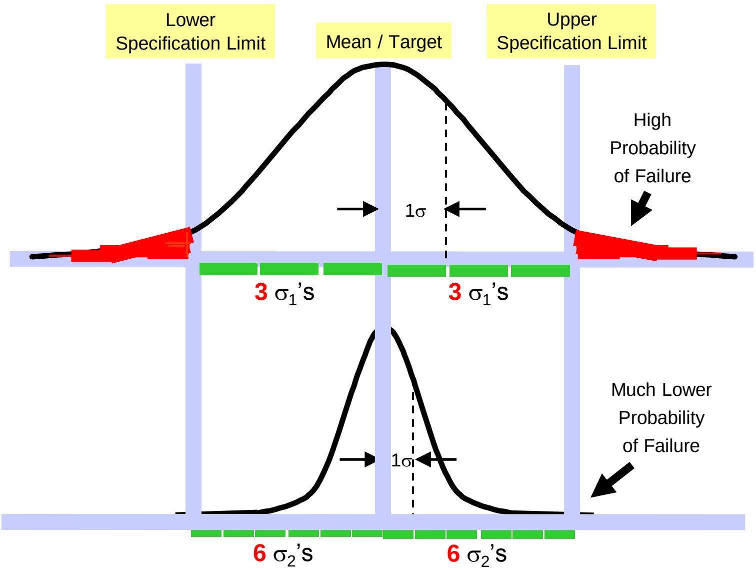
Six Sigma Green Belt & Black belt with Minitab Application



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LEAN PRACTICIONER-: POSCO MAHARASHTRA STEEL

Some Current Leadership Challenges

- Delighting Customers
- Reducing Cycle Times
- Keeping up with Technology Advances
- Growing Overseas Markets
- Reducing Costs
- Responding More Quickly
- Structuring for Flexibility
- Retaining People
- Developing Succession Plans
- Integrating Systems Post-Merger

Global acceptability

The world over, organizations seeking better ways of improving their profitability have adopted Six Sigma because of its ability in giving quick tangible results. These organizations include General Electric, Allied signal, Honda, Sony, Canon, Polaroid, Texas instruments and many more fortune 500 companies across the globe.

- **Indian Companies**
- **Whirlpool ,**
- **Motorola ,**
- **GE ,**
- **Honeywell**
- **ICICI Bank**
- **Standard Chartered**
- **Satyam**
- **Wipro**
- **TATA Special Steel**
- **Samtel**
- **LG Electronics**
- **Samsung**
- **TATA Johnson Controls**
- **GTL**
- **Cummins**

Six Sigma – Where it is applicable

Typical Six Sigma projects pertain to:

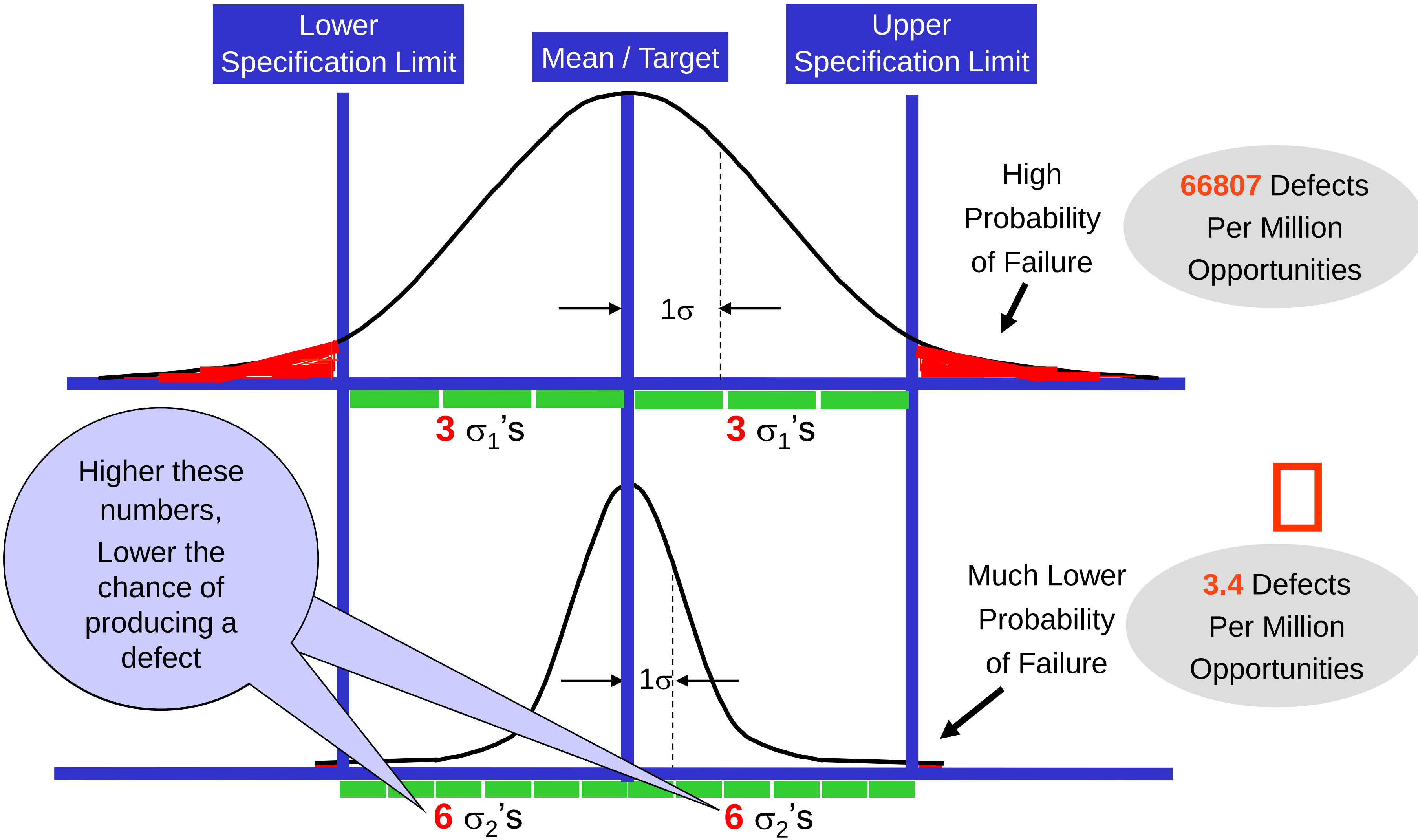
- Defect Reduction
- Quality Improvement
- Cost Reduction
- Productivity Improvement
- Employee Satisfaction
- Customer Satisfaction
- Sales Growth
- Profitability

Typical Applications

- Manufacturing
- Commercial
- Sales & Marketing
- Sourcing
- Information Systems
- Human Resources

- Any other?

What is Six Sigma?

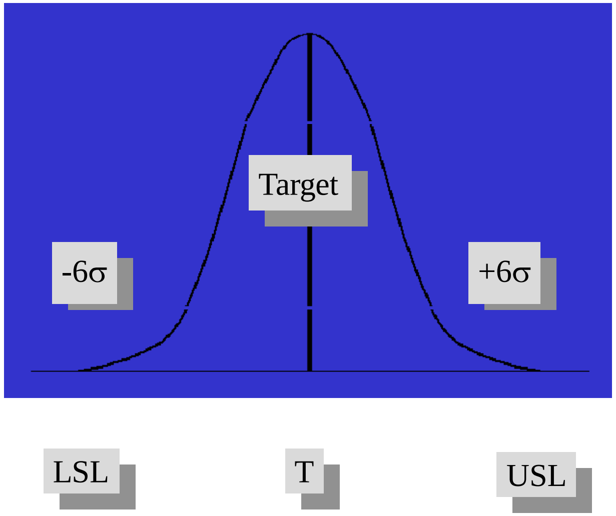


Six Sigma is….

3.4 defects per 1000000 opportunities

That means a process efficiency of 99.99966%

In other words, process standard deviation (σ) should be so less that your process performance can fit 12σ within the customer specified limits. So, no matter how much your process deviates from target, you always meet what customer wants.



USL: Upper Specification Limit for a Performance Standard. Anything above this is a defect.

LSL: Lower Specification Limit for a Performance Standard. Anything below this is a defect.

