C’
    - Without the cause is ‘B’
  - To validate the Process/Product changes
    - Before change is ‘C’
    - After change is ‘B’
  - To validate the improvement actions
    - Without action is ‘C’
    - With the action is ‘B’
  - To compare between two entities (eg: two suppliers, two machines, two departments, two assembly lines etc..)
    - Any thing can be ‘B’ or ‘C’
  - Process qualification
    - One extreme of the setting is ‘B’ and another extreme is ‘C’

Data Collection

- First we should decide the response based on the application
- Some examples
  - If we are are validating a ‘new grinding wheel’ introduction, response could be Finish
  - If we are validating a cause ‘Molecular weight of the material’, response could be ‘Settling time’
  - If we are comparing two suppliers, response could be ‘Rejection percentage’

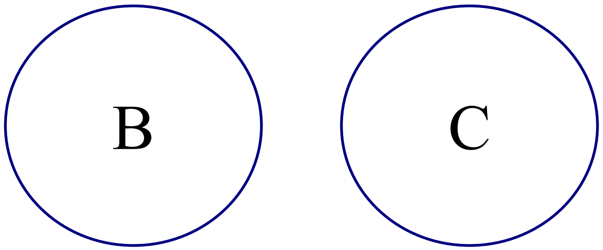
Data Collection

Data collection
Analysis
Conclusion

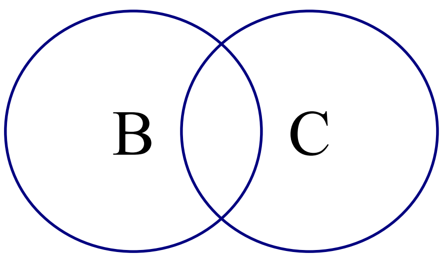
- Before we collect data, we should do any one of the following assumptions
  - The responses with ‘B’ condition will be clearly distinct from the responses with ‘C’ condition. There will not be any overlap
  - The responses with ‘B’ condition may overlap with the responses with the ‘C’ condition
- Depending on the assumption done above, the sample size for data collection will vary

Data Collection

Data collection
Analysis
Conclusion



If this is the assumption, we can validated with 3B and 3C



If this is the assumption, we require minimum 6B and 6C. Sample sizes are further increased in steps of 3 (9B,9C 12B, 12C etc..)

Data Collection

- Once the assumption is finalized the data is collected based on the sample size
- Samples can be
  - Parts
  - Days
  - Weeks
  - Shifts
  - Months
  - Batches

Data Collection

Data collection → Analysis → Conclusion

- Example
  - A coil spring manufacturer has introduced a new operation ‘Shot peening’ to improve the life of the springs. He wants to use B Vs C to validate this new operation
- What is the response --------------------------
- What application of B Vs C is this -----------------

Data Collection

- Data collected for 3 springs with Shot peening ('B') and 3 springs without shot peening ('C') are given below

Without shot peening ('C') in cycles	With Shot peening ('B')
87,500	1,05,000
85,550	1,20,235
95,000	1,15,250

Analysis for 3B and 3C

Without shot peening ('C') in cycles	With Shot peening ('B')
87,500	1,05,000
85,550	1,20,235
95,000	1,15,250

•Check whether are there any overlaps in the responses in the data. If the answer is no, then the cycle has improved because of the process change

•If there is overlap, then the cycle has not improved because of the process change

Data collection

Analysis

Conclusion

Analysis for 6B and 6C

- In case of 6B and 6C, find out the total count
- If the total count is >=6, then there is a difference between B and C, otherwise not
- In case of no difference, increase the sample size

Analysis – Quantifying the amount of improvement

Data collection
Analysis
Conclusion

- Find out the average of 'B' and 'C' conditions
- Find out the difference between the averages (X_b – Xc)
- Find out the Sigma of 'B' values (Sigma (b))
- Get the 'K' value from the table provided based on the CL %
- If (X_b – Xc) >= K * Sigma (b), then the conclusion is

  (X_b – Xc) improvement has taken place at the assumed CL%

Analysis – 'K' value for 95% CL

Sample size	K
3,3	4.2
6,6	2.96
9,9	2.42
12,12	2.1
15,15	1.87
18,18	1.71
21,21	1.58
24,24	1.48
27,27	1.40
30,30	1.32

Analysis – 'K' value for 90% CL

Sample size	K
3,3	3.7
6,6	2.61
9,9	2.13
12,12	1.85
15,15	1.65
18,18	1.51
21,21	1.39
24,24	1.30
27,27	1.23
30,30	1.17

Analysis – ‘K’ value for 50% CL

Data collection → Analysis → Conclusion

Sample size	K
3,3	2
6,6	1.41
9,9	1.15
12,12	1
15,15	0.89
18,18	0.81
21,21	0.75
24,24	0.70
27,27	0.66
30,30	0.63

Analysis – Quantifying the amount of improvement

Data collection
Analysis
Conclusion

	Without shot peening ('C') in cycles	With Shot peening ('B')
	87,500	1,05,000
	85,550	1,20,235
	95,000	1,15,250
Average	89,350	1,13,495

