Six Sigma Implementation

Tools Application Rules Checklist

20th June2007

Six Sigma Implementation

Tools Application Rules Index

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SIX SIGMA

- 3 Sigma Level--------- Tolerance= 6σ

  Defect Rate= 2700ppm

- 6 Sigma Level--------- 50% of Tolerance= 6σ

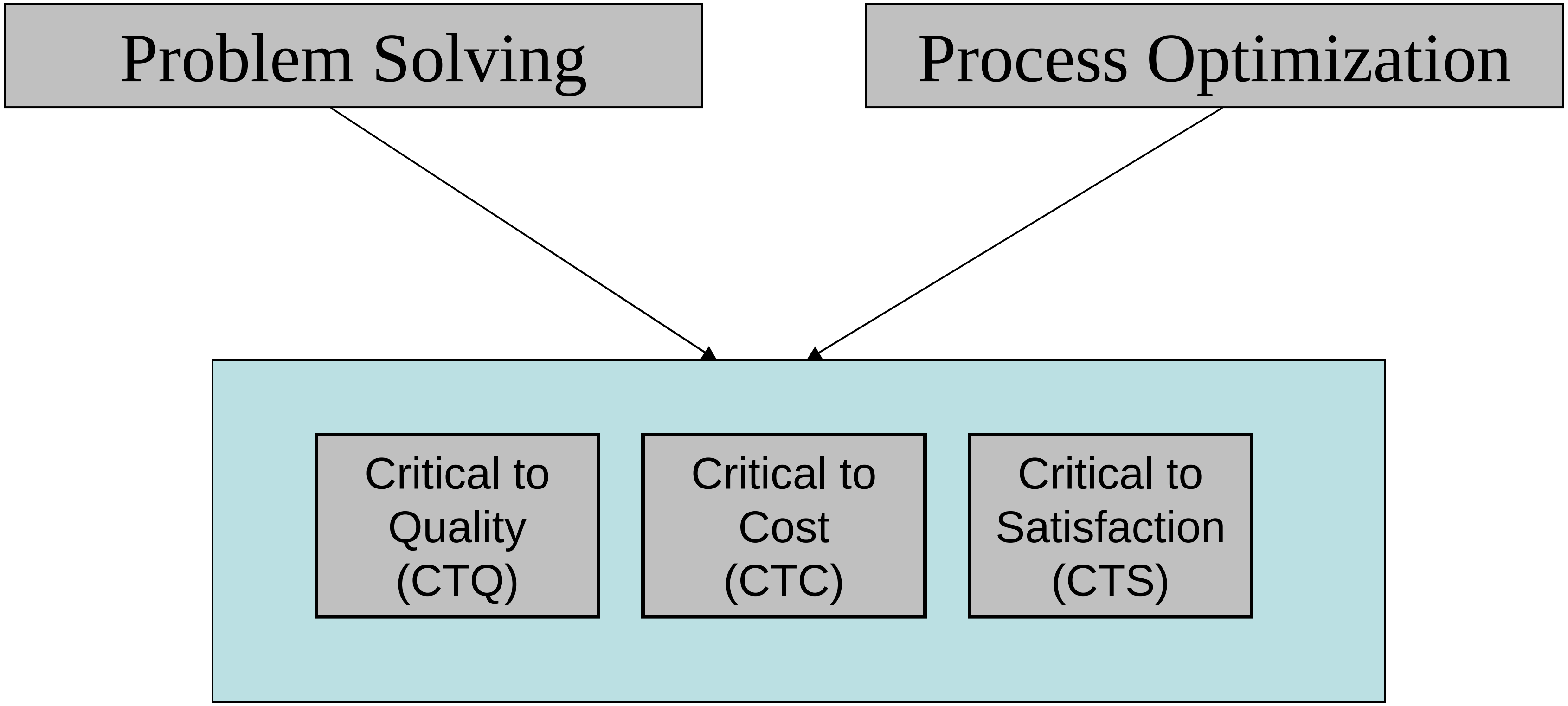
  Defect Rate= 3ppb

Six sigma – General understanding

- Key to the success of Six Sigma:
  - Process knowledge
  - Knowledge in selection and application of DOE tools
  - Top Management Commitment
  - Strong Review Mechanism
- Six Sigma was first developed by: Mr Bill Smith, Motorola, 1986
- Six Sigma Improvement Process structure adopted: DMAIC
- Funneling for identification of cause is done till it is found that cause is controllable.
- Cause which is controllable is the root cause of the problem.
- Six Sigma is all about reducing & eliminating wastes in all processes.
- Methodology adopted for six Sigma is Funneling.
- Objective of Six Sigma is to improve RTY and operate all processes at “Six Sigma level”.
- Objective of Six Sigma is to operate all measurable outcome of the processes at “Six Sigma level” and attribute outcomes of the processes at “Zero Defect.”
- Key to achieving Six Sigma Level is “ Process knowledge, correct selection and application of DOE Tool and innovative solutions in improving the process”
- Six sigma is the estimated Part to Part variation at 99.73% CL

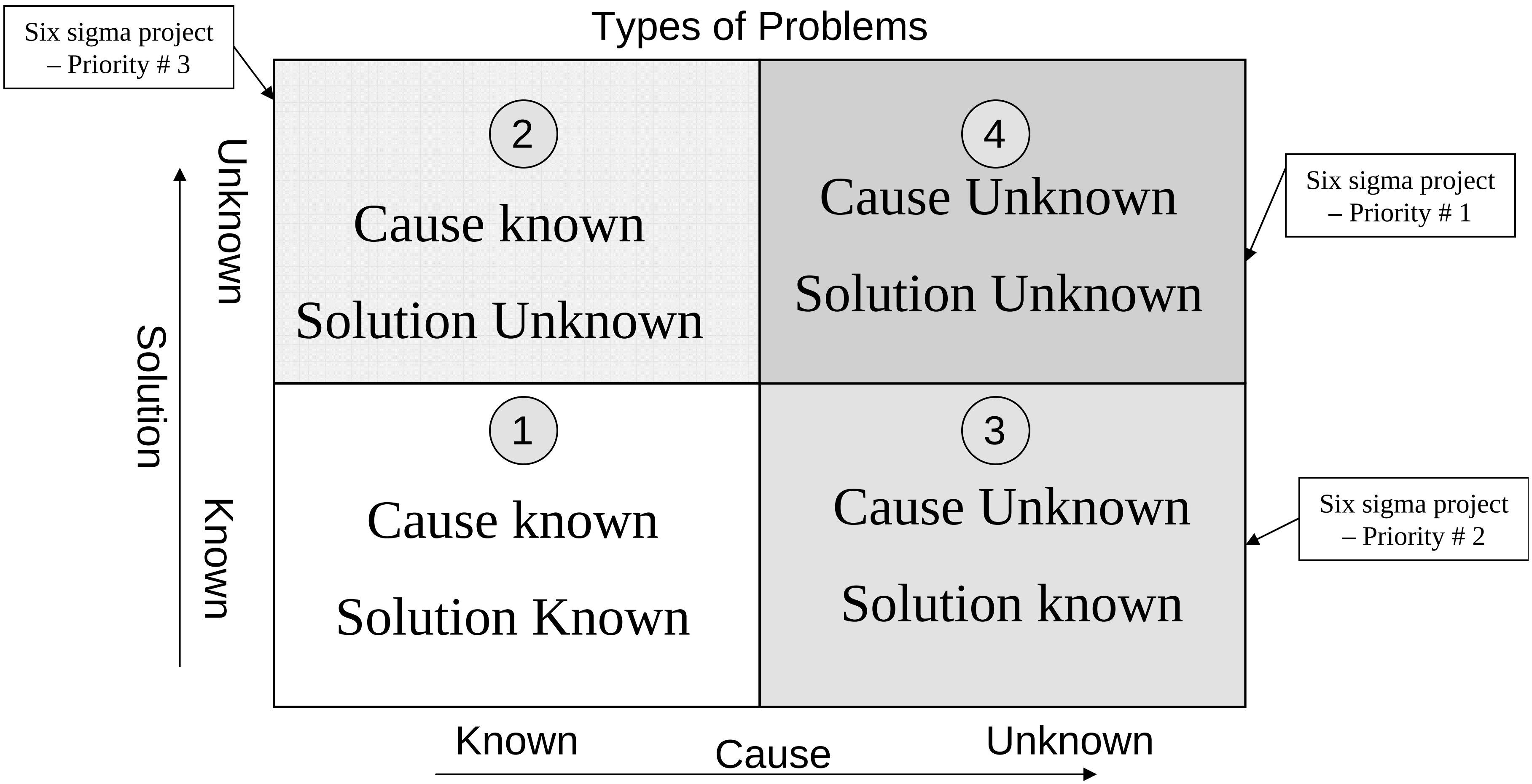
Key skills of BB : Process knowledge, Good observation and correct selection of tools

Selection of Six sigma Projects



Key skills of BB : Process knowledge, Good observation and correct selection of tools

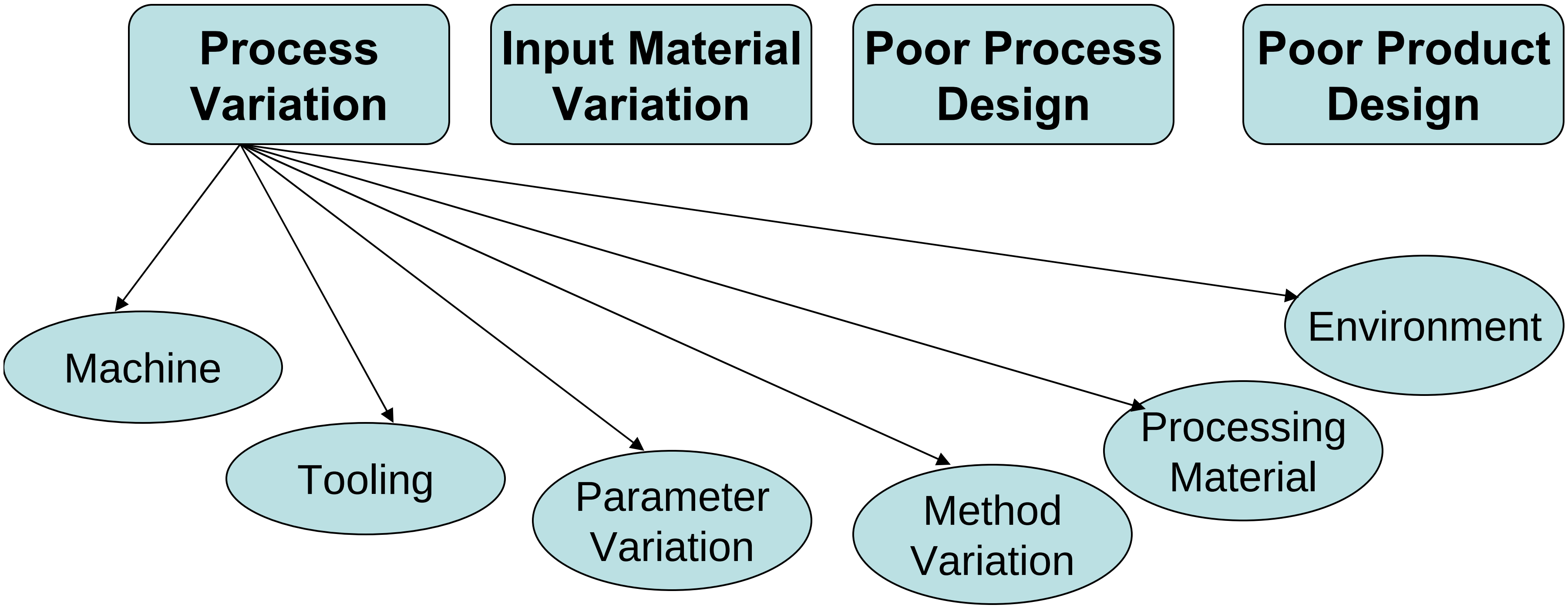
How to select Problem solving BB projects



Always check the Basic machine condition for any obvious abnormalities and correct it before selecting the project. Select it as a project only if the problem persists after ensuring basic machine condition

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Source of Variations



Key skills of BB : Process knowledge, Good observation and correct selection of tools

DMAIC Process

Define the Problem

- Provide full information about the problem such as the rejection %, Suspected sources of variations for the problem, type of response

Measure & Analysis

Apply DOE techniques and arrive at the "Root cause" (Controllable cause) for the problem