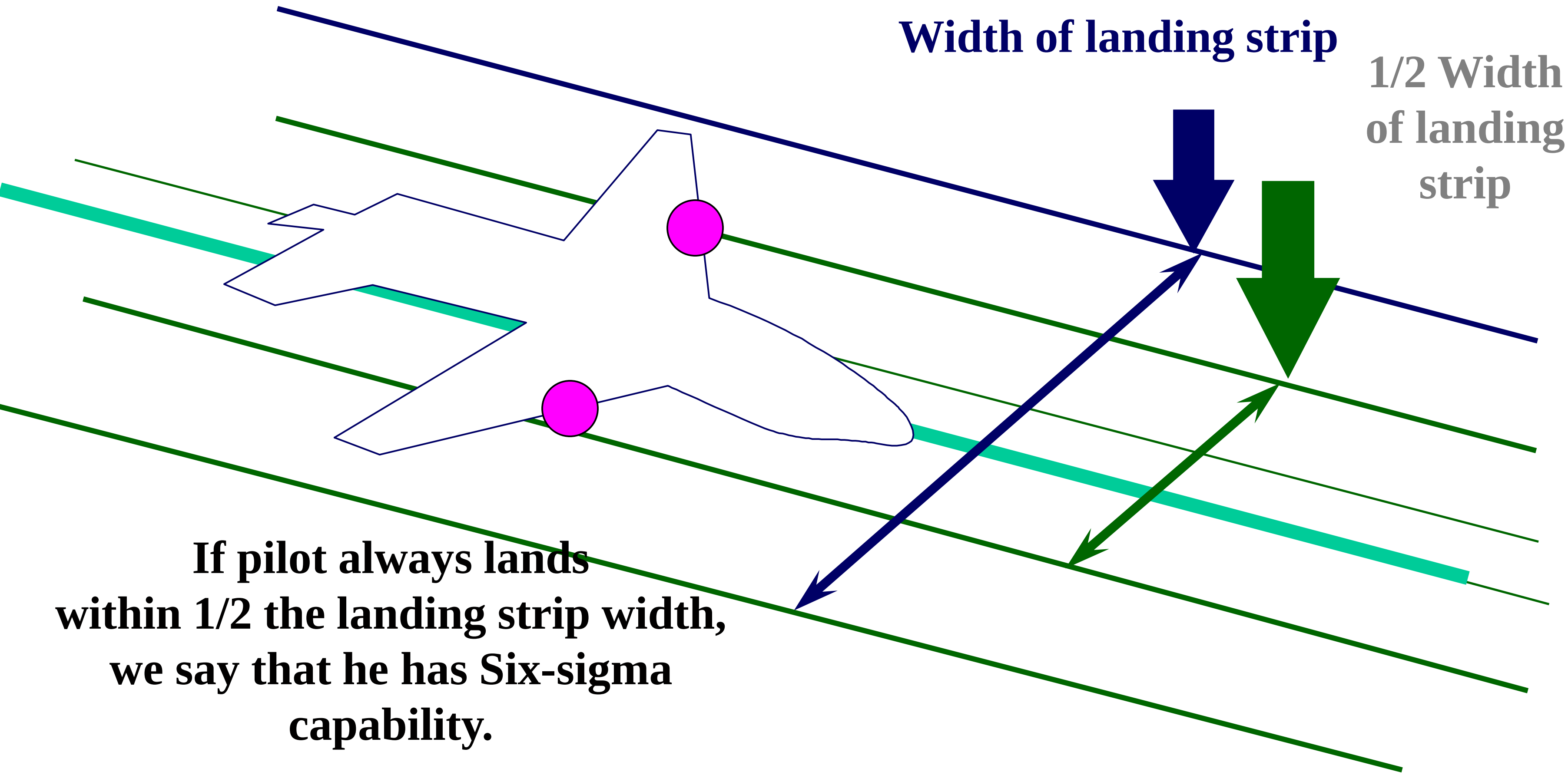
Target: Ideally the middle point of USL & LSL.

Six Sigma is….

	DEFECT RATE (PPM)	COST OF POOR QUALITY (% OF SALES)	
6σ	3.4	< 1 %	WORLD CLASS
5σ	233	10 % - 15 %	
4σ	6,210	15 % - 20 %	INDUSTRY AVERAGE
3σ	66,807	20 % - 30 %	
2σ	308,537	30 % - 40 %	NON-COMPETITIVE
1σ	690,000	> 40 %	

*COPQ stands for Cost of poor quality

Pilot's six-sigma performance



If pilot always lands within 1/2 the landing strip width, we say that he has Six-sigma capability.

Six Sigma Benefits

- Continuous Defect Reduction in Products & Services
- Enhanced Customer Focus
- Process Sustenance
- Performance Dashboards & Metrics
- Project Based Improvement, with Visible Milestones
- Sustainable Competitive Edge
- Global Acceptance of the Quality System

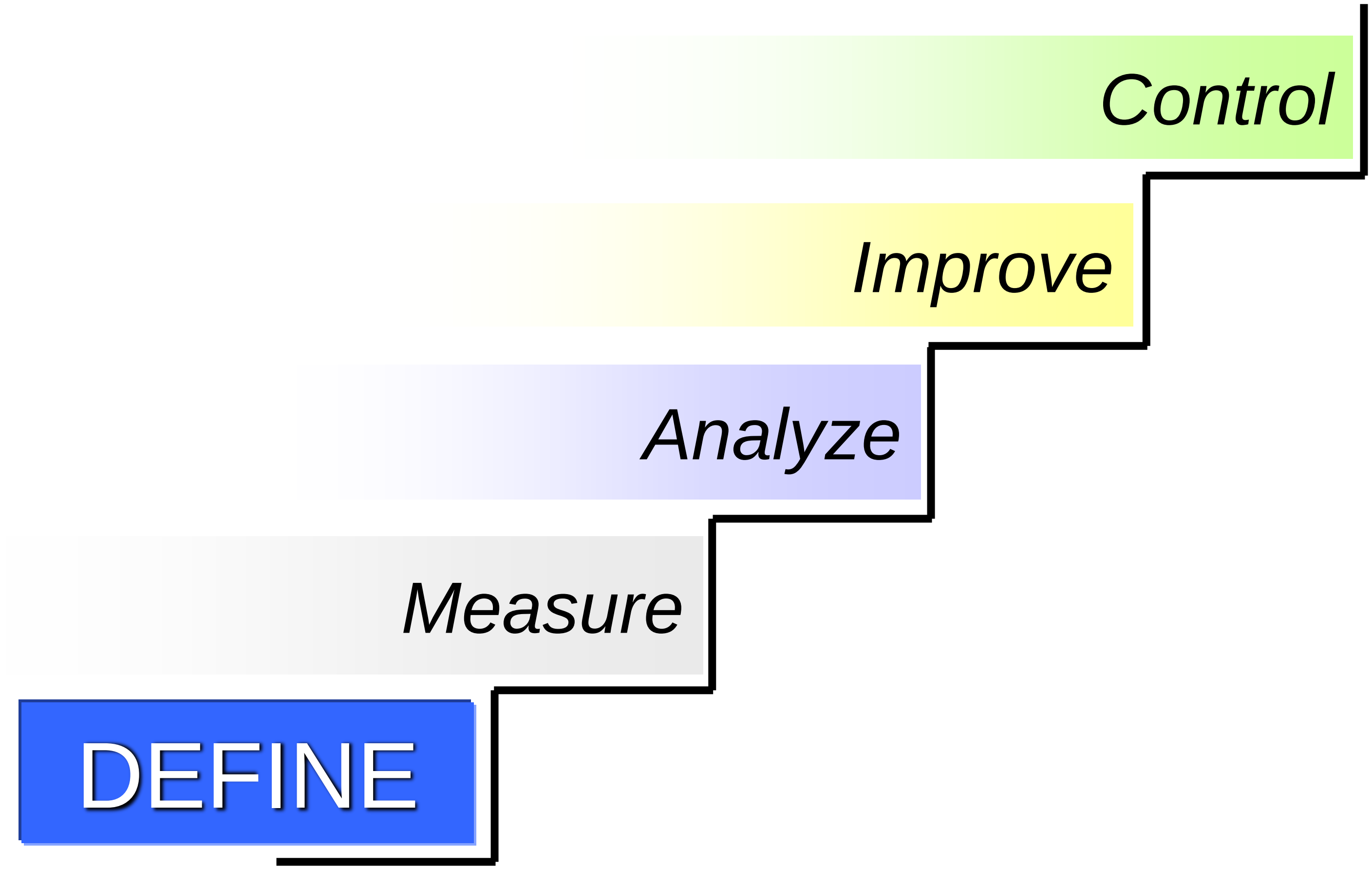
DMAIC Overview

- DMAIC is one of the many Six Sigma methodologies
- DMAIC applies to an existing process that needs improvement
- It’s best applicable to continuous defect reduction in cross-functional / uni-functional environment

DMAIC Overview

DMAIC Phase	Problem Solving Roadmap
Define	What are the various problems Which problems we will work on Who will work on the problem By When the problem will be eliminated
Measure	What is the Project Y What is the specification on Y What are the issues with Measurements on Y
Analyze	What is the existing baseline on Y How much we want to improve What are the possible Xs impacting Y
Improve	What are the probable Xs impacting Y Where we should set these Xs
Control	How the results will be sustained in the long run

Six Sigma



Introduction - DEFINE

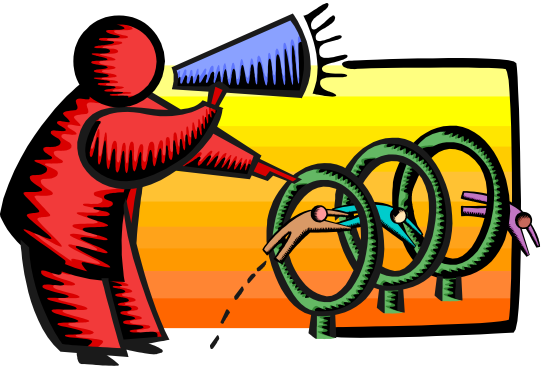
DMAIC

- DEFINE pertains to selection of right problem, with right team, setting the right focus thereby bringing the entire team to a common understanding of the problem

- DEFINE also ensures that we function effectively as a team during the course of the project

Define - Deliverables

- Define CTQs
- Define Customer
- Project Scoping
- Team Charter
- Project agreement Form
- Loss Gain Matrix
- Elevator Speech



Define Business CTQ

CTQ (Critical to Quality)

A CTQ is a

Product or Service

characteristic

that satisfies a

Customer Requirement

OR

Process Requirement

- Business CTQ
- Customer CTQ
- Internal CTQ

What are Business CTQs?