Difference between averages (Xb – Xc) = 24145

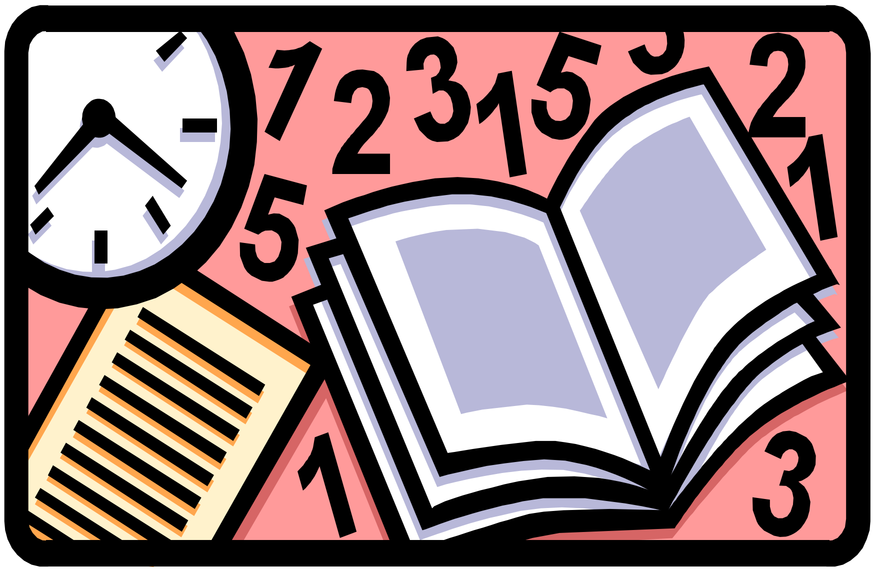
Sigma (b) = 7767.6

K (95% CL) = 4.2

K * Sigma = 32623.92

What is the conclusion ?