Improve

Validate the Root cause using B vs C

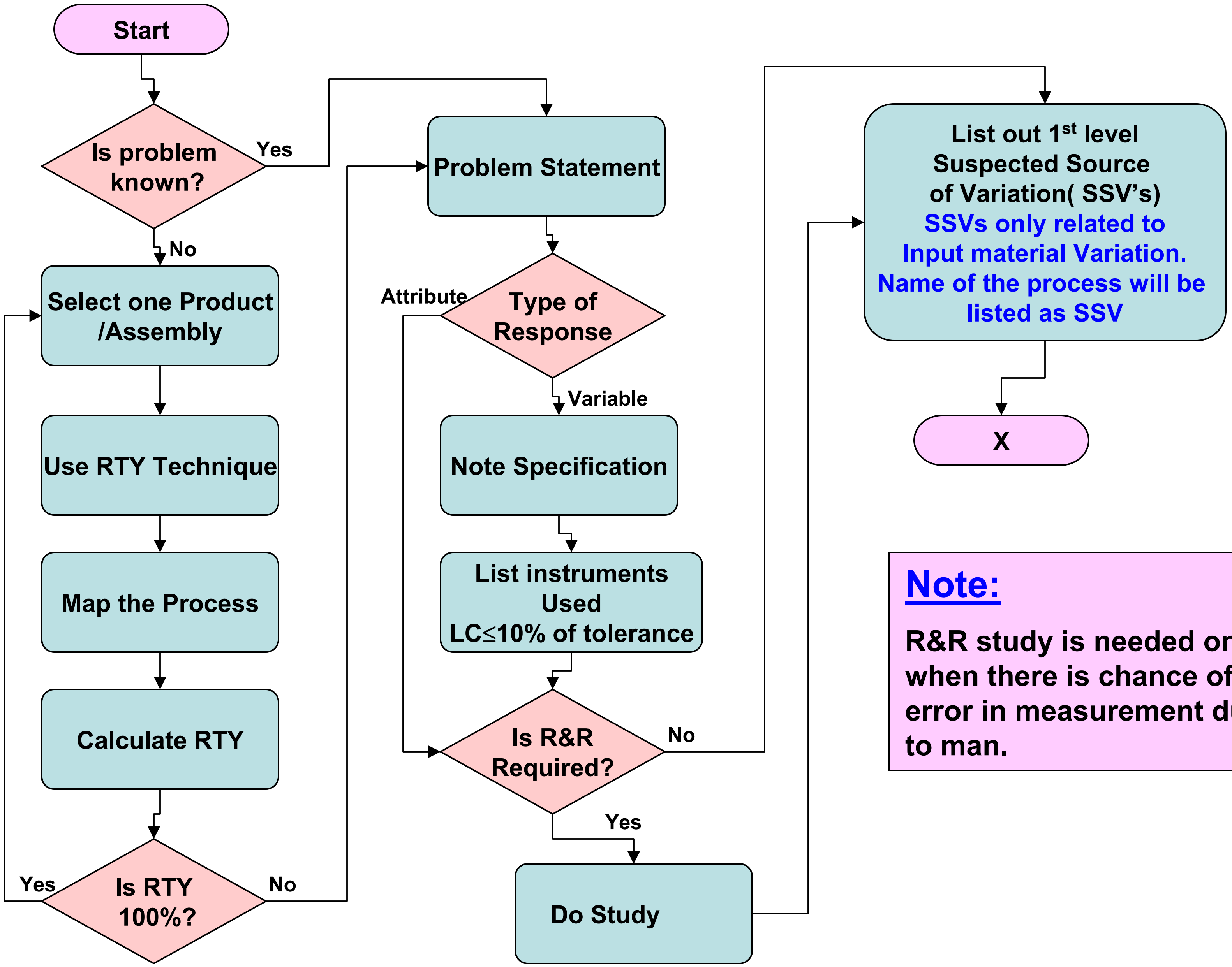
Identify and Implement solution for eliminating the root causes

Control

Identify and Implement control measures for the root cause to make sure that the problem is prevented from occurring again

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Define the Problem



Note:

R&R study is needed only when there is chance of error in measurement due to man.

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Suspected Source of Variation (SSVs)

To start with List down only First Level source of variation

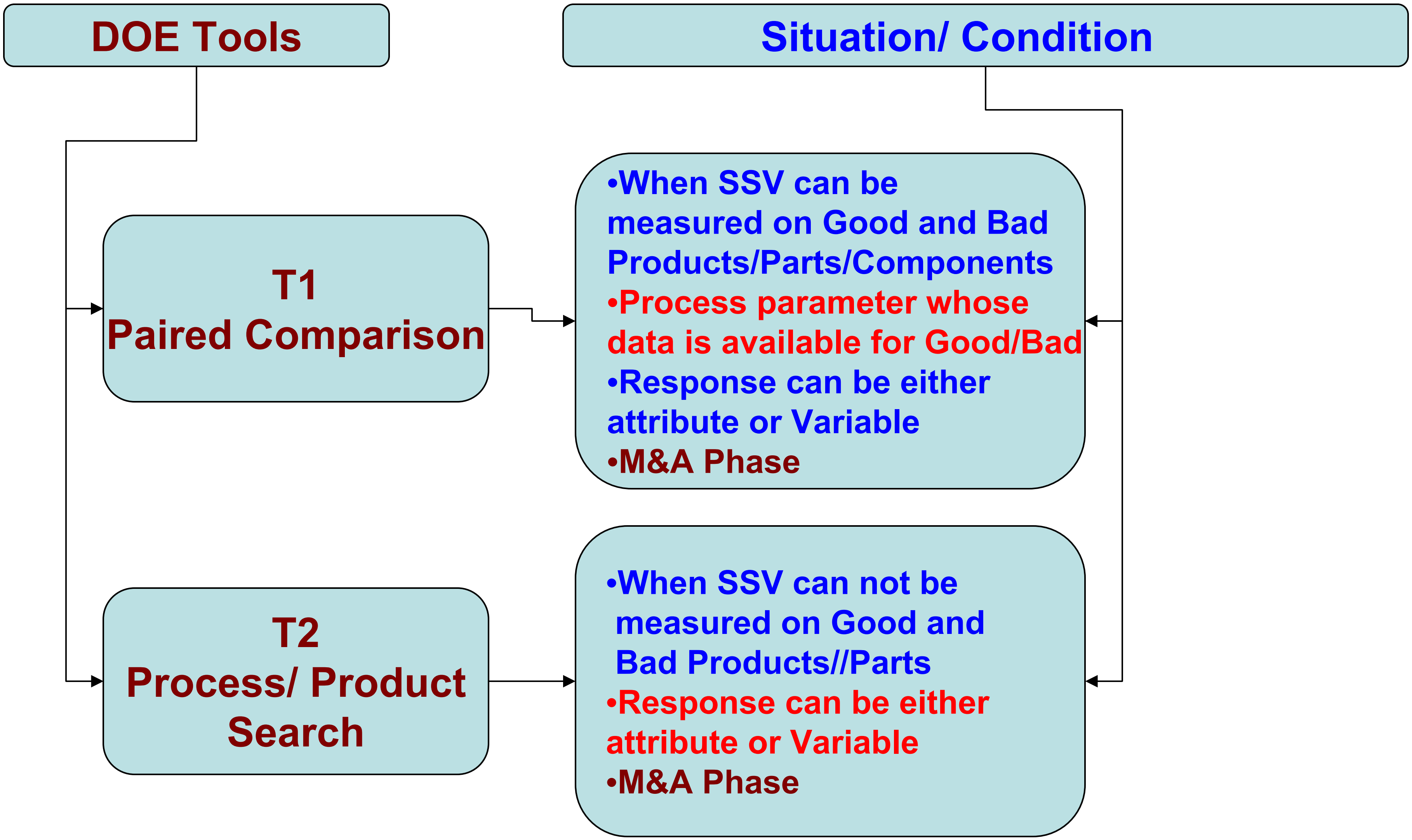
- **Last Process in which the response is generated**
  - **Do not brainstorm and list down the detailed sources of variations within the process**
- **Input Material Parameters which can technically create the problem**

Do not list down SSV related to Process and Product design. (SSV which can not vary during process)

- Some examples are Speed of spindle, Feed Rate, Time, Injection pressure, Limit switch position

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A phase: Selection of Tools for SSV



Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A phase: Selection of Tools for SSV

DOE Tools	Situation/ Condition
T3 Component search	•When problem is on an assembled product & the assembly can be dis-assembled and re-assembled without damaging parts •Response can be either attribute or Variable •M&A Phase
T4 Modified Component search	•When problem is on an assembled product & if some parts get damaged during disassembly •Response can be either attribute or Variable •M&A Phase

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A phase: Selection of Tools for SSV

DOE Tools	Situation/ Condition
T5 Multi Vari Analysis	When input material is not the Cause of the problem and process Is the only cause of the problem Response has to be Variable •M&A Phase
T6 Concentration charts	•When the problem can come at any location on the product and we have to study the defect pattern •Response can be either attribute or Variable •M&A Phase

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A phase: Selection of Tools for SSV

DOE Tools	Situation/ Condition
T7 **B Vs C**	When root cause of the problem Or optimal setting for a process is identified and it has to validated Improvement Phase
T8 **Variable Search**	When the problem is due to design parameters of Product/ Process & parameters are >3 Process to be optimized for >3 design parameters M&A Phase

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Selection of Tools for SSV

DOE Tools	Situation/ Condition
T9 **Full Factorial**	When the problem is due to design parameters of Product/ Process & parameters are ≤ 3 Process to be optimized for <=3 Design parameters M&A Phase
T10 **Variation Analysis**	When the action on root cause is implemented and type of control to be decided for monitoring. This can be done both for Root X as well as Big Y Control Phase

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Selection of Tools for SSV

DOE Tools	Situation/ Condition
T11 R&R study	When the measurement variation can come due to method of checking and we have to find out the variation due to the person who is checking Define phase
T12 Calibration	When the variation can come due to Instrument and we have to find out the variation of the instrument only Define phase

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Steps after selection of Tools for SSV during M&A Phase

1. **Data Collection** (**Minimum data collection without affecting the production processes**)

2. **Analysis** (**Simple analysis without using calculators and big jargons so that anybody can do it)**

3. **Conclusion** (**Accurate conclusion on the cause(s))**

↓

Root Cause Identification

Key skills of BB : Process knowledge, Good observation and correct selection of tools

DOE Tool 1

Paired Comparison

Application:

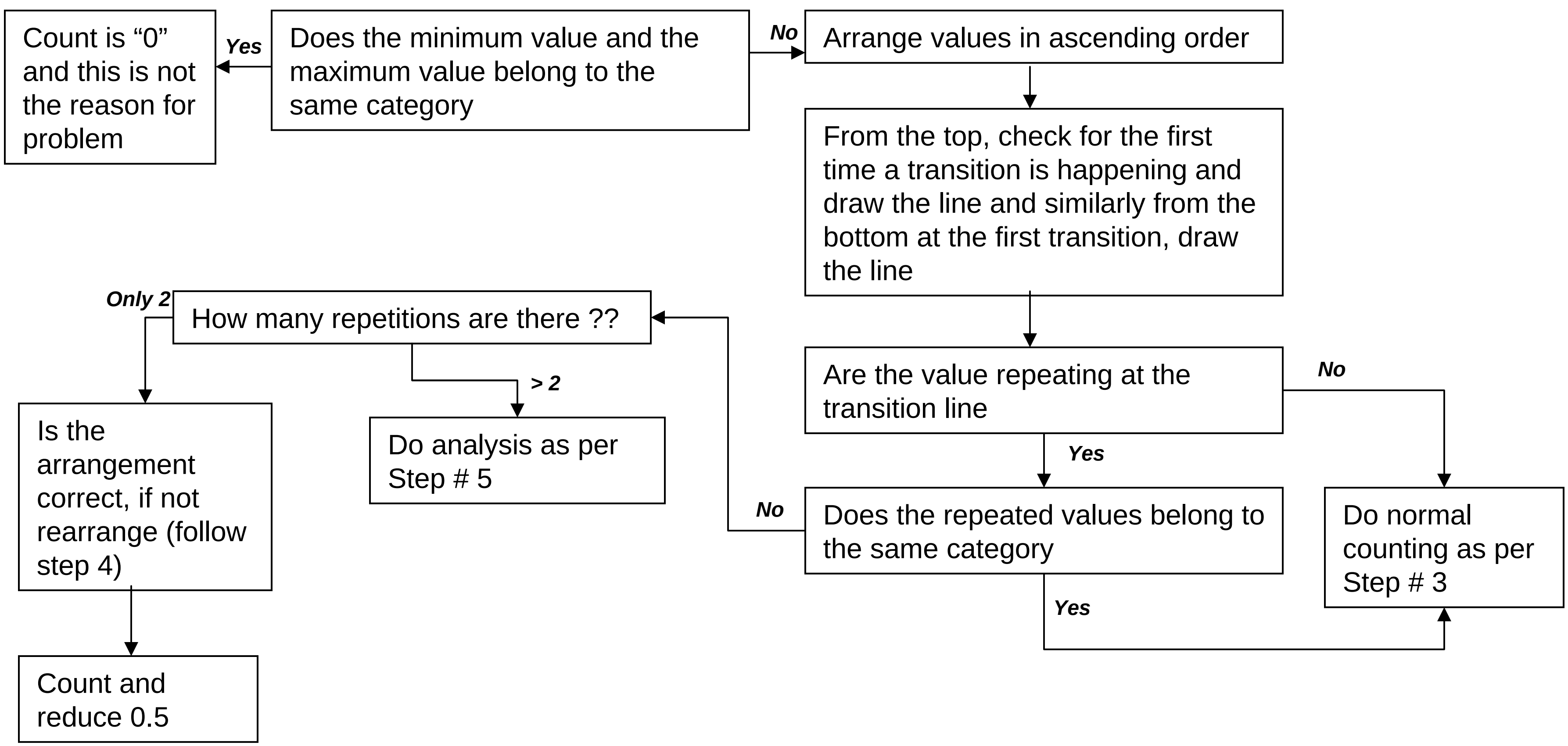
- Is used when SSV is measurable on both good and bad products
- Good & Bad are selected based on the response defined in the problem definition
- Response can be Variable or attribute
- SSV can be Variable or attribute
- Is applicable to input material related SSV or to the process parameter variation provided the historic data is available with traceability

M&A Phase: DOE1- Paired Comparison rules Checklist

Data Collection	Analysis	Conclusion
Select 8 BOB and 8 WOW if the response is "variable"	If the maximum and minimum value belong to the same category, then the cause is eliminated and the Total count is 0	If the Total count is >=6, then the SSV is the confirmed cause for the problem
Select 8 Good and 8 WOW if the response is "attribute"	If the maximum and minimum value belong to different category, do the counting as per the flow diagram given in the next slide	For one problem, we can have more than one SSV with counts >=6. In this case, all are the confirmed causes
If the response is attribute and WOW selection is not possible, select 8 Good and 8 Bad		We cannot prioritize causes with Total count >=6, based on the Count value.
If the rejection percentage is <=0.5%, select 6 BOB and 6 WOW instead of 8 BOB and 8 WOW		If we have to prioritize the causes with Total count >=6, then apply Variable Search or Full factorial tool
Measure the SSV's on the Good and Bad products and record the data if the SSV is variable		For all the causes with Count >=6, fix the specification based on the "GOOD" band
If the SSV is attribute, scale on a scale of 0-3, 0 – SSV not present 1- SSV present with less severity, 2- SSV present with medium severity, 3- SSV present with high severity and record the data		Fine tune the specification by adding or subtracting the existing tolerance depending on where the GOOD band is located
If the Problem statement is "Parameter variation", select the BOB as the product with less variation from target and WOW as the product with maximum variation from the target value		For geometrical parameters, Do not do fine tuning, Fix only USL based on the data, since the LSL is always zero
Remember !! – The BOB and WOW are selected based on the Response		Calculate the variation as the maximum – minimum of all the 12 or 16 data
		If the Variation is <=75% of the New tolerance, then the Confirmed cause is a "ROOT CAUSE"
		If the Variation is >75% of the New tolerance, then the Confirmed cause is only a "CAUSE" and this should be taken as Y and drilled down further