- Business CTQs drive the business goals & vision
- Typical Business CTQs are
  - Operational Excellence
  - Cost Reduction
  - Productivity Improvement
  - Employee Satisfaction
  - Customer Satisfaction
  - Sales Growth
  - Profitability

DMAIC

Define your Customer

Who is your customer?

- A customer is someone who
  - Uses your product or service
  - Decides to buy your product or service
  - Pays for your product or service
  - Gets impacted by your product or service
- Internal & External customers
- Primary & Secondary customers
- Key concepts
  - Different markets / segments
  - Different customer requirements
  - Product / Service chain

DMAIC

Explore Customer CTQ

Customer CTQs

- Six Sigma begins with the customer
- Customers find it easier to define what they do not want
- Customer CTQs are defined by customers
- Sources of customer CTQs
  - Survey results
  - Service reviews
  - Meetings

Examples of Customer CTQs

DMAIC

A Car Purchaser

- Good Acceleration
- Spacious
- Affordable
- Power Steering
- Loan Facility

A TV Purchaser

- Flat Screen
- Good Sound
- NTSC / PAL Compatible
- Affordable
- Good After Sales Service

A Caller to Help Desk

- Quick Answering
- Courteous Response
- Quick Problem Resolution

A Prospective Employee

- Good Salary
- Location Preference
- Flexible Working Hours
- ESOPs
- Separate Cabin

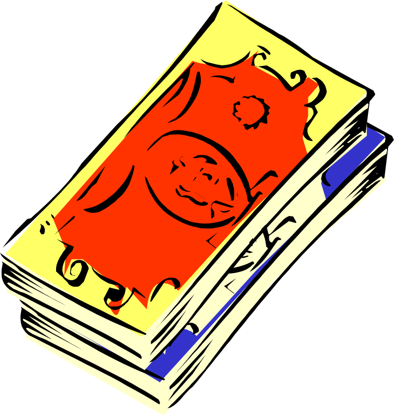
Example of an Air Conditioner

DMAIC

Customer CTQ's

VOC Table

Sl. No.	Who is the customer?	What customer said (Voice of Customer)	What customer meant				
			What is the need?	When is the need felt?	Where is the need felt?	Why is the need felt?	How is the situation handled now?
1	Household member	AC should be silent	Sound sleep	At night	In the bedroom	To remain fresh next morning	Uses a ceiling fan that makes a lot of noise
		AC should be efficient	Good cooling	At night	In the bedroom	It gets very hot in May-June	Uses a ceiling fan that is not so effective in summer
		AC should not cost much	Affordability	N/A	N/A	Limited finance	N/A



Project Agreement Form

Project Agreement Form

Tool

Project Agreement Form

DMAIC Project Agreement Form

(Tick / fill all that apply)

Project Title:			
Champion:		**Project No:**	
Green Belt:		**Black Belt:**	
Customer CTQ:		**CBP / Internal CTQ:**	

Project Selection Check-list

1	How important is it to your customer?	High	Medium	Low
2	Is there a champion who feels that the project is important?	(Yes / No)		
3	Is it part of your current job responsibilities & objectives?	(Yes / No)		
4	Is the CTQ measurable?	(Yes / No)		
5	Is data available or easily generated?	(Yes / No)		
6	Are benefits easily measurable?	(Yes / No)		
7	Is the process stablized or at least controllable?	(Yes / No)		
8	Is the scope narrow enough to finish it in 4-6 months?	(Yes / No)		
9	Does the project have a high potential for translation?	(Yes / No)		
10	Have you ensured that no obvious solutions are available?	(Yes / No)		

Problem Statement (why are we doing this project?)

Project Scope (use inside-outside technique)

Project Team Members

Sl. No.	Name of the Team Member	Functional Role	Project Responsibilities
1			
2			
3			
4			
5			
6			
7			

Project Deadlines:	Completion of Define phase	Completion of Measure phase	Completion of Analyze phase	Completion of Improve phase	Project closure
(indicate the month)					

Projected Financial Benefits:		(attach details)

Signatures:

Champion: ____________________

Black Belt: ____________________

Finance: ____________________

Green Belt: ____________________

DMAIC Project Agreement Form

Defining a Problem Statement

- A well-defined problem statement describes the 'pain'
  - What is wrong or not meeting your customer's needs?
  - When and where do the problems occur?
  - How big is the problem?
  - What's the negative impact of the problem?

Defining a Problem Statement

DMAIC

Poor Example:

Our customers are angry with us and thus delay paying their bills.

Good Example:

In the last 3 months, 12% of our customers are late, by over 45 days in paying their bills. This represents 20% of our outstanding receivables & negatively affects our operating cash flow.