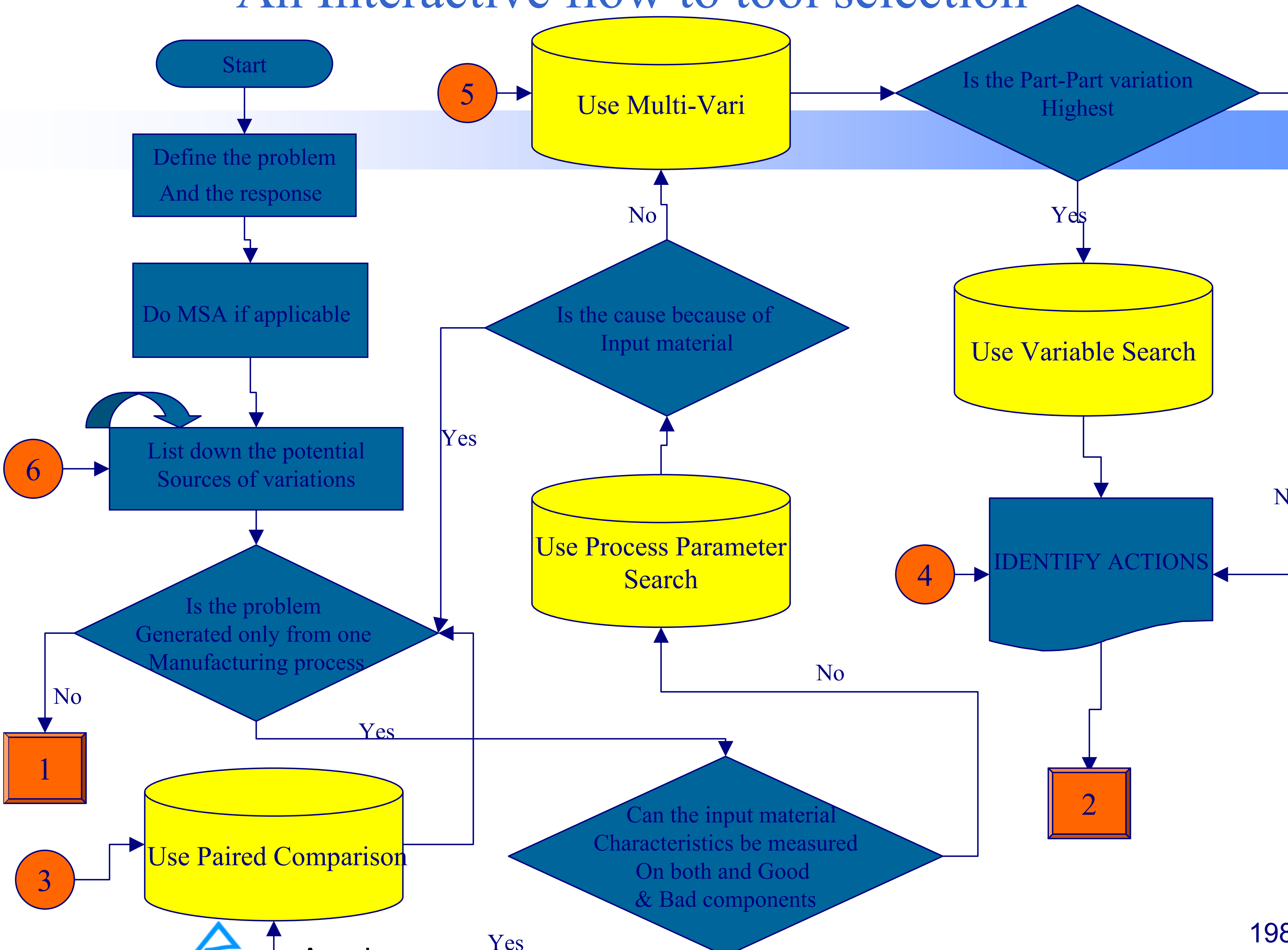
Exercise # 10 – B Vs C



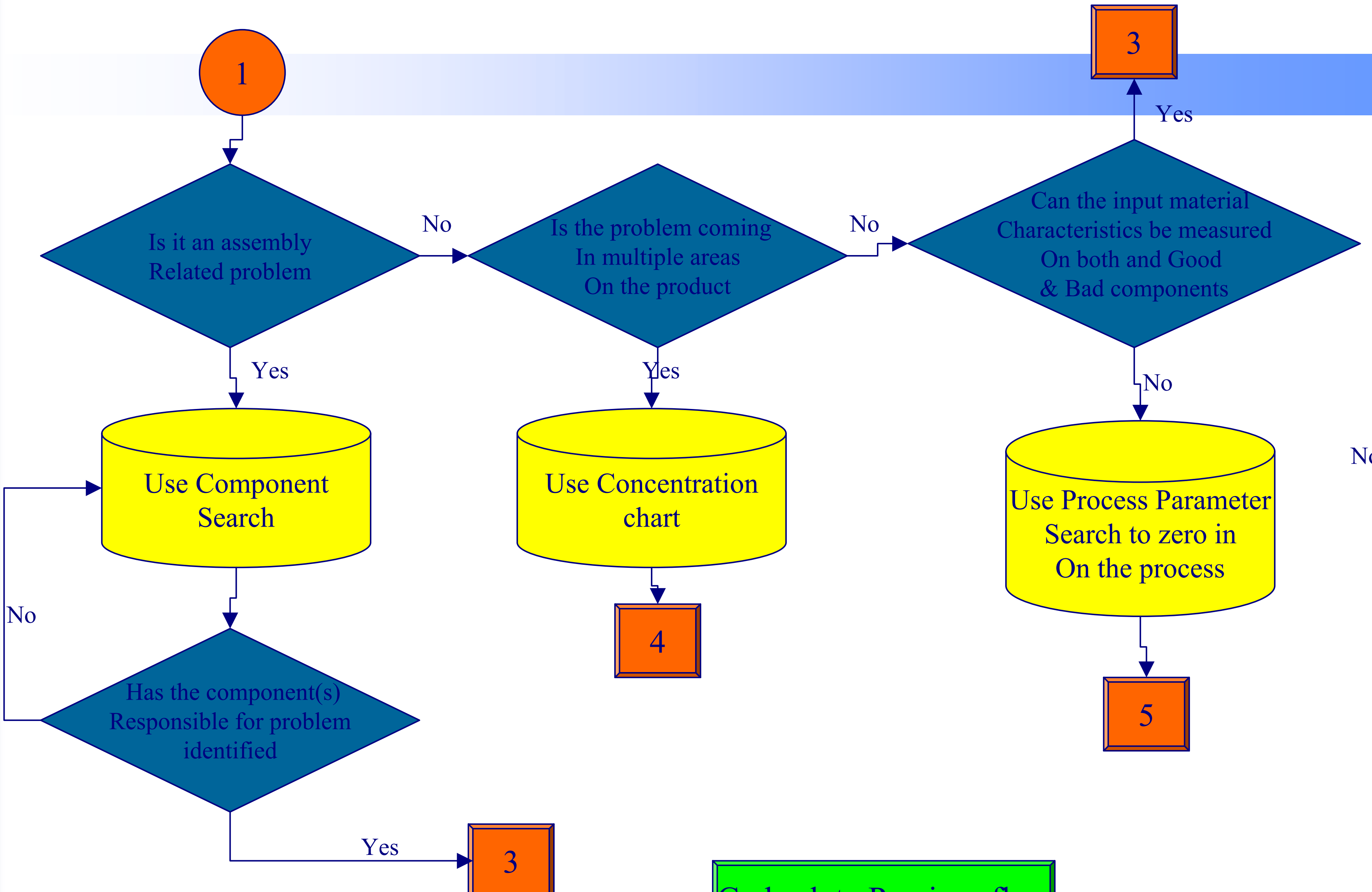
- Validate whether the cause established is correct or not

Tool selection – A Quick interactive flow diagram

An Interactive flow to tool selection



An Interactive flow to tool selection



Go back to Previous flow

An Interactive flow to tool selection