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Flow diagram for finding total count



DOE Tool 2

Product/Process Search

Application:

- When the sources of variation is not measurable on both Good and Bad Products/Parts
- SSV related to process parameter or product characteristics that can not be measured on Good and Bad parts.
- Is used when SSV are process/ machine parameters like Temperature, Pressure, pouring time, etc.
- related to input material dimensions, but the dimensions will get changed during processing preventing the application of paired comparison.
- Response can be Variable or attribute. SSV's can be attribute or variable

M&A Phase: DOE2- Product/Process search rules checklist

Data Collection	Analysis	Conclusion
Follow Method # 1 data collection when the following conditions are satisfied	Same rules as Paired Comparison	Same rules as Paired comparison
-Rejection % is > 1% -Input material SSV' s can be checked near the machine -Inspection cycle time of the SSV's are less than the Process cycle time of one part -Response can be checked/measured near the machine -Response can be checked/measured immediately after the process is completed		
If any one of the above conditions are not satisfied, then follow Method # 2 data collection		
Decide the lot size for Method # 2 data collection based on the historic rejection.Eg: if the historic rejection is 8%, decide the lot size as 100 pcs		
If Method #2 data collection is done and 8 or 6 bad is not obtained in the lot, then check the following condition if the response is variable -Find out the variation of the entire data -If the variation is >=80% of tolerance, further data collection is not required -If the variation is <80% of tolerance, then collect for one more lot and again check the variation of both the data. Do like this till variation is >=80% of tolerance		
If Method #2 data collection is done and 8 or 6 bad are not obtained and the response is attribute, then we have to collect more data till we get 6 or 8 Bad		

Key skills of BB : Process knowledge, Good observation and correct selection of tools

DOE Tool 3

Component Search

Application:

- When the problem is on an assembled product & assembly can be disassembled and reassembled without damaging the parts
- Is used for assembly related problems (HV Failure, Leakage, Vibration, Pressure Drop, etc.)
- Response can be Variable or attribute

M&A Phase: DOE3- Component Search rules checklist

Variable response

Data Collection	Analysis	Conclusion
Stage #1	**Stage # 1**	**Stage # 1**
Take one BOB and one WOW assembly	D = Difference of the Median d = Average of Ranges	D/d ratio >=3, Components are the reasons for the problem and Assembly process is not the reason for the problem
Note down the data as selected	When calculating d value, the number of decimal places should be one decimal more than in the data	D/d ratio >=1.25 and <3 and there is "No overlap" between the 3 data of Good and 3 data of Bad, then Components are the reasons for the problem and Assembly process is not the reason for the problem
Disassemble and Reassemble BOB assembly two times and record the data. Use the same components		D/d ratio >=1.25 and <3 and there is "Overlap" between the 3 data of Good and 3 data of Bad, then Assembly Process is the reason for the problem
Disassemble and Reassemble WOW assembly two times and record the data. Use the same components		D/d ratio <1.25, then Assembly Process is the reason for the problem
Totally, we will have 3 data for Good assembly and 3 data for Bad assembly		If the conclusion is Assembly process is the reason for the problem, use Multivari analysis as the next tool
		If the conclusion is component is the reason for the problem, the go to Stage # 2

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE3- Component Search rules checklist

Variable response

Data Collection	Analysis	Conclusion
Stage #2	**Stage # 2**	**Stage # 2**
List down the Components in the descending order of suspect level	When plotting the data, represent bad assembly data as “dotted line” and Good assembly data as “Sold line”	Both lines crossing the middle line (Average of median line). Conclusion: Only component creating problem
“-” indicates Bad assembly and “+” indicates Good assembly	For A+R- data, use the Bad assembly legend	Only one line crossing the middle line. Conclusion: One of the component creating the problem
Swap the first component. The swapping is represented as A-R+ and A+R-	For A-R+ data, use the good assembly legend	No line crosses the middle line: Component not at all creating the problem
A-R+ means – Component A taken from Bad assembly and put inside Good assembly	Decision line (Middle line) is Average of Medians	If we get, A as one of the components, B as one of the components creating the problem, we should not go for C, we have to interchange A&B together
A+R- means – Component A taken from Good assembly and put inside Bad assembly		Stop the swapping, when the conclusion comes as the Only component creating the problem
Do the conclusion as per the conclusion rules and then decide to interchange the next component		If A is “one of the components” and B is “the only component”, Do paired comparison only on B
Stage # 3 – Paired Comparison	**Stage # 3 – Paired Comparison**	**Stage # 3 – Paired comparison**
Select 8 BOB and 8 WOW assemblies. Remove the parts pinpointed earlier as per step 2 and then check the suspected dimensions on those parts	Same rules as Paired comparison	Same rules as Paired comparison

M&A Phase: DOE3- Component Search rules checklist

Attribute response

Data Collection	Analysis	Conclusion
Stage #1	**Stage # 1**	**Stage # 1**
Take one Good and one Bad assembly	No calculations are done	Good assembly remains Good and Bad assembly remains Bad, Components are the reasons for the problem and Assembly process is not the reason for the problem
Dissemble and Reassemble Good assembly two time and Bad assembly two times. Use the same components		Good assembly becomes bad or Bad assembly becomes good, then Assembly process is the reason for the problem
No data will be measured and recorded. Just record the status of the assembly as "Good" and "Bad"		If Components are the reason for the problem go to Stage #2
		If Assembly process is the reason for the problem, then we have investigate by "Observing the assembly process"

M&A Phase: DOE3- Component Search rules checklist

Attribute response

Data Collection	Analysis	Conclusion
Stage #2	**Stage # 2**	**Stage # 2**
List down the Components in the descending order of suspect level	No graph is plotted as in the variable response	If Good assembly becomes Bad assembly, and Bad assembly becomes Good assembly, then Component interchanged is the "Only reason" for the problem
"-" indicates Bad assembly and "+" indicates Good assembly		If Good assembly remains Good and Bad assembly remains Bad, then the Component interchanged is "Not at all" the reason for the problem
Swap the first component. The swapping is represented as A-R+ and A+R-		If Good assembly becomes Bad and Bad assembly remains Bad, then the Component interchanged is "One of the component" creating the problem
A-R+ means – Component A taken from Bad assembly and put inside Good assembly		If Good assembly remains Good and Bad assembly becomes Good, then the Component interchanged is "One of the component" creating the problem
A+R- means – Component A taken from Good assembly and put inside Bad assembly		If we get, A as one of the components, B as one of the components creating the problem, we should not go for C, we have to interchange A&B together
Do the conclusion as per the conclusion rules and then decide to interchange the next component		Stop the swapping, when the conclusion comes as the Only component creating the problem
Stage # 3 – Paired Comparison	**Stage # 3 – Paired Comparison**	If A is "one of the components" and B is "the only component", Do paired comparison only on B
Select 8 Good and 8 Bad assemblies. Remove the parts pinpointed earlier as per step 2 and then check the suspected dimensions on those parts	Same rules as Paired compairson	Same rules as Paired comparison

Key skills of BB : Process knowledge, Good observation and correct selection of tools

DOE Tool 4

Modified Component Search

Application:

- When the problem is on an assembled product & when we disassemble, some parts will get damaged
- For this tool to be used, some parts should not get damaged and can be reused
- If there is an assembly problem and all the parts are getting damaged during disassembly, use “Product/Process search tool”
- Response can be Variable or attribute

M&A Phase: DOE4- Modified Component Search rules checklist

Variable response

Data Collection	Analysis	Conclusion
Stage #1	**Stage # 1**	**Stage # 1**
Take one BOB and one WOW assembly	D = Difference of the Median d = Average of Ranges	D/d ratio >=3, Assembly process and replaced parts are not the reasons. The components that are not getting damaged are the reasons for the problem
Note down the data as selected	When calculating d value, the number of decimal places should be one decimal more than in the data	D/d ratio >=1.25 and <3 and there is "No overlap" between the 3 data of Good and 3 data of Bad, Assembly process and replaced parts are not the reasons. The components that are not getting damaged are the reasons for the problem
Disassemble and Reassemble BOB assembly two times. Replace the parts that are getting damaged with new parts and record the response.		D/d ratio >=1.25 and <3 and there is "Overlap" between the 3 data of Good and 3 data of Bad, then Assembly process "or" the replaced parts are the reasons for the problem
Disassemble and Reassemble WOW assembly two times. Replace the parts that are getting damaged with new parts and record the response.		D/d ratio <1.25, then Assembly Process or the replaced parts are the reason for the problem
Totally, we will have 3 data for Good assembly and 3 data for Bad assembly		If the conclusion is Assembly process or the replaced parts are the reason for the problem, use "Product/Process search" tool to investigate the replaced parts dimensions.
		After doing Product/Process search, if all the dimensions of the replaced parts are eliminated, then do "Multivari analysis" on the Assembly process
		If the conclusion is Assembly process and the replaced parts are not the reasons, then go to Stage # 2

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE4- Modified Component Search rules checklist

Variable response

Data Collection	Analysis	Conclusion
Stage #2	**Stage # 2**	**Stage # 2**
List down the Components in the descending order of suspect level	When plotting the data, represent bad assembly data as “dotted line” or “Red color line” and Good assembly data as “Sold line” or “Green color line”	Both lines crossing the middle line (Average of median line). Conclusion: Only component creating problem
“-” indicates Bad assembly and “+” indicates Good assembly	For A+R- data, use the Bad assembly legend	Only one line crossing the middle line. Conclusion: One of the component creating the problem
Swap the first component. The swapping is represented as A-R+ and A+R-. Whenever the swapping is done, the replace the damaged parts with a new one.	For A-R+ data, use the good assembly legend	No line crosses the middle line: Component not at all creating the problem
A-R+ means – Component A taken from Bad assembly and put inside Good assembly		If we get, A as one of the components, B as one of the components creating the problem, we should not go for C, we have to interchange A&B together
A+R- means – Component A taken from Good assembly and put inside Bad assembly		Stop the swapping, when the conclusion comes as the Only component creating the problem
Do the conclusion as per the conclusion rules and then decide to interchange the next component		If A is “one of the component” and B is “the only component”, Do paired comparison only on B
Stage # 3 – Paired Comparison	**Stage # 3 – Paired Comparison**	**Stage # 3 – Paired comparison**
Select 8 BOB and 8 WOW assemblies. Remove the parts pinpointed earlier as per step 2 and then check the suspected dimensions on those parts	Same rules as Paired comparsion	Same rules as Paired comparison

M&A Phase: DOE4- Modified Component Search rules checklist

Attribute response

Data Collection	Analysis	Conclusion
Stage #1	**Stage # 1**	**Stage # 1**
Take one Good and one Bad assembly	No calculations are done	Good assembly remains Good and Bad assembly remains Bad, Assembly Process and the Replaced parts are not the reasons for the problem. Components that are not damaged are the reasons for the problem
Dissemble and Reassemble Good assembly two times and Bad assembly two times. Replace the parts that are getting damaged		Good assembly becomes bad or Bad assembly becomes good, then Assembly process "or" the replaced parts are the reason for the problem
No data will be measured and recorded. Just record the status of the assembly as "Good" and "Bad"		If Components that are not damaged are the reason for the problem go to Stage #2
		If Assembly process or the replaced parts are the reason for the problem, then do "Product/Process search" for the dimensions of the replaced parts
		After Product/Process search, if all the dimensions are eliminated, then the Assembly process has to be investigated through "Observation"

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE4- Modified Component Search rules checklist

Attribute response

Data Collection	Analysis	Conclusion
Stage #2	**Stage # 2**	**Stage # 2**
List down the Components in the descending order of suspect level	No graph is plotted as in the variable response	If Good assembly becomes Bad assembly, and Bad assembly becomes Good assembly, then Component interchanged is the "Only reason" for the problem
"-" indicates Bad assembly and "+" indicates Good assembly		If Good assembly remains Good and Bad assembly remains Bad, then the Component interchanged is "Not at all" the reason for the problem
Swap the first component. The swapping is represented as A-R+ and A+R-. During swapping, replace the parts that are getting damaged with new ones.		If Good assembly becomes Bad and Bad assembly remains Bad, then the Component interchanged is "One of the component" creating the problem
A-R+ means – Component A taken from Bad assembly and put inside Good assembly		If Good assembly remains Good and Bad assembly becomes Good, then the Component interchanged is "One of the component" creating the problem
A+R- means – Component A taken from Good assembly and put inside Bad assembly		If we get, A as one of the component, B as one of the component creating the problem, we should not go for C, we have to interchange A&B together
Do the conclusion as per the conclusion rules and then decide to interchange the next component		Stop the swapping, when the conclusion comes as the Only component creating the problem
Stage # 3 – Paired Comparison	**Stage # 3 – Paired Comparison**	If A is "one of the components" and B is "the only component", Do paired comparison only on B
Select 8 Good and 8 Bad assemblies. Remove the parts pinpointed earlier as per step 2 and then check the suspected dimensions on those parts	Same rules as Paired compairson	Same rules as Paired comparison

Key skills of BB : Process knowledge, Good observation and correct selection of tools

DOE Tool 5

Multi vari analysis

Application:

- Is used only when response is “variable”.
- Is used only when the problem is generated from a manufacturing process.
- Used to identify what source of variation is the highest in a process
- Response is analyzed in this tool
- All input material parameters are eliminated by using other DOE tools

Types of Variation:

Part to Part Variation:

Variation between consecutive parts from the process is termed as Part to Part variation.