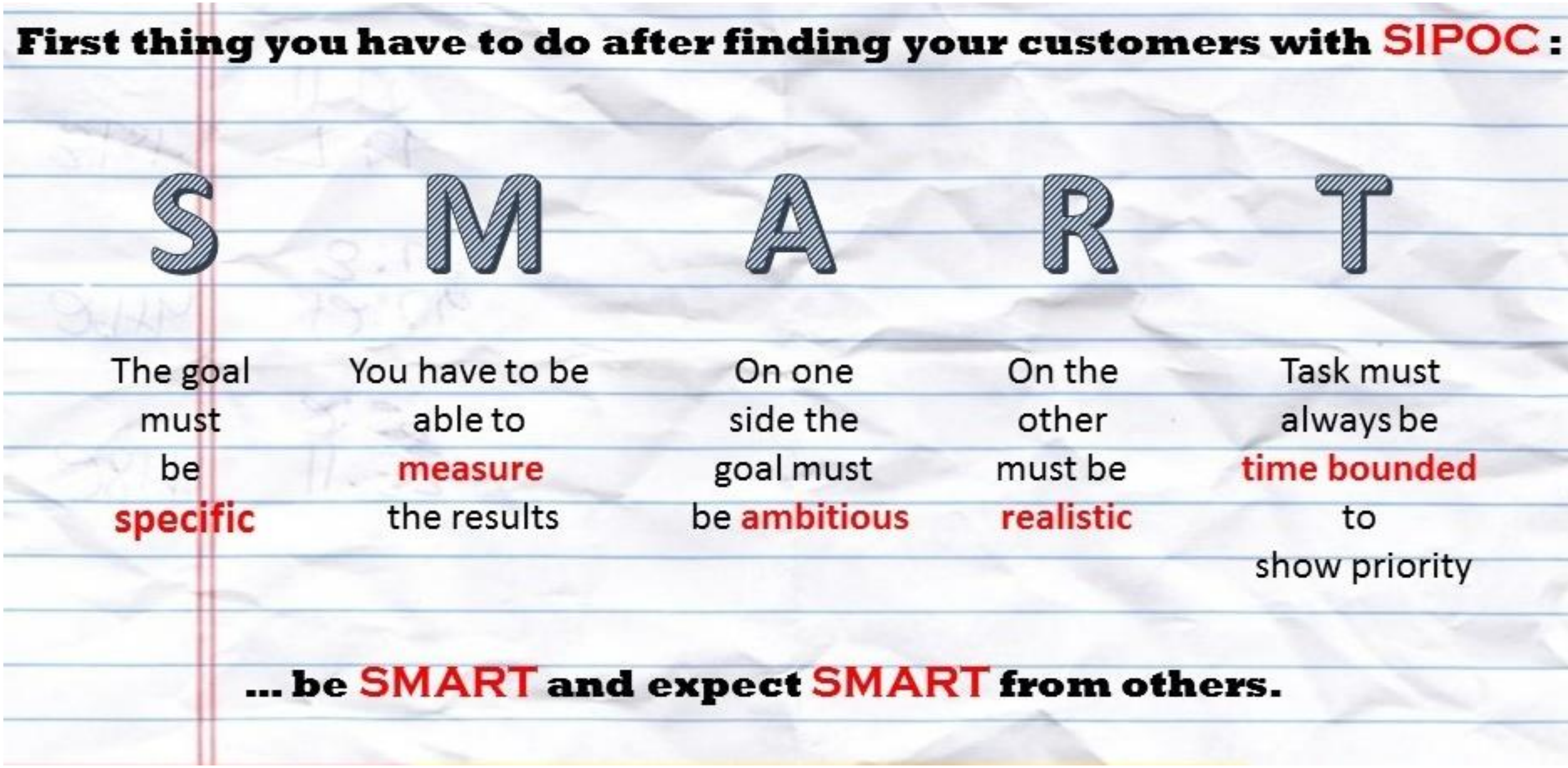
What

When

Magnitude

Consequence

Evaluation of Team Charter



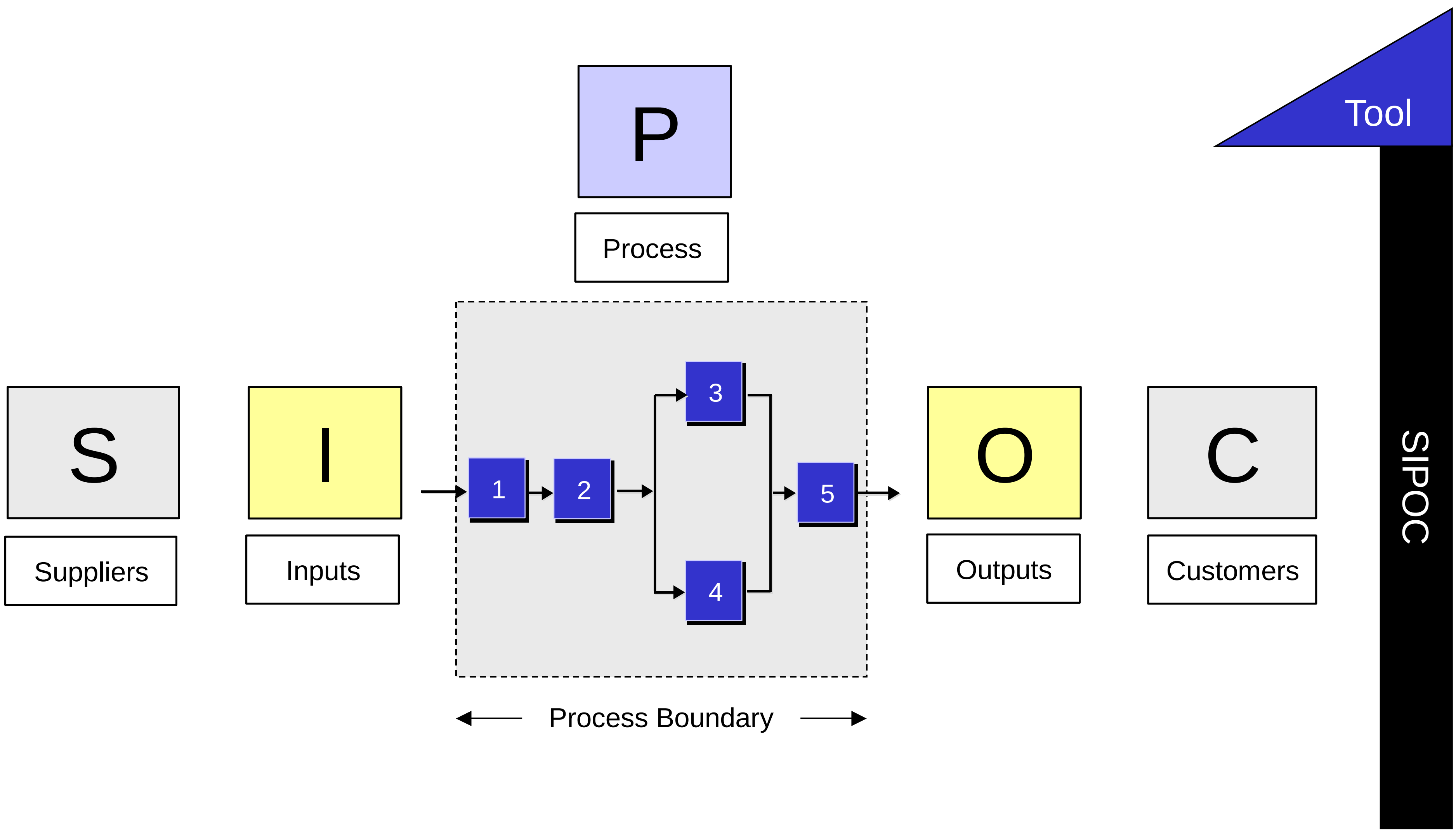
Deliverables of Measure

- Process Map
- Define unit / specifications / defect
- Understand data characteristics
- Find opportunities for error (OFE)
- Design sampling plan for establishing process baseline on ‘Y’
- Validate Measurement System for ‘Y’

DMAIC

As-is Process Mapping

SIPOC


DMAIC
Tool
SIPOC
P
Process
S
Suppliers
I
Inputs
1
2
3
4
5
O
Outputs
C
Customers
Process Boundary

Process Elements

- Suppliers
  - Manage the supplier by giving clear specifications on requirements or data
- Inputs
  - Data / unit required to execute the process
- Process Boundary
  - Identified by the hand-off at the input (the start point of process) and the output (the end point of the process)
- Outputs
  - Output of a process creating a product or service that meets a customer need
  - In your project, output characterizes the pain area / project theme
  - For example, if pain area is truck loading during despatch, output measured for your project could be time taken in loading
- Customers
  - Users of the output

Which is the better approach ?

- COPIS is the better approach in order to use SIPOC tool
- Thought process: COPIS
- Actual process: SIPOC

SIX SIGMA WAY

How

LEAN

Process Elements

DMAIC

	Six Sigma	Lean Thinking
Theory	Reduce variation	Remove waste
Application Guidelines	1. Define 2. Measure 3. Analyze 4. Improve 5. Control	1. Identify value 2. Identify value stream 3. Flow 4. Pull 5. Perfection
Focus	Problem / Defect focused	Flow focused
Assumptions	-> A problem exists but physical visibility is less. -> Figures & numbers are valued. -> System output improves if variation in all processes is reduced.	-> Problems are visible. - >Waste removal will improve business performance. -> Many small improvement are better than systems analysis.
Primary Effect	Uniform process output	Reduced flow time
Secondary Effect	-> Less Waste, Fast throughput -> Less inventory, Fluctuation-performance measures for managers -> Improved quality	-> Less variation, Uniform output, Less inventory, New accounting system -> Flow-performance measure for managers -> Improved quality
Criticisms	-> System interaction not considered. (**Six Sigma w/o LEAN tools can not address question of Process flow optimization).** -> Processes improved independently	-> Statistical or systems analysis not valued **(This excludes advanced statistical tools often reqd to achieve process capability to make the process Truly LEAN).** **->**Process flow in totality is improved.

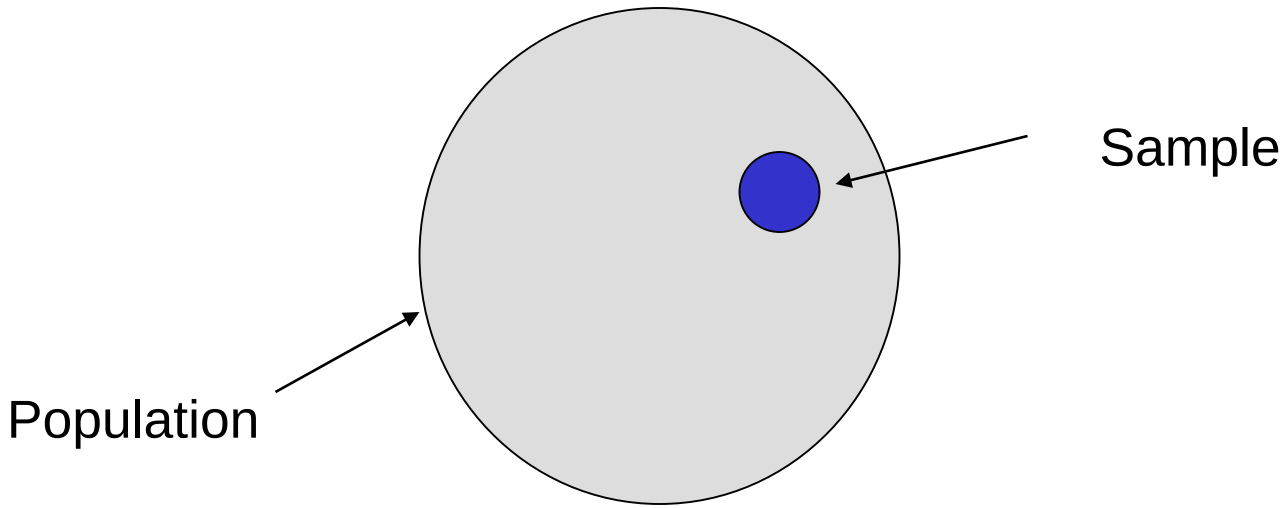
Benefits of Process Mapping

DMAIC

- Tremendous value in having teams just discuss the process
- Brings entire team to a common understanding of the process flow
- Simple & visible structure for thinking through a complex process
- Enables seeing the entire process as a team
- Enables seeing that changes are not made in a vacuum and will carry through, affecting the entire process down the line
- Magnifies non value-added areas or steps
- Identifies cycle times of each step in the process
- Helps re-examine (if needed) the scope and charter of your project

Introduction to Sampling

- We do sampling all the time
- Populations & Samples
- Practical aspects – Cost & Time
- Sampling is done to study a representative portion of population
- Any term describing the characteristics of a sample is called statistic
- Any term describing the characteristics of a population is called parameter



Tool

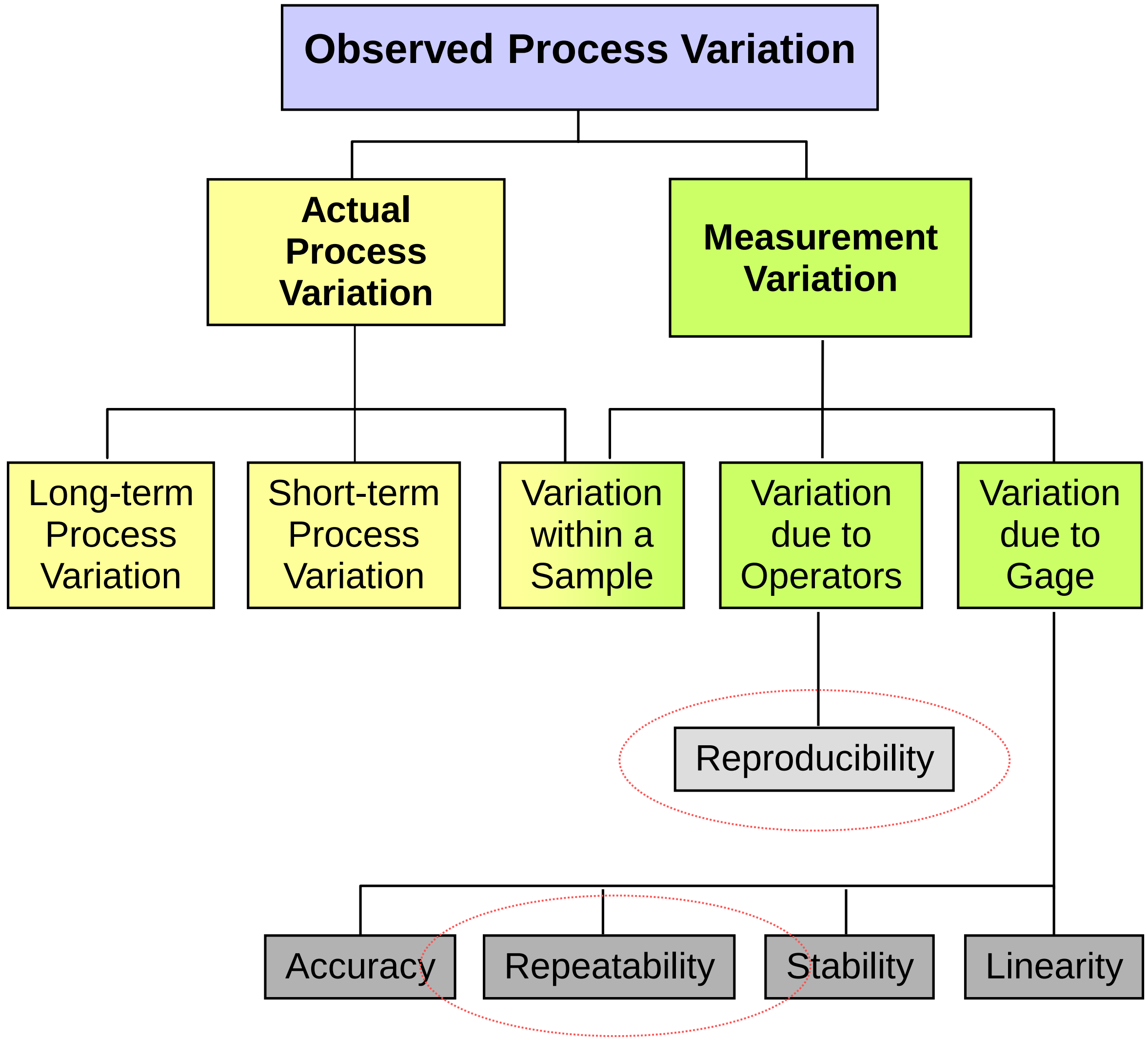
Sampling

Populations & Samples

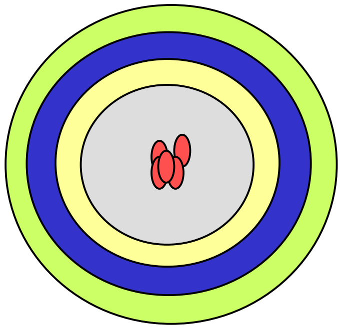
DMAIC

Table 1.60	Population	Sample
Definition	Collection of items being considered	Portion of the population chosen for study
Characteristics	'Parameter'	'Statistic'
	Population Size = **N**	Sample Size = **n**
	Population Mean = μ	Sample Mean = $\overline{Y}$
	Population Standard Deviation = σ	Sample Standard Deviation = s