SSV's for Part to Part variation:

- Operator
- Machine(Equipment) - Hardware
- Measurement
- Process Design(design of fixture, toolings, clamping method, specification of process parameter)

specification of process parameter= coolant, feed, speed, etc

Types of Variation:

Time to Time:

Variation between time blocks from the process is termed as Time to Time variation.

SSV's for Time to Time variation:

- Same as reasons for Part to Part variation if the Time to Time variation is less than or equal to Part to Part variation
- If the Time to Time variation is > Part to Part variation, then it is due to Events(power failure, Tool offset, Adjustment, Dressing, break down, etc)

Types of Variation:

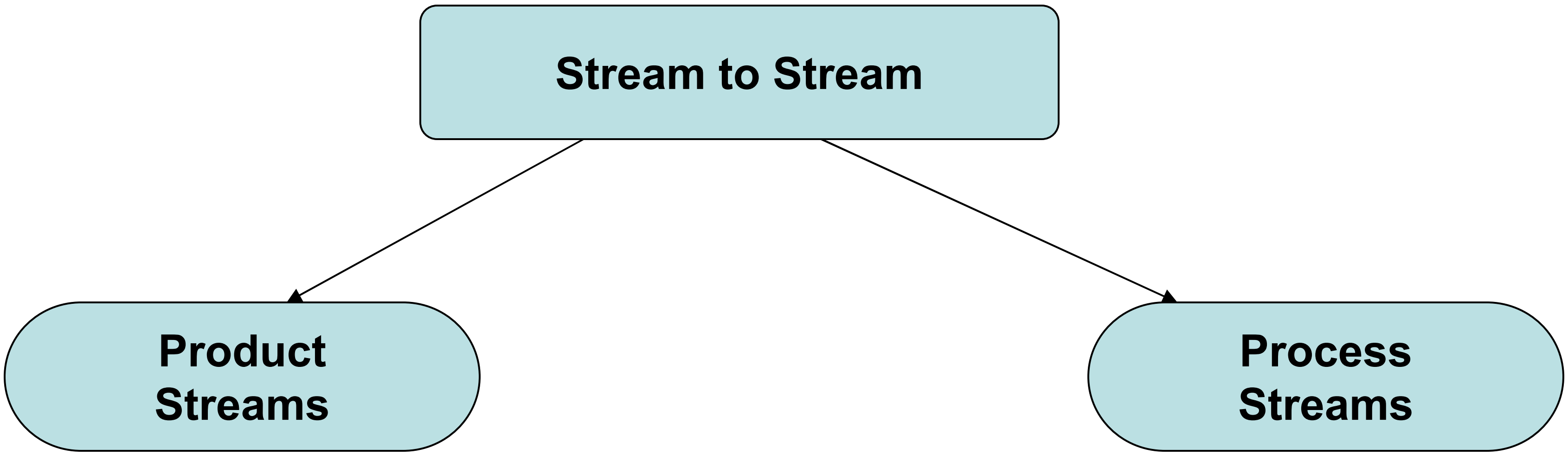
Stream to Stream:

Variation between streams from the process is termed as Stream to Stream variation.

SSV's for Stream to Stream variation:

- **Same as Part to Part variation provided the Stream to stream variation is <= Part to Part variation**
- **If Stream to Stream variation is >= Part to Part variation, then the reason is due to abnormality in streams.**

Identifying Stream



Checking response at multiple locations on the product

- Run out
- Taper
- Journal to Journal
- Pin to Pin

How the process is designed

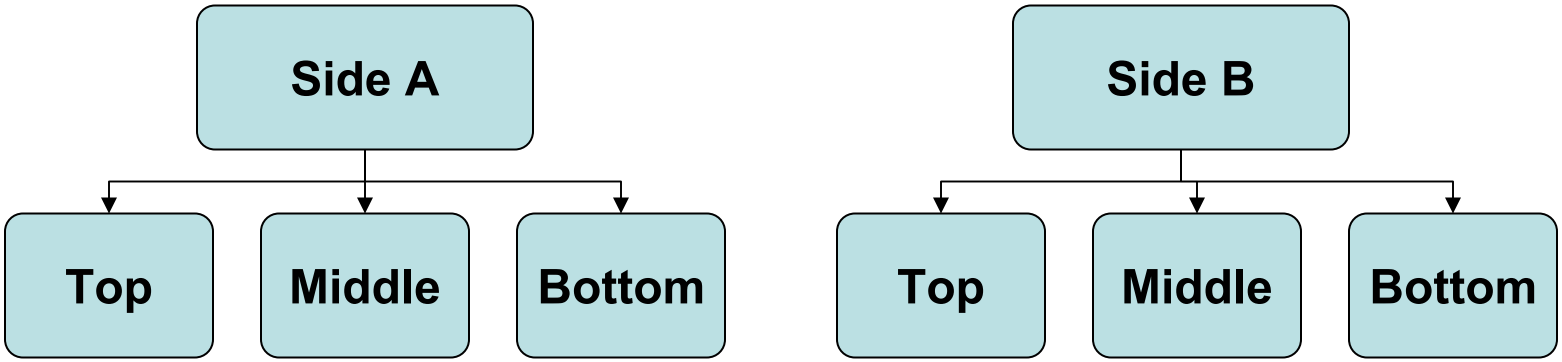
- Spindle to Spindle
- Fixture to Fixture
- Cavity to Cavity
- Line to Line

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Types of Stream & No. of Streams

Example

Measuring diameter at three places on both sides



In the above example, there are two levels in the tree. Hence there are two types of stream to stream variations

Side to Side is one level and Top-Middle-Bottom is another level

No. Sides = 2

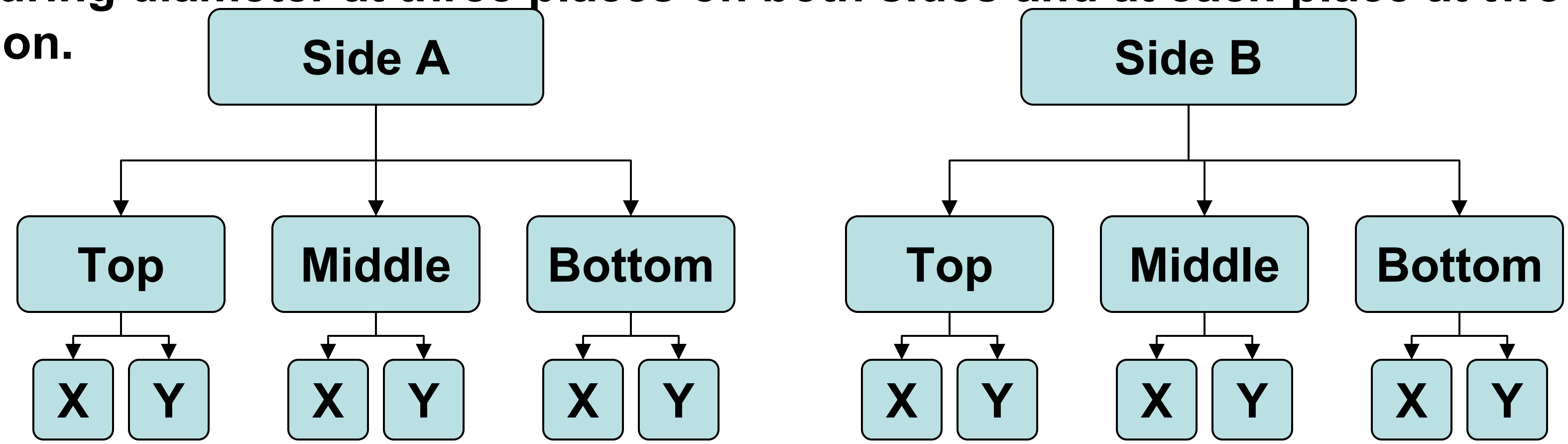
No. of places = 3

Total No. of streams = 6

Types of Stream & No. of Streams

Example

Measuring diameter at three places on both sides and at each place at two location.



In the above example, there are three levels in the tree. Hence there are three types of stream to stream variations

Side to Side is one level, Top-Middle-Bottom is second level and X-Y is third level

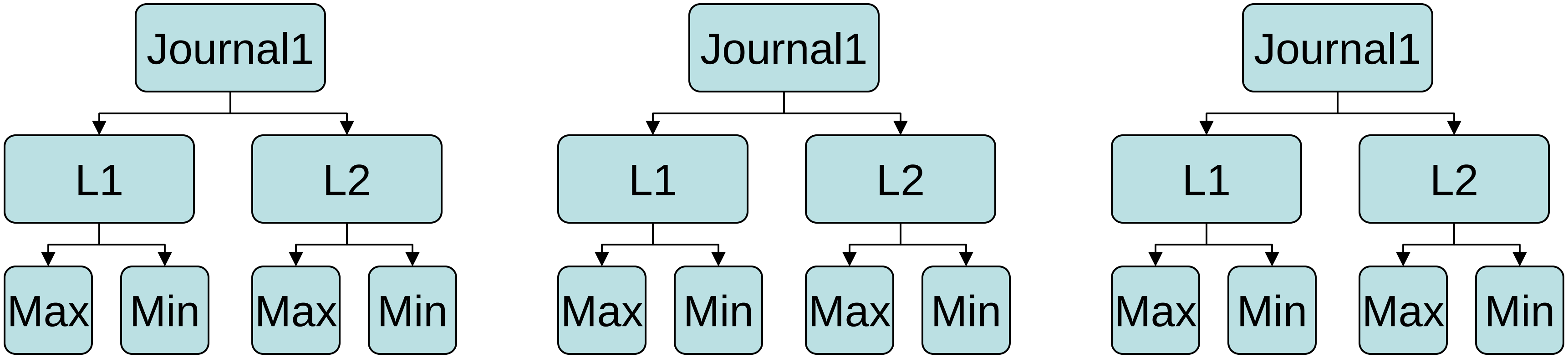
No. Sides	**= 2**
No. of places	**= 3**
No. of locations	**= 2**
Total No. of streams	**= 12**

M&A Phase: DOE5- Multi vari analysis rules checklist

Data Collection	Analysis	Conclusion
Collect continuously 3 parts from each "Process stream". This is for one time block Eg: if there are 3 process streams, then we have to collect 9 parts. Measure the response and record the data. This time block is "Time 1"	For doing the analysis manually, refer to the next slides for the procedure	Check among all which variation is highest.
Calculate the Range of the entire data (Maximum – Minimum of the entire data). This is the Variation	Analysis using Minitab	If Part to Part variation is highest, then do "Test of Equal Variances" in Minitab to find out whether Part to Part variation is equal in all the streams or is different in the streams
If the Variation is >=80% of tolerance, then stop the data collection	To find out which variation is highest Stat -> ANOVA -> Fully Nested ANOVA Select the response, select the parameters in the same order as entered	For Test of equal variances, Levene's test, P value <=0.05, then the conclusion is there is a difference in Part to Part variation in the streams
If the Variation is <80% of tolerance, then collect data for one more time block. This time block is called "Time 2"	For doing "Test of Equal Variances" Stat -> ANOVA -> Test of Equal variances Select one factor at a time	If the P value is >0.05, then the Part to Part variation is same in all the streams
Calculate the variation for both the Time -1 and Time -2 data. Check for the same rule as above. If the condition is satisfied, stop data collection, otherwise continue data collection		If P value is >0.05, then check the basic machine condition and rectify for any abnormalities.
Stop data collection, when Variation is >=80% of tolerance		After checking, still if the Part to Part variation is high, then do Variable search or Full factorial for Parameter design
Ensure that "No known planned/unplanned events" are coming in the 3 consecutive parts within Time block		
If there are events, coming within the 3 parts, split and create two time blocks, so that events will come between the time blocks		
Never delete any data for analysis		
Events should always be "Between time blocks"		

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Example



Part to Part Variation

	J1				J2				J3			
	L1		L2		L1		L2		L1		L2	
	max	min	ma x	min	max	min	max	min	max	min	max	min
1	10	12	5	6	10	10	12	5	10	10	5	5
2	21	16	5	7	11	14	10	6	20	13	5	5
3	16	8	10	8	12	20	6	8	26	18	10	10
Range	11	8	5	2	2	10	6	3	16	8	5	5
4	33	25	4	5	26	20	15	4	30	25	5	12
5	31	20	16	16	16	13	14	5	30	25	4	13
6	7	4	4	18	15	11	12	14	15	12	12	11
Range	26	21	12	13	11	9	3	10	15	13	8	2

Example

Time to Time Variation

	J1				J2				J3				Average
	L1		L2		L1		L2		L1		L2		
	max	min	max	min	max	min	max	min	max	min	max	min	
1	10	12	5	6	10	10	12	5	10	10	5	5	
2	21	16	5	7	11	14	10	6	20	13	5	5	
3	16	8	10	8	12	20	6	8	26	18	10	10	
Average													10.69
4	33	25	4	5	26	20	15	4	30	25	5	12	
5	31	20	16	16	16	13	14	5	30	25	4	13	
6	7	4	4	18	15	11	12	14	15	12	12	11	
Average													15.06
Range													4.36

Key skills of BB : Process knowledge, Good observation and correct selection of tools

Example

Stream to Stream Variation (Max to Min Variation)

	J1				J2				J3			
	L1		L2		L1		L2		L1		L2	
	max	min	max	min	max	min	max	min	max	min	max	min
1	10	12	5	6	10	10	12	5	10	10	5	5
2	21	16	5	7	11	14	10	6	20	13	5	5
3	16	8	10	8	12	20	6	8	26	18	10	10
Average	15.7	12.0	6.7	7.0	11.0	14.7	9.3	6.3	18.7	13.7	6.7	6.7
Range	3.7		0.3		3.67		3.0		5.0		0	
4	33	25	4	5	26	20	15	4	30	25	5	12
5	31	20	16	16	16	13	14	5	30	25	4	13
6	7	4	4	18	15	11	12	14	15	12	12	11
Average	23.67	16.33	8.00	13.00	19.00	14.67	13.67	7.67	25.00	21.00	7.00	12.00
Range	7.3		5		4.33		6.0		4.0		5	