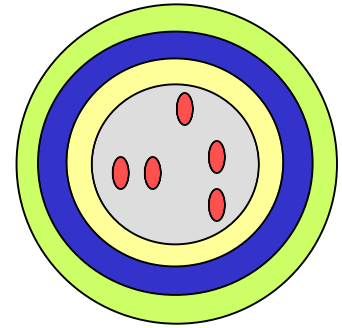
Sources of Variation



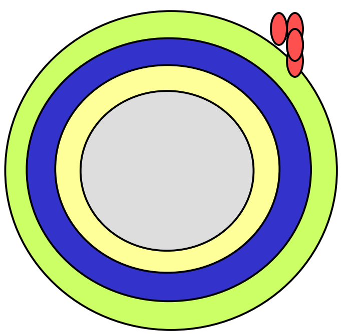
Accuracy & Precision



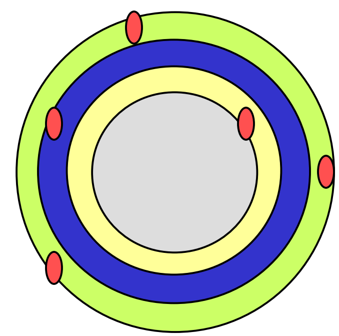
Accurate & Precise



Accurate, but not Precise

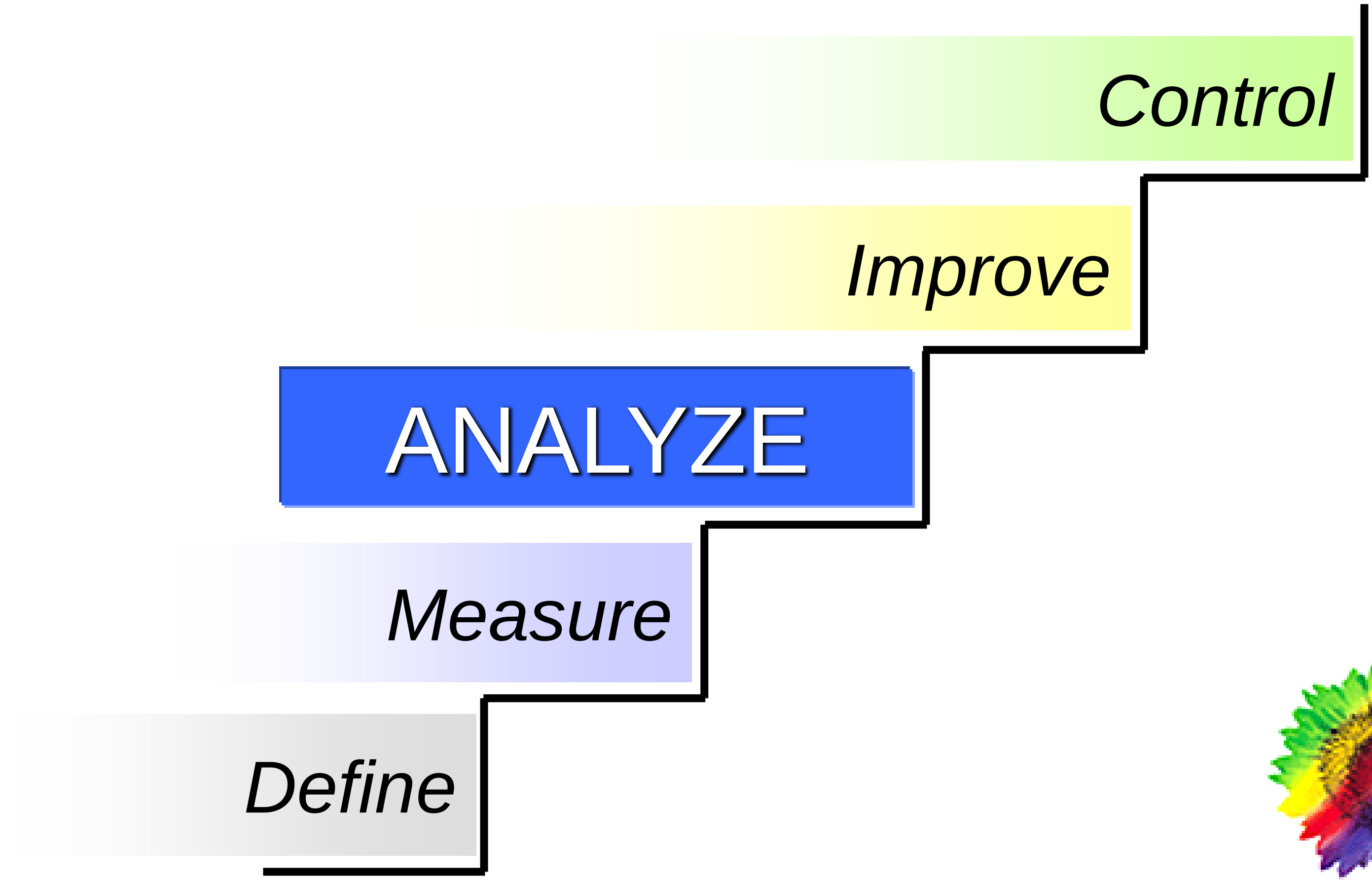


Precise, but not Accurate



Not Accurate, not Precise

Six Sigma



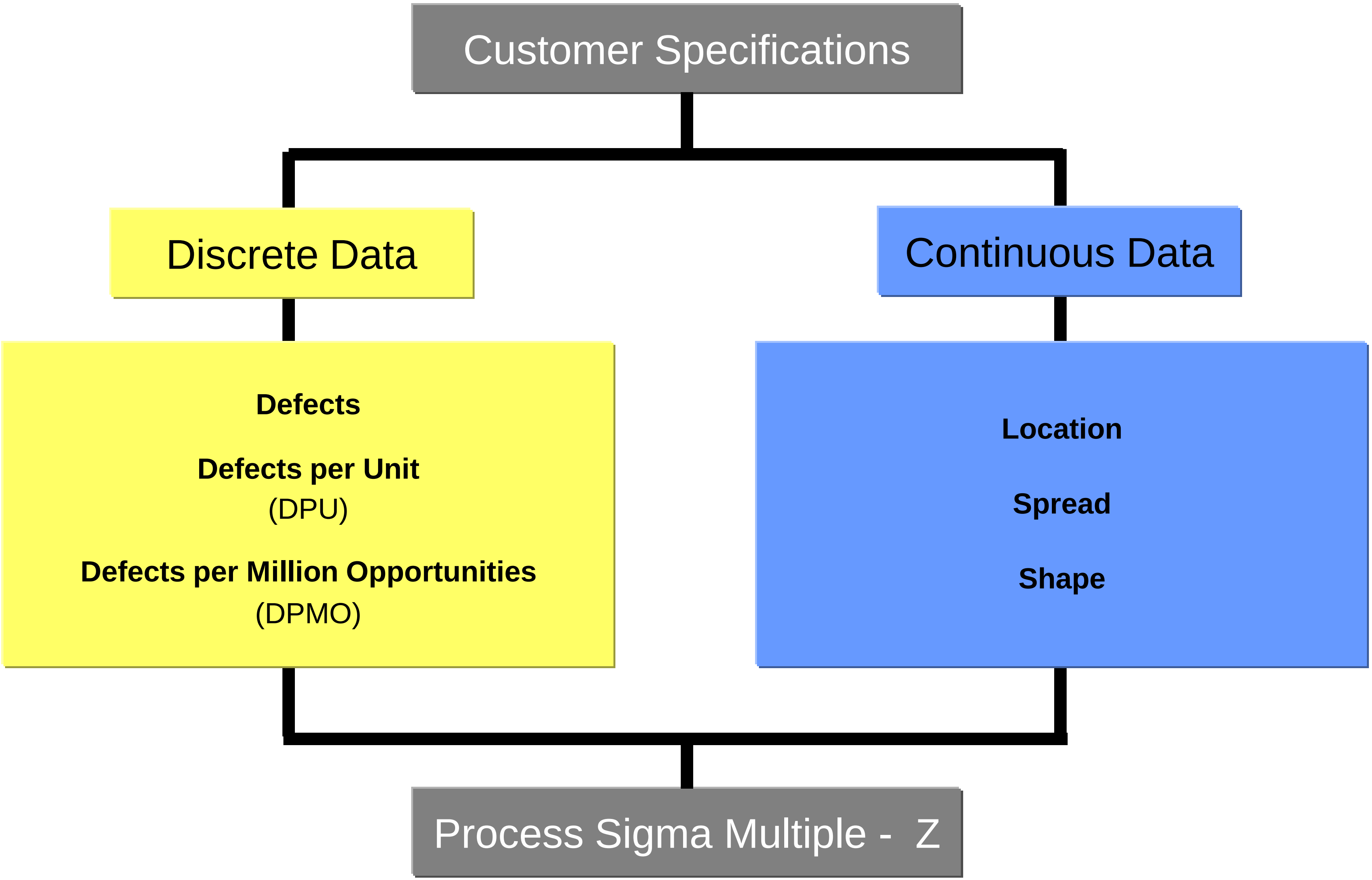
WIPRO
Applying Thought

Deliverables of Analyze Phase

- Compute Process Sigma Multiple using collected data
- Estimate population parameter from sample statistic
- Perform Entitlement & Benchmarking Exercise
- Establish Process Improvement Goal
- Review Financial Benefits & revise improvement target, if required
- Identify potential X's that contribute to variation in 'Y'
- Separate vital few X's from trivial many for further screening

Compute Process Sigma Multiple Using Collected Data

Six Sigma Metrics



Normal Distribution

Introduction to Normal Distribution

DMAIC

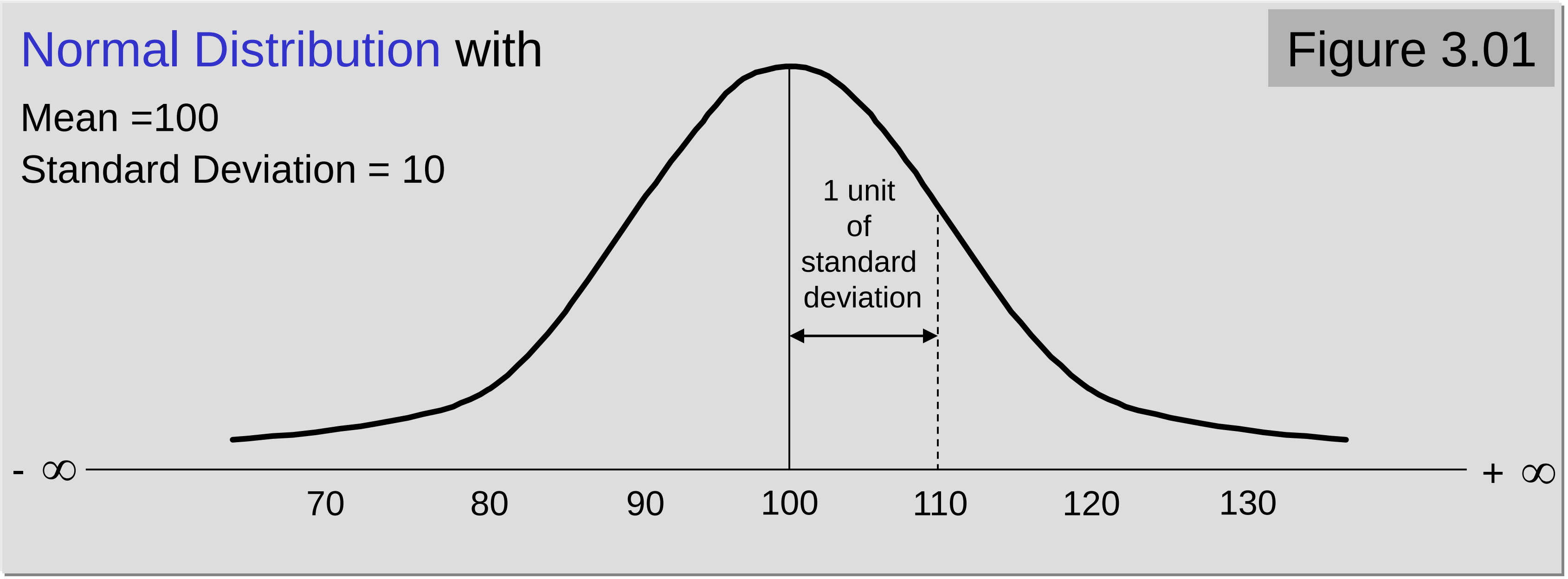
Tool

Normal Distribution

- Developed by astronomer *Karl Gauss*
- Most prominently used distribution in statistics
- Applicability to many situations where given the population knowledge, we need to predict the sample behavior
- It comes close to fitting the actual frequency distribution of many phenomena
  - Human characteristics such as weights, heights & IQ's
  - Physical process outputs such as yields

Introduction to Normal Distribution

DMAIC



- It's a Probability Distribution, illustrated as N (μ, σ)
- Simply put, a probability distribution is a ***theoretical*** frequency distribution
- Higher frequency of values around the mean & lesser & lesser at values away from mean
- Continuous & symmetrical
- Tails asymptotic to X-axis
- Bell shaped
- Total area under the Normal curve = 1