Example

Stream to Stream Variation (L1 to L2 Variation)

	J1				J2				J3				
	L1		L2		L1		L2		L1		L2		
	max	min	max	min	max	min	max	min	max	min	max	min	
1	10	12	5	6	10	10	12	5	10	10	5	5	
2	21	16	5	7	11	14	10	6	20	13	5	5	
3	16	8	10	8	12	20	6	8	26	18	10	10	
Average	13.8		6.8		12.8		7.8		16.2		6.7		
Range	7.0				5.0				9.5				
4	33	25	4	5	26	20	15	4	30	25	5	12	
5	31	20	16	16	16	13	14	5	30	25	4	13	
6	7	4	4	18	15	11	12	14	15	12	12	11	
Average	20.0		10.5		16.8		10.7		22.8		9.5		
Range	9.5				6.2				13.33				

Example

Stream to Stream Variation (J1- J2- J3 Variation)

	J1				J2				J3				Range
	L1		L2		L1		L2		L1		L2		
	max	min	max	min	max	min	max	min	max	min	max	min	
1	10	12	5	6	10	10	12	5	10	10	5	5	
2	21	16	5	7	11	14	10	6	20	13	5	5	
3	16	8	10	8	12	20	6	8	26	18	10	10	
Average				10.3				10.3				11.4	1.08
4	33	25	4	5	26	20	15	4	30	25	5	12	
5	31	20	16	16	16	13	14	5	30	25	4	13	
6	7	4	4	18	15	11	12	14	15	12	12	11	
Average				15.3				13.8				16.2	2.42

Part to Part Variation	26.00
Time to Time Variation	4.36
Stream to Stream Variation (Max to Min Variation)	7.30
Stream to Stream Variation (L1 to L2 Variation)	13.33
Stream to Stream Variation (J1- J2- J3 Variation)	2.42

DOE Tool 6

Concentration Chart

Application:

- Is used when the problem can come anywhere on the product and we have to find out whether the defect is concentrated in one area or not (eg: blow holes, cracks, porosity, underfill etc..)
- Is used when defect can generated at multiple streams from the process and streams are too high to apply Multi-Vari Analysis.

M&A Phase: DOE 6- Concentration chart rules checklist

Data Collection	Analysis	Conclusion
Collect 30 bad parts	Calculate for each zone, the Weighted sum of the severity	If in any zone the defect severity % is >=80%, then the defect is concentrated in that zone
Scale the severity of defect on a scale of 1-3. 1 – Less severity 2- Medium severity 3 – High severity	Calculate the % with respect to the total in each zone	If in all the zones the defect severity is <80%, then the defect is coming randomly
Divide the part into different zones depending on the geometry		
Count on every part, the number of defects generated in each zone		
Note down the severity in each zone		

DOE Tool 7

B Vs C

Application:

- Is used to validate the root cause of the problem identified using other DOE tools. (DOE Tool 1-6)
- If the cause is validated, then we can calculate how much the improvement has taken place
- Tool is applied only when B & C condition can be created alternately.
- Response is monitored in terms of Big Y

M&A Phase: DOE 7- B vs C rules checklist

Data Collection	Analysis	Conclusion
If the tool used for finding out the cause or root cause is Paired comparison or Product/Process search and the total count is full count (16 or 12), then the sample size is 3B and 3C	For 3B and 3C, check whether is there any overlap in the data or not. If there is no overlap, then the cause is validated If there is Overlap, then increase the sample size by another 3 and validate as per 6B,6C	For 3B, 3C, if there is no overlap, then the root cause is validated For 3B, 3C, if there is a overlap, then increase the sample size by 3
In all other situations, the sample size is 6B, 6C	For 6B, 6C, find out the count using the same rules as “Paired comparison”	For 6B,6C if the total count is >=6, then the cause is validated
If the response is variable, produce 6 or 3 pieces in B condition and 6 or 3 Pieces in C condition		For 6B,6C, if the total count is <6, then the cause is not validated and we have to go back to M&A phase
If the response is attribute, produce 6 or 3 batches in B condition and 6 or 3 batches in C condition	Quantifying Improvement	Quantifying improvement
If the response is variable, measure the actual value of the response as the data for analysis	Quantify improvement only when the cause as per the above rule is validated	If (Xb – Xc) is >= K * Sigma (b), then the amount of improvement can be declared at 95% CL. If it is less, then get the K value at 90% CL and do the same check
If the response is attribute, rejection % in each batch will be taken as the data for analysis	When calculating average, round off the decimal place to one decimal more than the data	If (Xb-Xc) is < K* Sigma(b) even at 90% CL, increase the sample size in multiples of 3
If the validation is done using batches, decide the batch quantity to get at-least one bad product. Eg: if the historic rejection is 1%, then the batch quantity will be taken as 100 pcs	When calculating Sigma (b), round off the decimal to one decimal more than the data	Maximum boundary for the sample size is 12B, 12C. In 12B, 12C, if the amount of improvement cannot be declared, then go back to M&A phase
Always collect data by alternating between the B and C condition		

DOE Tool 8

Variable Search

Application:

- Is used when design parameters are >3.
- Can be used for problem solving only when all the variation related SSV's are eliminated and the cause is confirmed as Process design
- Is also used for existing process optimization to arrive at an optimal setting for cost, productivity and quality
- There are 6 stages in the techniques, numbered as Stage # 0, Stage 1, Stage #2, Stage #3, Stage #4, Stage #5

Six stages in Variable Search:

Stage 0: To identify the design parameters and identifying '-' and '+' setting for each parameters

Stage 1: To find out whether the parameters and the levels identified in stage 0 are correct or not.

Stage 2: To find out which parameters are important and which of the parameters are not important.

To find out whether the contribution of "not important" parameters are zero or not

Stage 3: To validate the significant parameters found in stage2.

Stage 4: Do factorial analysis and find out the contribution of each of the significant parameters and also the contribution of the interactions

Stage 5: Make a mathematical equation based on the contribution of significant parameters and arrive at the optimal setting

DOE Tool 8

Variable Search

Application: Problem Solving

M&A Phase: DOE 8 – Variable Search rules checklist

Application – Problem solving

Stage # 0 rules

• Two types of design parameters can be selected for Study. One type of design parameter are the parameters taken from the SSV's and another are the New Design parameters

•*Listing of Parameters*

•Identification of Design parameters from SSV's

- •Check whether the Top or Bottom count is >=3
- •If yes, then list that parameter from the SSV as a design parameter

•Identification of New Design parameters

- •New design parameters are identified based on the technical knowledge of the problem

•Response is the Problem

•In this application, there will be only one response

•*Identification of – and + settings*

•For Design parameters selected from SSV's

- •Values which have given WOW results are – setting
- •Values which have given BOB results are + setting

•For New Design parameters

- •Existing setting is the – setting
- •+ setting is identified based on technical reasoning and "favorable for Quality" (setting which will reduce the problem)

If the response is attribute, then the data we will take as response is the rejection % of a batch

M&A Phase: DOE 8- Variable Search rules checklist

Application: Problem solving

Data Collection	Analysis	Conclusion
Stage # 1	**Stage # 1**	**Stage # 1**
If the response is variable, then we have to produce 3 pieces in – setting and 3 pieces in + setting	D = Difference of Median d = Average of Ranges	If D/d ratio is >=3, then the settings identified in stage # 0 are correct and we can go to Stage # 2
If the response is attribute, then we have to produce 3 batches in – setting and 3 batches in + setting	Calculate D/d ratio	If D/d ratio is >=1.25 and <3, and there is no overlap then the settings identified in Stage # 0 are correct and we can go for Stage # 2
If the response is attribute, the batch quantity will be based on the existing rejection % and the rule is we have to decide the quantity to get at-least one bad. Eg: if the rejection percentage is 2%, then the batch quantity will be 50 pcs.		If D/d ratio is <1.25, the settings identified in Stage # 0 are wrong, and we go back to Stage # 0 for changing the + condition or for adding new design parameters
If the response is attribute, the rejection % of each batch will be tracked as response		After two iterations, if we are getting still D/d ratio <1.25, then identify the + setting in Stage # 0 as the setting which will give "more rejection"
Produce the 3 pieces or batches by alternating between the – and + setting. Do not produce 3 pieces or batches continuously in – and 3 pieces or batches continuously in + setting		
We will have 3 data in – setting and 3 data in + setting		

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE 8- Variable Search rules checklist

Application: Problem solving

Data Collection	Analysis	Conclusion
Stage # 2	**Stage # 2**	**Stage # 2**
List down the parameters in the descending order of suspect level	Middle line is the Average of Median	If both the lines cross the middle line (Average of median), then that parameter is the "ONLY PARMETER" creating the problem
Start with the first parameter, which is marked as "A". Produce one piece or one batch in A-R+ and one piece of one batch in A+R-.	Calculate 1.45*d, d – average of ranges Round off 1.45*d to the same decimal as data. Always round off to the higher value	If any one line cross the middle line, then that parameter is "ONE OF THE PARAMETER" creating the problem
If the response is variable, measure the actual value. If the response is attribute, calculate rejection % for the batch	UDL(+) = Median (+) + 1.45*d LDL(+) = Median (+) – 1.45*d Draw these limits as "Solid or Green line"	If no line crosses the middle line, then that parameter is "NOT AT ALL THE PARAMETER" creating the problem
If A parameter is concluded as "one of the parameter" and B parameter is concluded as "one of the parameter", then do not go for C parameter. Do A&B together	UDL(-) = Median (-) + 1.45*d LDL(-) = Median (-) – 1.45*d Draws these limits as "Dotted or Red line"	If we conclude that the parameter is "NOT AT ALL" creating the problem, then check whether the "Solid or Green line" is within the "Solid or Green limits" and "Dotted or Red line" is within the "Dotted or Red limits" If yes, then the contribution of the parameter is "ZERO" If not, then the contribution of the parameter is "NOT ZERO"
Stop the data collection, once we get the conclusion as "ONLY PARAMETER" creating the problem	Draw the + setting line as "Solid line" or "Green color line" Draw the – setting line as "Dotted line" or "Red color line" For A-R+, use the + setting legend for plotting the data point For A+R-, use the – setting legend for plotting the data point	If we conclude that the parameter is the "ONLY PARAMETER" , then check whether the "Solid or Green line" is within the "Dotted or Red limit" and "Dotted or Red line" is within the "Solid or Green limit" If yes, then the contribution of other parameters are "ZERO" If not, then the contribution of other parameters is "Not ZERO"

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE 8- Variable Search rules checklist

Application: Problem solving

Analysis	Conclusion
Stage # 4	**Stage # 4**
Make the Factorial table only for the Important parameters identified in the previous stage	When the parameter is changed from the setting provided above the contribution to the other setting, the response "DECREASES" by the amount calculated For eg: if the contribution of A is -2, then when A parameter is changed from – setting to + setting, the response will "DECREASE" by 2
Parameters which are "NOT IMPORTANT" and which are having "ZERO CONTRIBUTION" can be completely ignored from this analysis.	If the contribution of A is +2, then when A parameter is changed from + setting to – setting, the response will "DECREASE" by 2
Parameters which are "NOT IMPORTANT" and which are "NOT" having "ZERO CONTRIBUTION" should be fixed at a setting favorable for Quality (Could be either – or + setting)	
Each row in the table should be read as Combination	
See the data collected in Stage #1 and Stage # 2, question each data and fit in the corresponding row of the table, provided it fits	
For finding contribution, find out the Average of – setting, Average of + setting and find out the difference	
Whichever setting is having a "higher average", put that setting above the contribution	
Number of rows in the table = 2 ^ n (n – Number of parameters)	
Number of interactions = Number of rows - 1 - number of parameters	
This analysis can also be done in Minitab	

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE 8- Variable Search rules checklist

Application: Problem solving

Analysis	Conclusion
Stage # 5	**Stage # 5**
Make the Math equation.	Work out multiple settings using Excel Find out the best setting in terms of Productivity and Cost
Coefficients of each parameter is ½ the Contribution	
If Y is variable and Lower is better (Eg" Runout), Calculate the boundary for optimization as Upper boundary = USL – 2.3*d Lower boundary = USL – 2.8*d	
If Y is variable and Higher is better (Eg: Strength), Calculate the boundary for optimization as Upper boundary = LSL + 2.8 *d Lower boundary = LSL + 2.3*d	
If Y is variable and Nominal is better (Eg: Diameter), Calculate the Boundary for optimization as Upper boundary = Target + 25% of tolerance Lower boundary = Target = 25% of tolerance	
If Y is attribute, then the Boundaries are Upper Boundary = 0 Lower Boundary = 0	

DOE Tool 8

Variable Search

Application: Process Optimization

M&A Phase: DOE 8 – Variable Search rules checklist

Application – Process Optimization

Stage # 0 rules

•*Listing of Parameters*

•All Parameters which are speed and cost related should be listed down like speed, feed, cycle time, current, gas flow etc..