Concept of Z Value

DMAIC

- To standardize different measurement units; such as, inches, meters, grams; a standard Z variable is used

$$Z = \frac{Y - \mu}{\sigma}$$

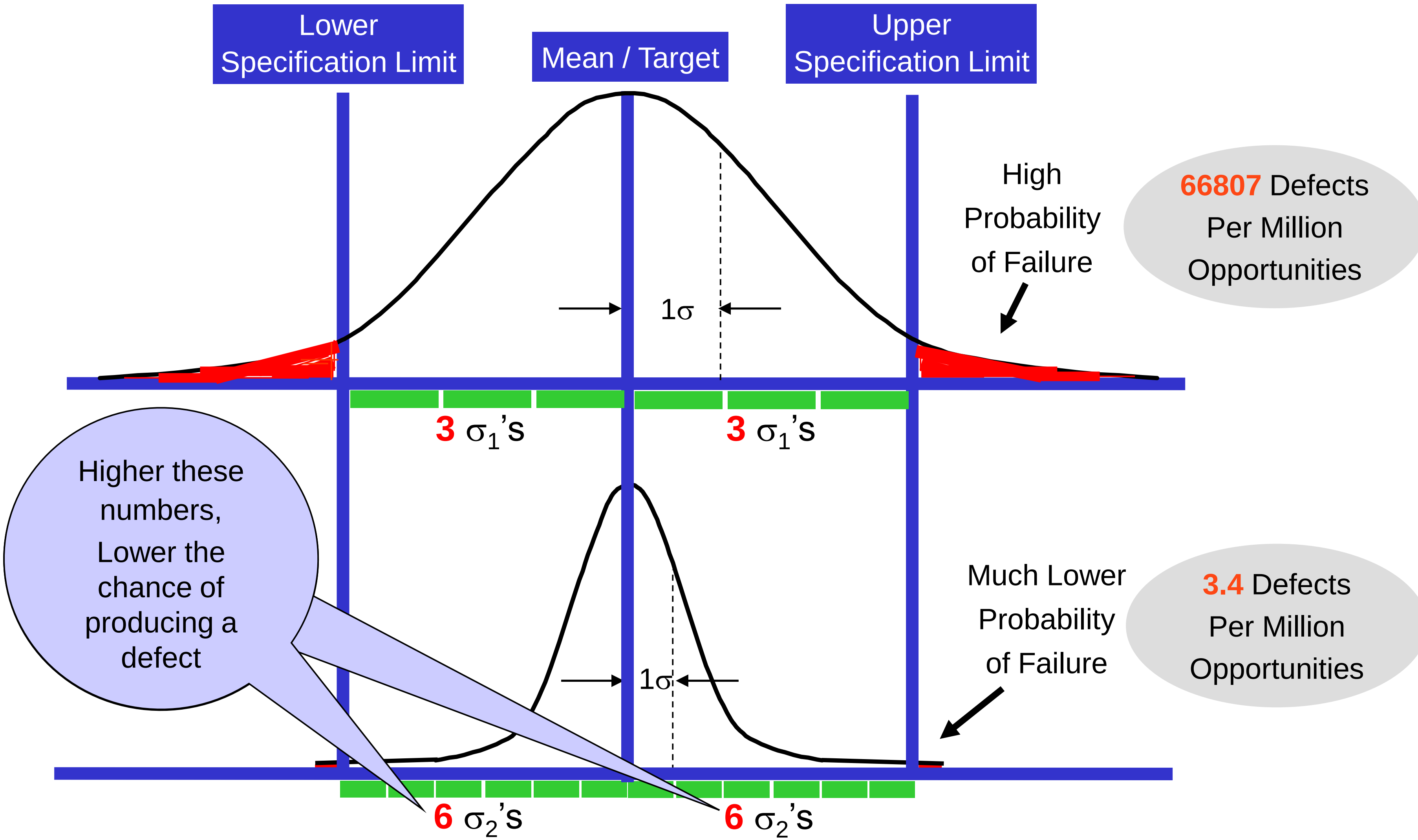
Where	Y =	Value of the data point we are concerned with
	μ =	Mean of the data points
	σ =	Standard Deviation of the data points
	Z =	Number of standard deviations between Y & the mean (μ)

- Z value is unique for each probability within the normal distribution

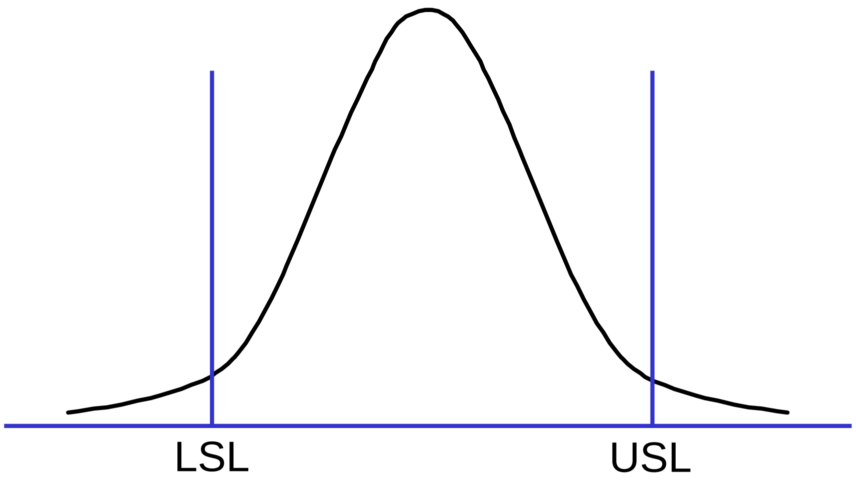
- It helps in finding probabilities of data points at anywhere within the distribution

Process Sigma Multiple for Continuous Data

What is A Six Sigma Process?



Process Capability (C_P)



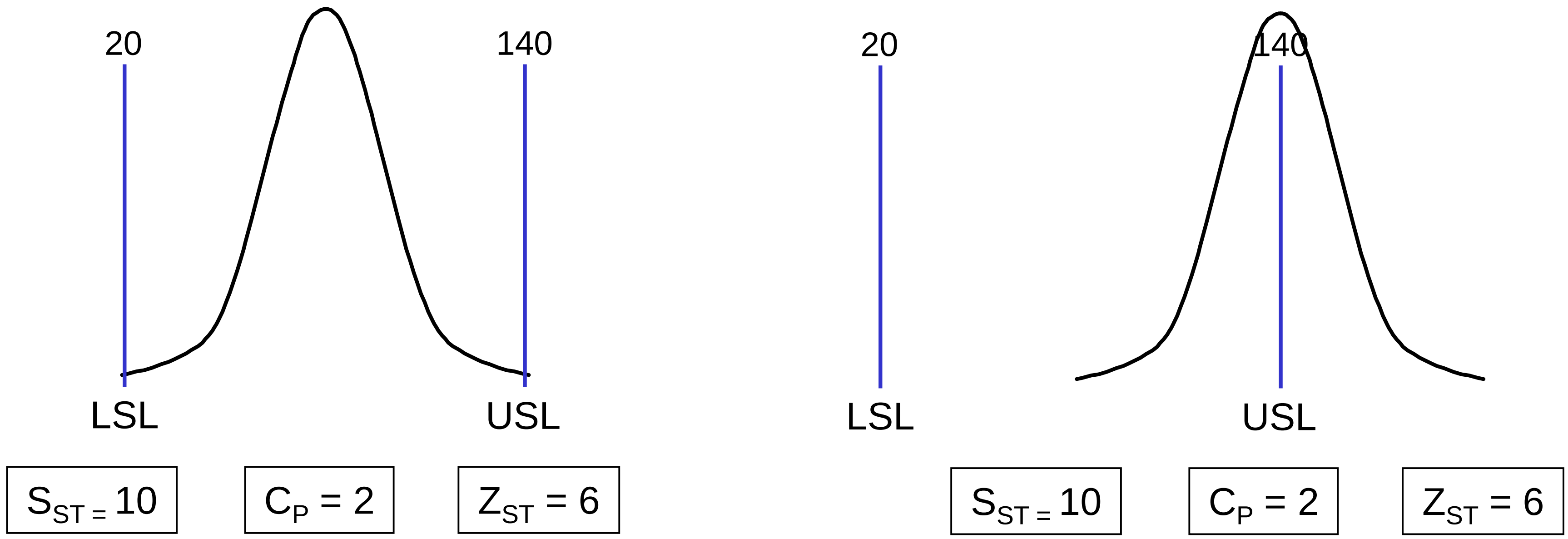
$$\text{Process Capability } C_P = \frac{USL - LSL}{6\,S_{ST}}$$

$$Z_{ST} = 3\,C_P$$

- C_P is a short term measure of process capability - *the 'could be' performance*
- C_P relates the process short term variation with the customer specification limits
- It does not take into account how centered data is
- For a six sigma process, $C_P = 2$ ($Z_{ST} = 3 * 2 = 6$)
- That means this process can fit 12 standard deviations between USL & LSL

Limitations of Process Capability (C_P)

DMAIC



- Even though almost 40% of the data is outside specification limits in graph 2, it is still a Six Sigma capable process, however, not performing to its potential
- C_P can not be used for one-sided specifications
- To address these issues, another measure, called C_{PK} is used

Capability Index (C_{PK})