•If any other parameters which has no effect on cycle time and cost, but has to be changed to take care of the Quality should also be listed. This is purely a technical decision

•Responses are all the Quality parameters that needs to be achieved in that process

•Responses will be Multiple

•*Identification of – and + settings*

•Current setting is the – setting

•+ setting is identified favorable for Cost and Productivity. Eg: if the current setting for Feed is 0.1mm/rev, then in the + setting, feed should be increased. How much we have to increase is an atmospheric decision. General thumb rule, is increase by at-least 15% from the current condition

M&A Phase: DOE 8- Variable Search rules checklist

Application: Process Optimization

Data Collection	Analysis	Conclusion
Stage # 1	**Stage # 1**	**Stage # 1**
If all the responses are variable, then we have to produce 3 pieces in – setting and 3 pieces in + setting	D = Difference of Median d = Average of Ranges	If D/d ratio is >=3, then we have to go for Stage # 2
If any one of the response is attribute, then we have to produce 3 batches in – setting and 3 batches in + setting	Calculate D/d ratio for every response	If D/d ratio is >=1.25 and <3 and no overlap, then we have to go for Stage # 2
If the response is attribute, batch quantity is 10 pcs		If D/d ratio is <1.25, then make the "+" setting as "-" setting and identify a new "+" setting. Produce another 3 pieces or batches and again calculate D/d ratio. Do this iteration, till we get difference in any one response
If the response is attribute, the rejection % of each batch will be tracked as response		If D/d ratio is >=1.25 and <3, and there is overlap, then make the "+" setting as "-" setting and identify a new "+" setting. Produce another 3 pieces or batches and again calculate D/d ratio
Produce the 3 pieces or batches by alternating between the – and + setting. Do not produce 3 pieces or batches continuously in – and 3 pieces or batches continuously in + setting		
We will have 3 data in – setting and 3 data in + setting for every response		

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE 8- Variable Search rules checklist

Application: Process Optimization

Data Collection	Analysis	Conclusion
Stage # 2	**Stage # 2**	**Stage # 2**
List down the parameters in the descending order of suspect level	Middle line is the Average of Median	If both the lines cross the middle line (Average of median), then that parameter is the "ONLY IMPORTANT PARMETER"
Start with the first parameter, which is marked as "A". Produce one piece or one batch in A-R+ and one piece of one batch in A+R-.	Calculate 1.45*d, d – average of ranges Round off 1.45*d to the same decimal as data. Always round off to the higher value	If any one line cross the middle line, then that parameter is "ONE OF THE IMPORTANT PARAMETER"
If the response is variable, measure the actual value. If the response is attribute, calculate rejection % for the batch	UDL(+) = Median (+) + 1.45*d LDL(+) = Median (+) – 1.45*d Draw these limits as "Solid or Green line"	If no line crosses the middle line, then that parameter is "NOT AT ALL THE PARAMETER"
If A parameter is concluded as "one of the parameter" and B parameter is concluded as "one of the parameter", then do not go for C parameter. Do A&B together	UDL(-) = Median (-) + 1.45*d LDL(-) = Median (-) – 1.45*d Draws these limits as "Dotted or Red line"	If we conclude that the parameter is "NOT AT ALL IMPORTANT", then check whether the "Solid or Green line" is within the "Solid or Green limits" and "Dotted or Red line" is within the "Dotted or Red limits" If yes, then the contribution of the parameter is "ZERO" If not, then the contribution of the parameter is "NOT ZERO"
Stop the data collection, once we get the conclusion as "ONLY IMPORTANT PARAMETER"	Draw the + setting line as "Solid line" or "Green color line" Draw the – setting line as "Dotted line" or "Red color line" For A-R+, use the + setting legend for plotting the data point For A+R-, use the – setting legend for plotting the data point	If we conclude that the parameter is the "ONLY IMPORTANT PARAMETER" , then check whether the "Solid or Green line" is within the "Dotted or Red limit" and "Dotted or Red line" is within the "Solid or Green limit" If yes, then the contribution of other parameters are "ZERO" If not, then the contribution of other parameters is "Not ZERO"

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE 8- Variable Search rules checklist

Application: Process Optimization

Analysis	Conclusion
Stage # 4	**Stage # 4**
Make the Factorial table only for the Important parameters identified in the previous stage	When the parameter is changed from the setting provided above the contribution to the other setting, the response "DECREASES" by the amount calculated For eg: if the contribution of A is -2, then when A parameter is changed from – setting to + setting, the response will "DECREASE" by 2
Parameters which are "NOT IMPORTANT" and which are having "ZERO CONTRIBUTION" can be completely ignored from this analysis.	If the contribution of A is +2, then when A parameter is changed from + setting to – setting, the response will "DECREASE" by 2
Parameters which are "NOT IMPORTANT" and which are "NOT" having "ZERO CONTRIBUTION" should be fixed at a setting favorable for Quality (Could be either – or + setting)	
Each row in the table should be read as Combination	
See the data collected in Stage #1 and Stage # 2, question each data and fit in the corresponding row of the table, provided it fits	
For finding contribution, find out the Average of – setting, Average of + setting and find out the difference	
Whichever setting is having a "higher average", put that setting above the contribution	
Number of rows in the table = 2 ^ n (n – Number of parameters)	
Number of interactions = Number of rows - 1 - number of parameters	
This analysis can also be done in Minitab	

Key skills of BB : Process knowledge, Good observation and correct selection of tools

M&A Phase: DOE 8- Variable Search rules checklist

Application: Process Optimization

Analysis	Conclusion
Stage # 5	**Stage # 5**
Make the Math equation.	Work out multiple settings using Excel Find out the best setting in terms of Productivity and Cost
Coefficients of each parameter is ½ the Contribution	
If Y is variable and Lower is better (Eg" Runout), Calculate the boundary for optimization as Upper boundary = USL – 2.3*d Lower boundary = USL – 2.8*d	
If Y is variable and Higher is better (Eg: Strength), Calculate the boundary for optimization as Upper boundary = LSL + 2.8 *d Lower boundary = LSL + 2.3*d	
If Y is variable and Nominal is better (Eg: Diameter), Calculate the Boundary for optimization as Upper boundary = Target + 25% of tolerance Lower boundary = Target = 25% of tolerance	
If Y is attribute, then the Boundaries are Upper Boundary = 0 Lower Boundary = 0	

Key skills of BB : Process knowledge, Good observation and correct selection of tools

DOE Tool 9

Full Factorial

Application:

- Is used when design parameters are <=3.
- Is used for Problem solving as well as Existing process optimization.

Note: Difference from Variable Search

In variable search , factorial table is constructed only for significant parameters while in Full Factorial , it is constructed for the all parameters identified.

In this tool, Stage # 2 of Variable search is not done, and the factorial table is made directly and data is collected. Rest of the procedure is same

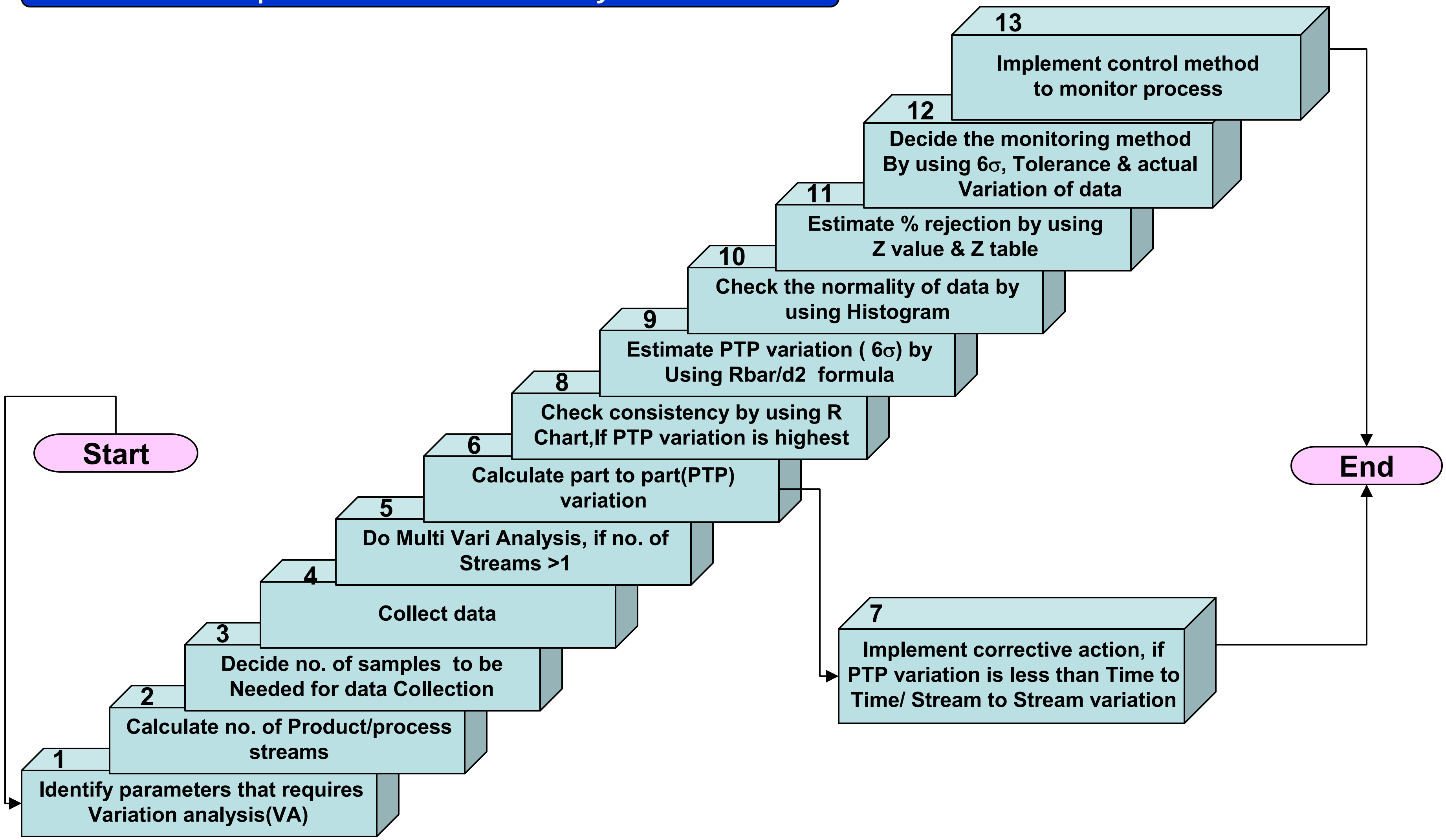
DOE Tool 10

Variation analysis

Application:

- Is used to identify the type of controls (monitoring method) that are required for the action implemented so that the problem does not recur again due to the same root cause.
- Is done only when Product dimensions are the root cause for the problem
- Five options of the control methods are
  - No inspection
  - Pre-control chart
  - X-bar and Range chart with sampling inspection
  - X-bar and Range chart with 100% inspection
  - Only 100% inspection
- Is used to prove that "Six Sigma (Estimated part to part variation) " is 50% of the tolerance if the Big Y is "Variable".

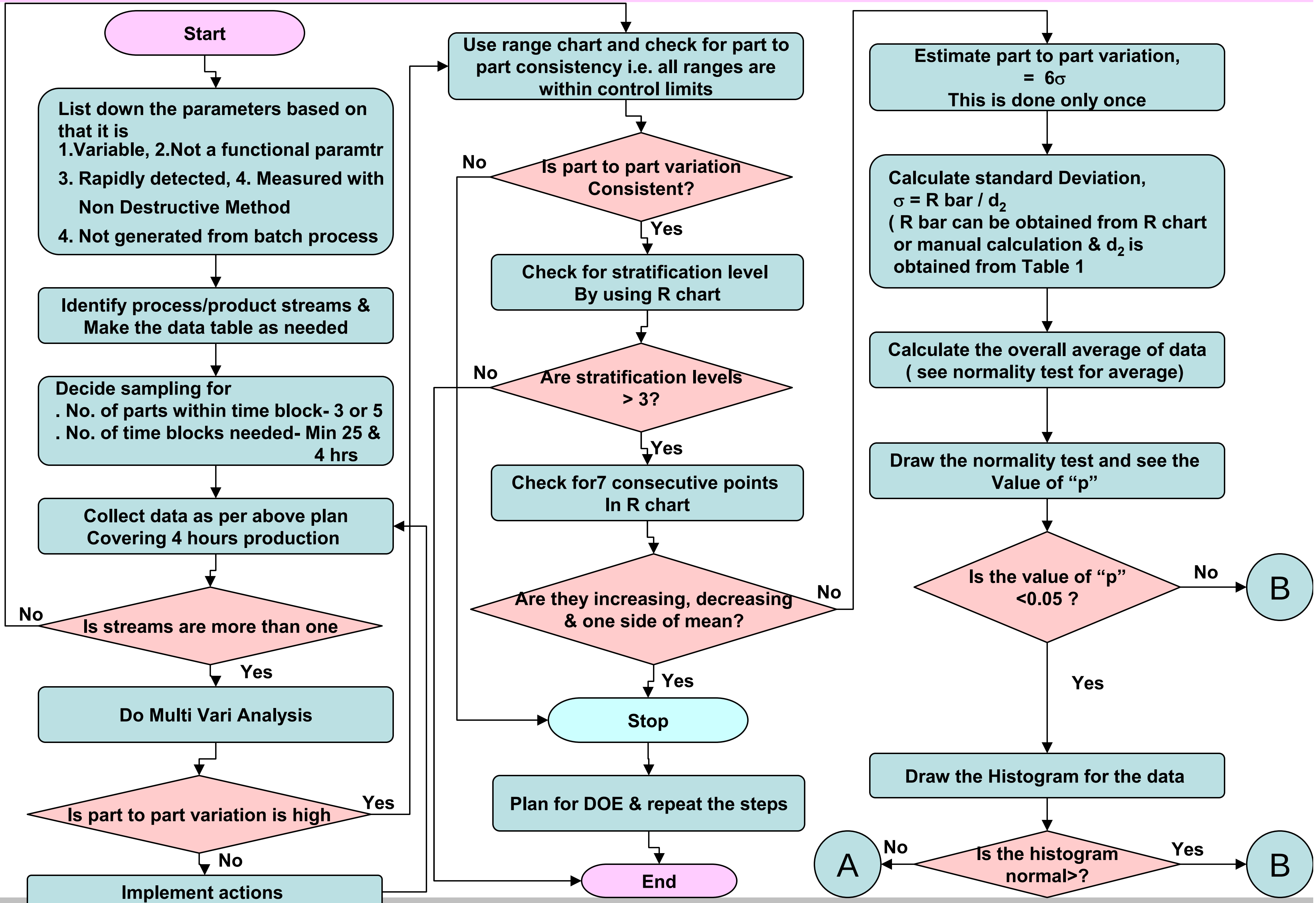
Steps for Variation Analysis



Key skills of BB : Process knowledge, Good observation and correct selection of tools

Control Phase

DOE 10 – Variation Analysis



Key skills of BB : Process knowledge, Good observation and correct selection of tools

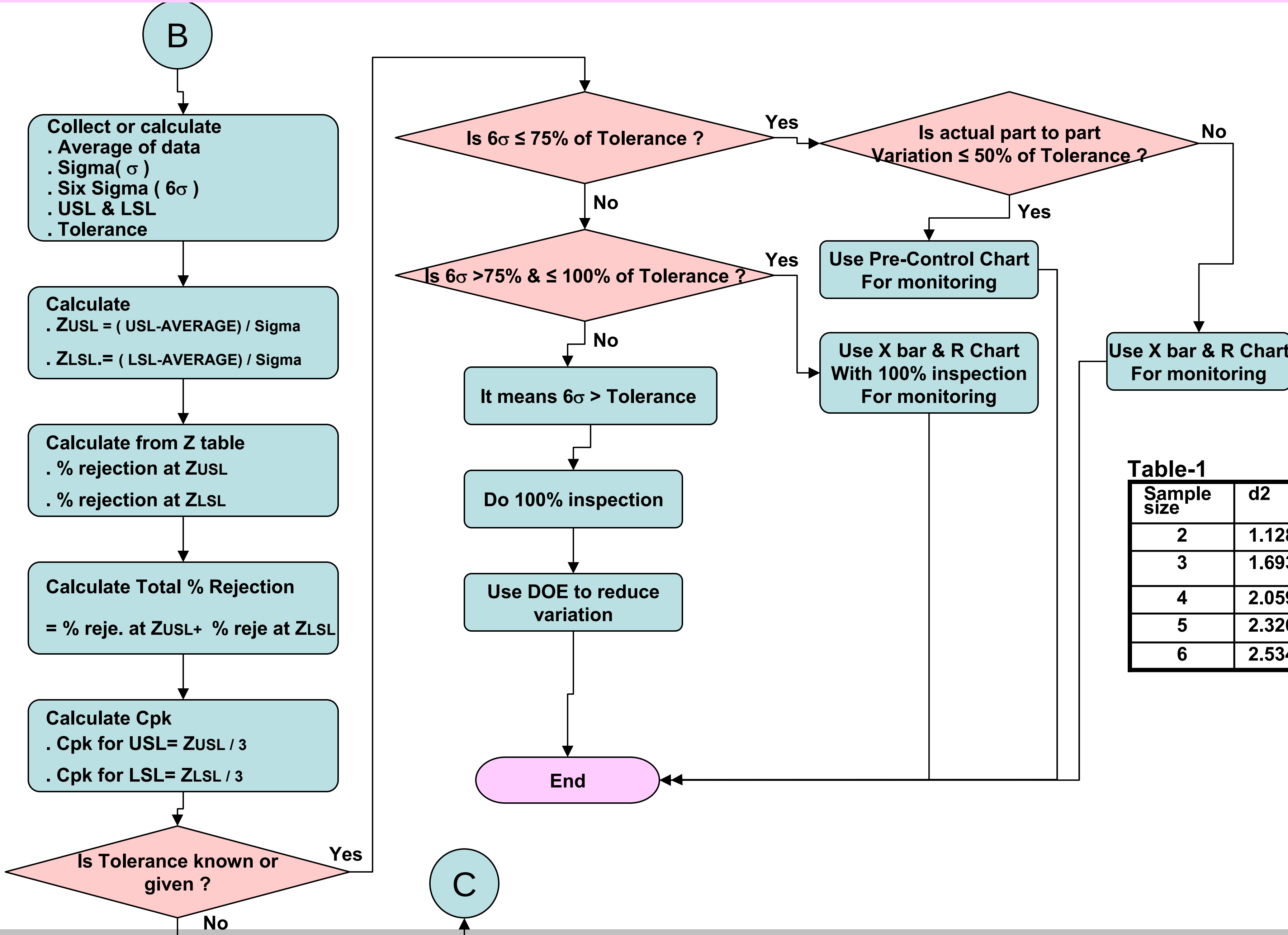
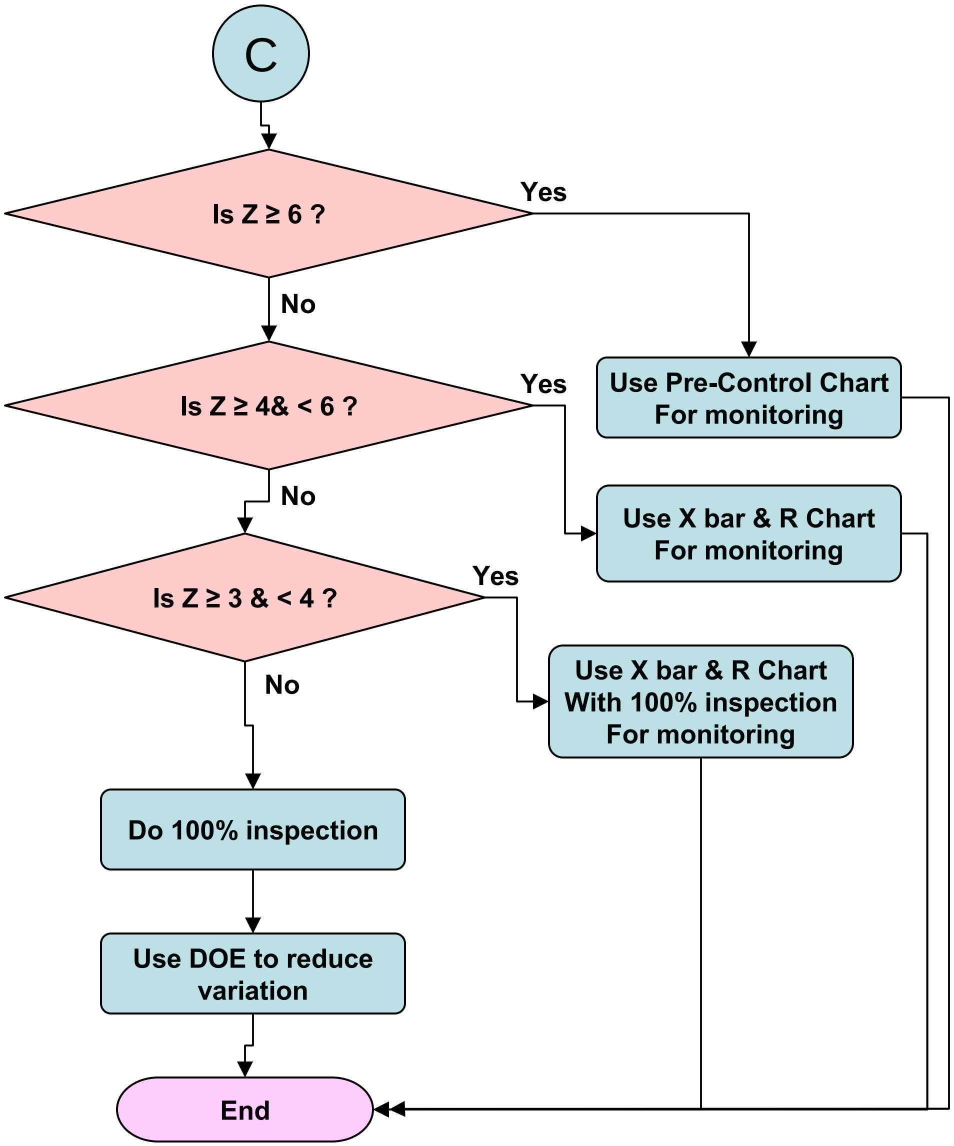
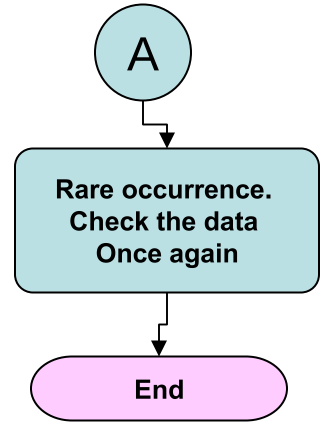


Table-1

Sample size	d2
2	1.128
3	1.693
4	2.059
5	2.326
6	2.534





Calculation of z value When Tolerance is not given
(Only Min Value is given)

Z value	% Rej.	Cpk	6σ as % of Tolerance
1	31.6	0.33	300%
2	4.55	0.67	150%
3	0.27	1	100%
4	60ppm	1.33	75%
5	0	1.66	60%
6	0	2	50%

Key skills of BB : Process knowledge, Good observation and correct selection of tools

DOE Tool 11

R&R study

Application:

- Is used when there is variation due to method of checking by a person
- Within person variation is termed as "Repeatability" and is equal to part to part variation. It is also called "Within Person Variation"
- Between person variation is termed as "Reproducibility" and is equal to time to time variation. It is also called "Person to Person Variation ".
- This study is done only once to find out the variation due to the method of checking
- Variation Analysis DOE tool is used to do R&R study.

Repeatability:

- The variation in measurements obtained with one instrument when used several times by one operator while measuring the identical characteristic on same part. This is within person variation.

Reproducibility:

- The variation in the average of measurements obtained with one instrument when used several times by different operator while measuring the identical characteristic on same part. This is person to person variation.

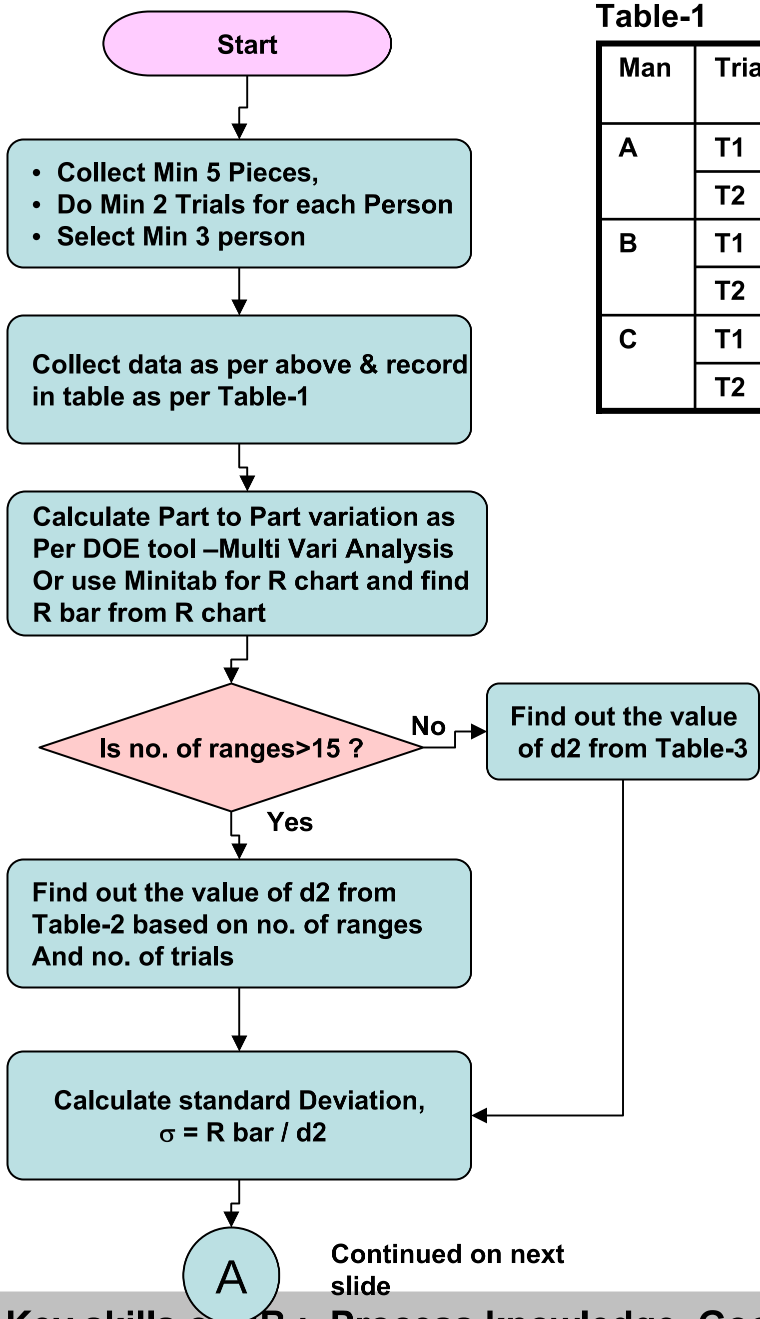


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Table-1

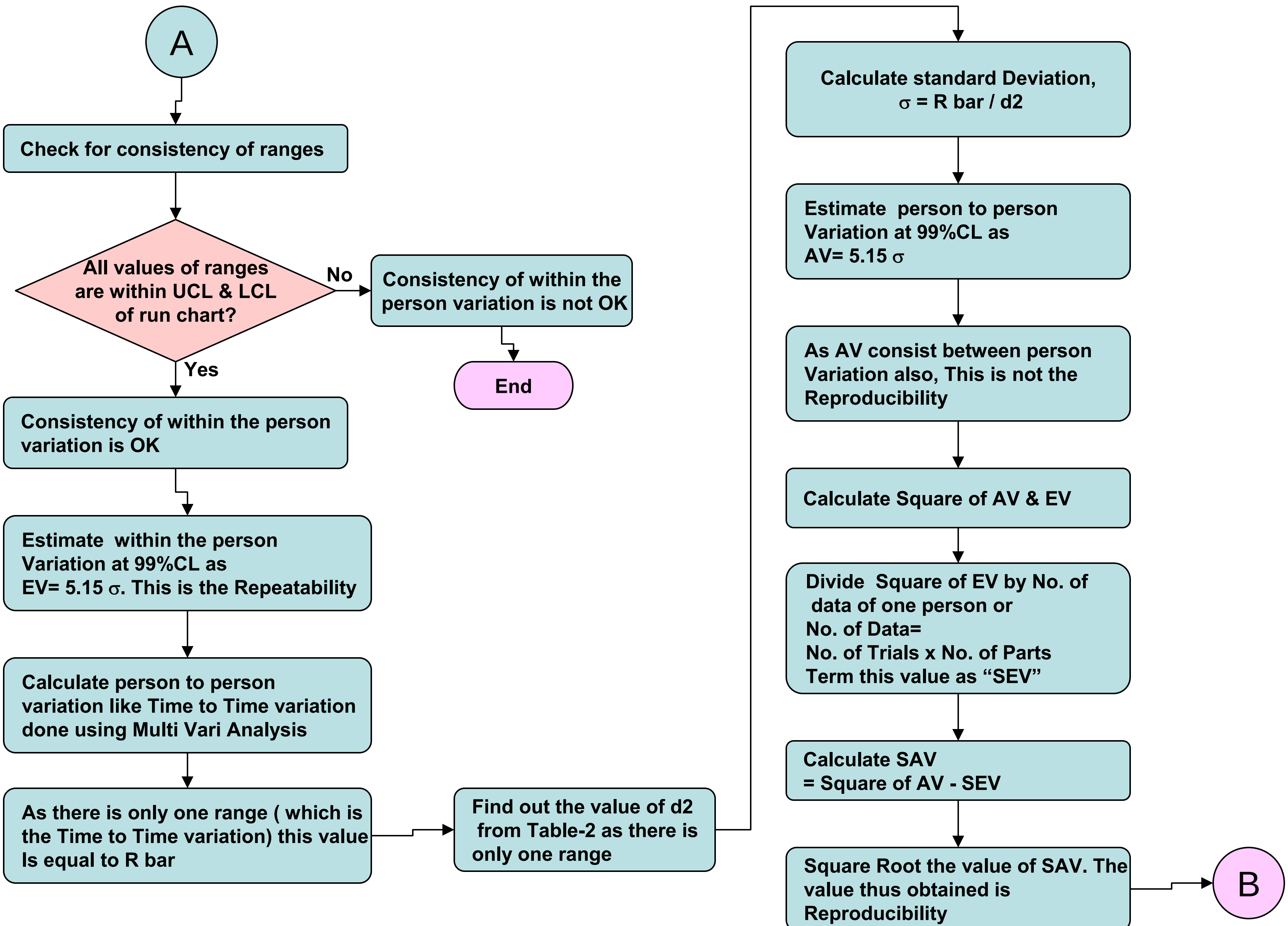
Man	Trial	Sample 1	Sample 2	Sample 3
A	T1	45.58	61.36	75.80
	T2	45.61	61.48	75.68
B	T1	45.39	60.83	75.47
	T2	45.33	60.86	75.43
C	T1	45.47	61.02	74.99
	T2	45.46	60.77	74.68

Table-3

Sample size	d2
2	1.128
3	1.693
4	2.059
5	2.326
6	2.534

Table-2

Ranges	Group Size (Trials)				
	2	3	4	5	6
1	1.41	1.91	2.24	2.48	2.67
2	1.28	1.81	2.15	2.4	2.6
3	1.23	1.77	2.12	2.38	2.58
4	1.21	1.75	2.11	2.37	2.57
5	1.19	1.74	2.1	2.36	2.56
6	1.18	1.73	2.09	2.35	2.56
7	1.17	1.73	2.09	2.35	2.55
8	1.17	1.72	2.08	2.35	2.55
9	1.16	1.72	2.08	2.34	2.55
10	1.16	1.72	2.08	2.34	2.55
11	1.16	1.71	2.08	2.34	2.55
12	1.15	1.71	2.07	2.34	2.55
13	1.15	1.71	2.07	2.34	2.55
14	1.15	1.71	2.07	2.34	2.54
15	1.15	1.71	2.07	2.34	2.54



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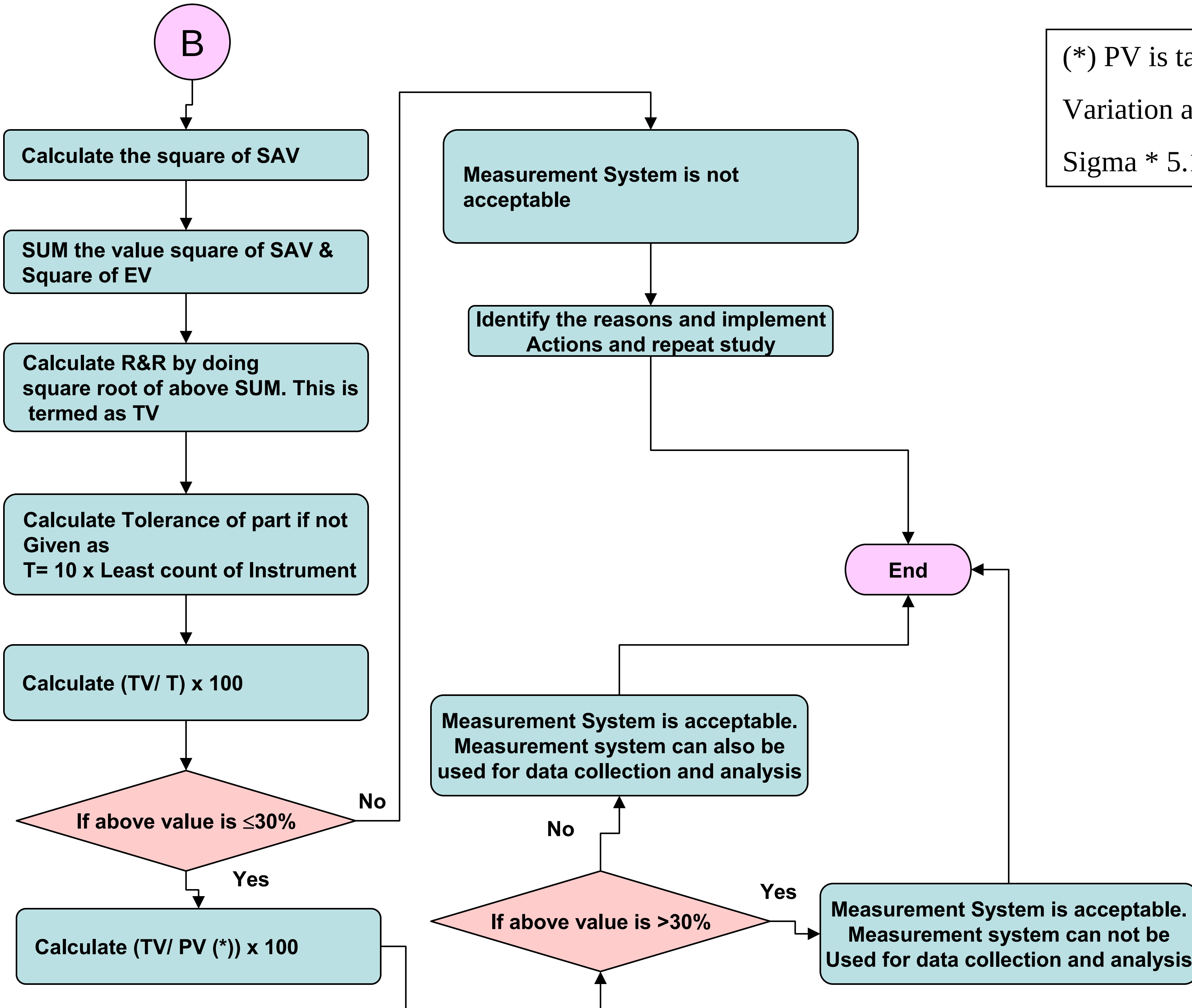
Key skills of BB : Process knowledge, Good observation and correct selection of tools



(*) PV is taken from the Variation analysis study as Sigma * 5.15

DOE Tool 12

Instrument Calibration

Error = Average of measurement – Value of Master

Measurement Uncertainty: Variation in the error

Types of Measurement Uncertainty:

1. Random Uncertainty
2. System Uncertainty

Linearity: Variation in the error across the range of the instrument

DOE 12 – Variation due to Instrument

1. Start
2. Collect Min 5 reading from instrument
3. Calculate average of above readings
4. Calculate Error = Actual average – Master Value
5. Calculate Range R = Max Value – Min Value
6. As there is only one range Hence R = R bar
7. Find out the value of d2 from Table 1 is for one range
8. Calculate standard Deviation, σ = R bar / d2
9. Calculate standard Deviation for Averages as σ x = σ / √ n Where n= no. of trials
10. Get the 't' value at 95% CL from Table 1 based on no. of trials
11. Estimate Variation at 95%CL as RU = ± (t x σ) and is termed as Random Uncertainty
12. If System(master) Uncertainty is also given then termed it as SU
13. Calculate Total Uncertainty as TU = ± √Sqr of RU + Sqr of SU
14. Calculate Upper & Lower Limit As UL = Error + TU, LL = Error - TU
15. Check whether zero lies between these limits. → A

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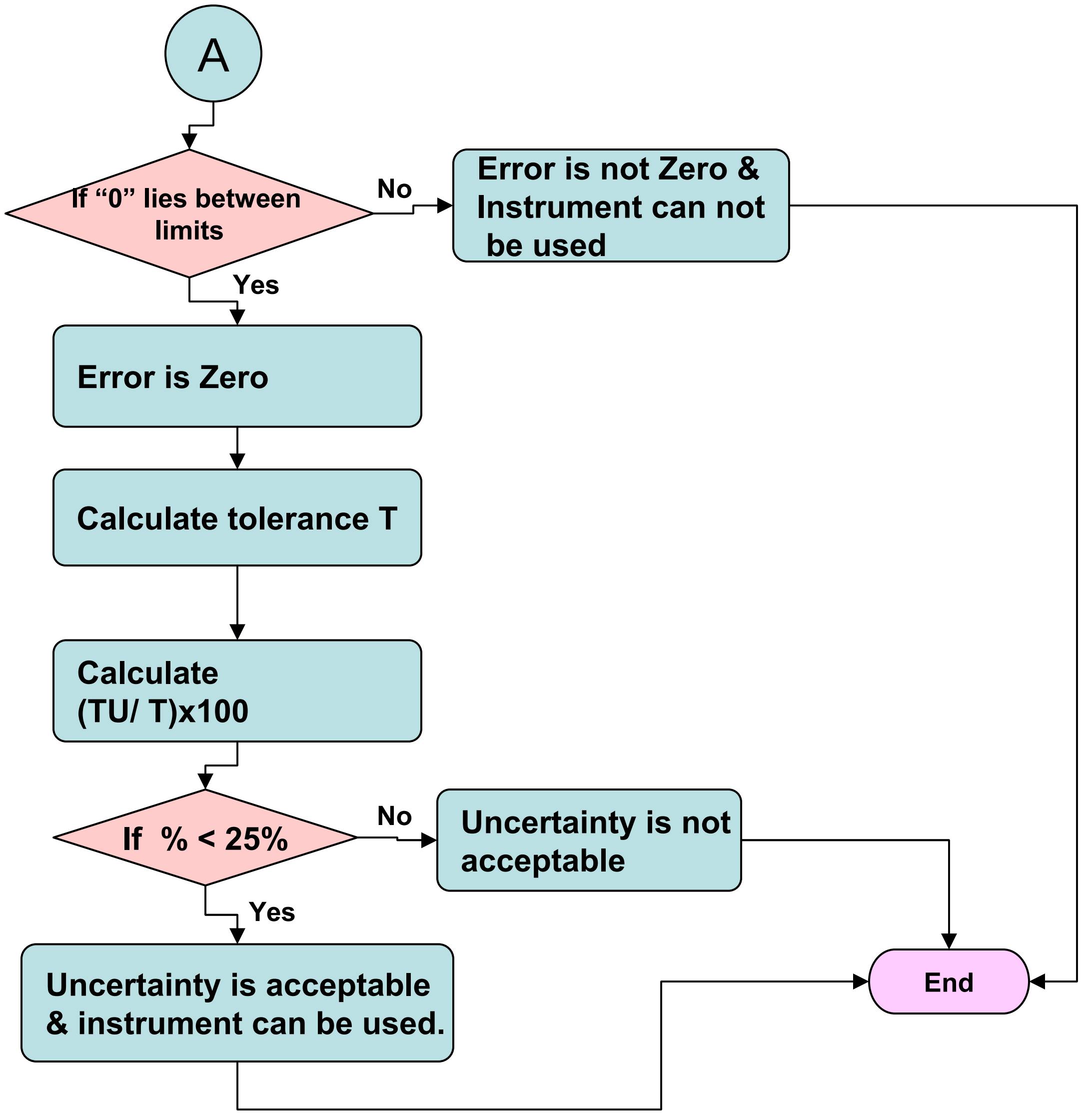
Table-1

d2 value

t values	Ranges / Trials	Group Size (Trials)				
		2	3	4	5	6
	1	1.41	1.91	2.24	2.48	2.67
12.706	2	1.28	1.81	2.15	2.4	2.6
4.3027	3	1.23	1.77	2.12	2.38	2.58
3.1825	4	1.21	1.75	2.11	2.37	2.57
2.7764	5	1.19	1.74	2.1	2.36	2.56
2.5706	6	1.18	1.73	2.09	2.35	2.56
2.4469	7	1.17	1.73	2.09	2.35	2.55
2.3646	8	1.17	1.72	2.08	2.35	2.55
2.3060	9	1.16	1.72	2.08	2.34	2.55
2.2622	10	1.16	1.72	2.08	2.34	2.55
2.2281	11	1.16	1.71	2.08	2.34	2.55
2.2010	12	1.15	1.71	2.07	2.34	2.55
2.1788	13	1.15	1.71	2.07	2.34	2.55
2.1604	14	1.15	1.71	2.07	2.34	2.54
2.1448	15	1.15	1.71	2.07	2.34	2.54


A
If “0” lies between limits
No
Error is not Zero & Instrument can not be used
Yes
Error is Zero
Calculate tolerance T
Calculate (TU/ T)x100
If % < 25%
No
Uncertainty is not acceptable
Yes
Uncertainty is acceptable & instrument can be used.
End