DMAIC

$$C_{PU} = \frac{USL - \bar{Y}}{3 S_{ST}}$$

$$C_{PL} = \frac{\bar{Y} - LSL}{3 S_{ST}}$$

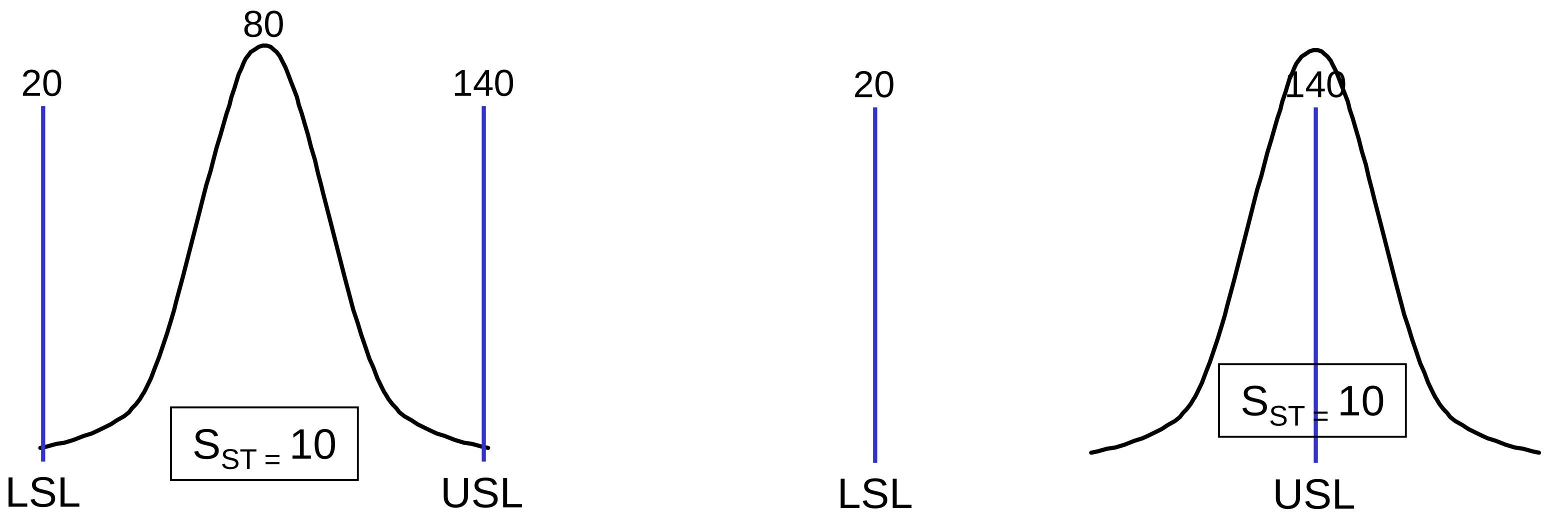
$$C_{PK} = \text{Minimum}(C_{PU}, C_{PL})$$

$$Z_{ST} = 3 C_{PK}$$

For one sided specifications

- C_{PK} is a better measure of process capability – '*could be' performance if shift was eliminated*
- It considers the data centering & forces the mean to be between the specifications
- C_{PK} enables Z_{ST} computation for one sided specifications as well
- $C_P >= C_{PK}$
- If C_P is >>> C_{PK}, process is capable but not centered adequately

Calculating C_{PK}



- Calculate C_{PK} of the previous two processes & compare with C_P

Performance Index (P_{PK})

DMAIC

$$P_{PU} = \frac{USL - \bar{Y}}{3\ S_{LT}}$$

$$P_{PL} = \frac{\bar{Y} - LSL}{3\ S_{LT}}$$

$$P_{PK} = \text{Minimum}\ (P_{PU}, P_{PL})$$

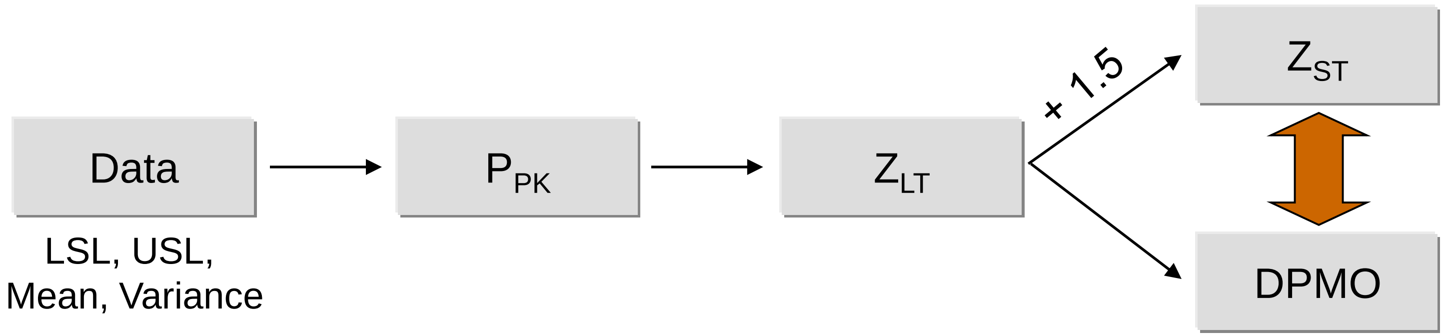
$$Z_{LT} = 3\ P_{PK}$$

- P_{PK} is a measure of *actual process performance*
- It is similar to C_{PK} except that it uses the long term standard deviation
- P_{PK} enables Z_{LT} computation for both one sided & two sided specifications
- Difference between P_{PK} & C_{PK} indicates the shift in the process

Key Concepts

DMAIC

- Capability is an internal measurement of the process behavior measured on a short term view
- Performance is an external view of the process behavior measured on a long term view
- Processes studied in actual projects may not have a shift of 1.5
- Due to limitations of multiple shift factors & C_P, process sigma multiple calculations for continuous data start from P_{PK}



Computing Sigma Multiple for Pizza Delivery

DMAIC

- Assume that the customers expect the pizza delivered latest within 1 hour (USL)

We already know that Mean = 47.5 S_{ST} = 6.2 S_{LT} = 6.4

Tool

$$P_{PU} = \frac{USL - \bar{Y}}{3 S_{LT}} = \frac{60 - 47.5}{3 * 6.4} = 0.65$$

P_{PK} = 0.65

Z_{LT} = 3 *0.65 = 1.95

DPMO = 25588

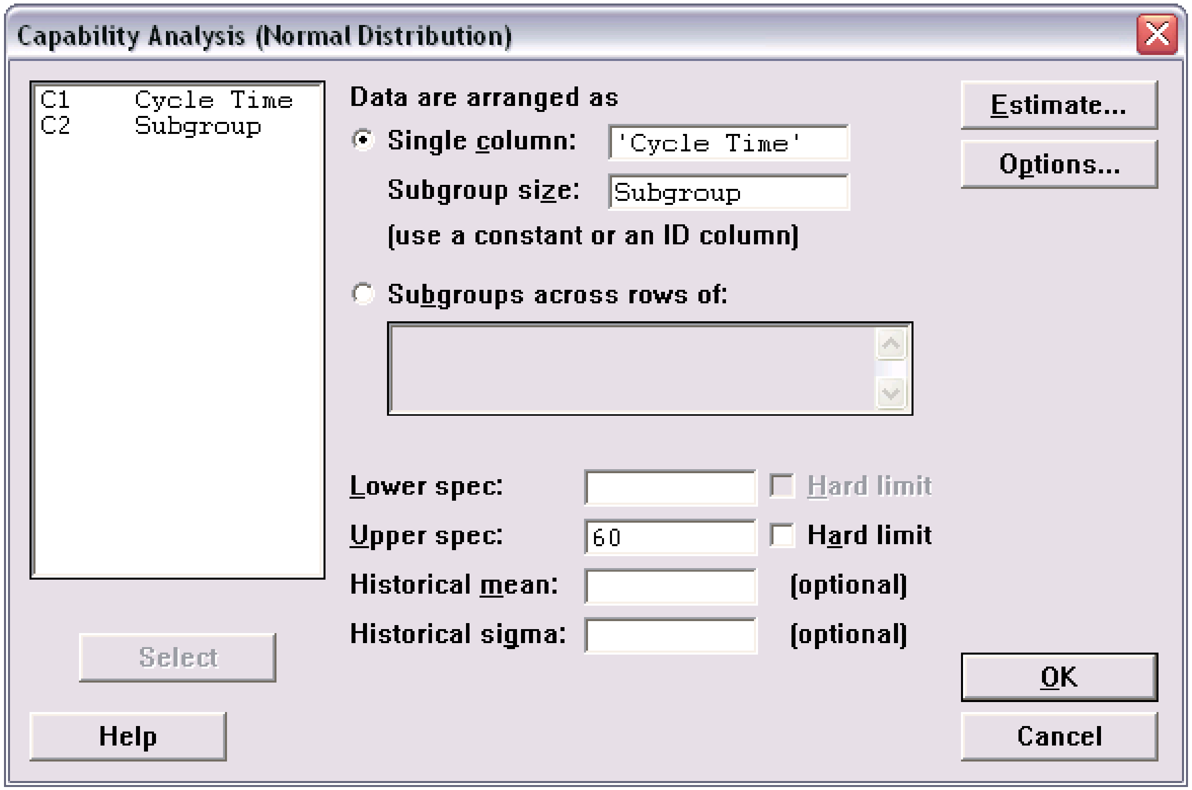
Z_{ST} = 1.95 + 1.5 = 3.45

Z Calculation – Continuous Data

- A standard shift factor of 1.5 is used even though process shift is not significant
- DPMO can be calculated from the Normal distribution table also

Using Minitab for Continuous Data Z Calculation

- STAT > QUALITY TOOLS > CAPABILITY ANALYSIS (NORMAL)



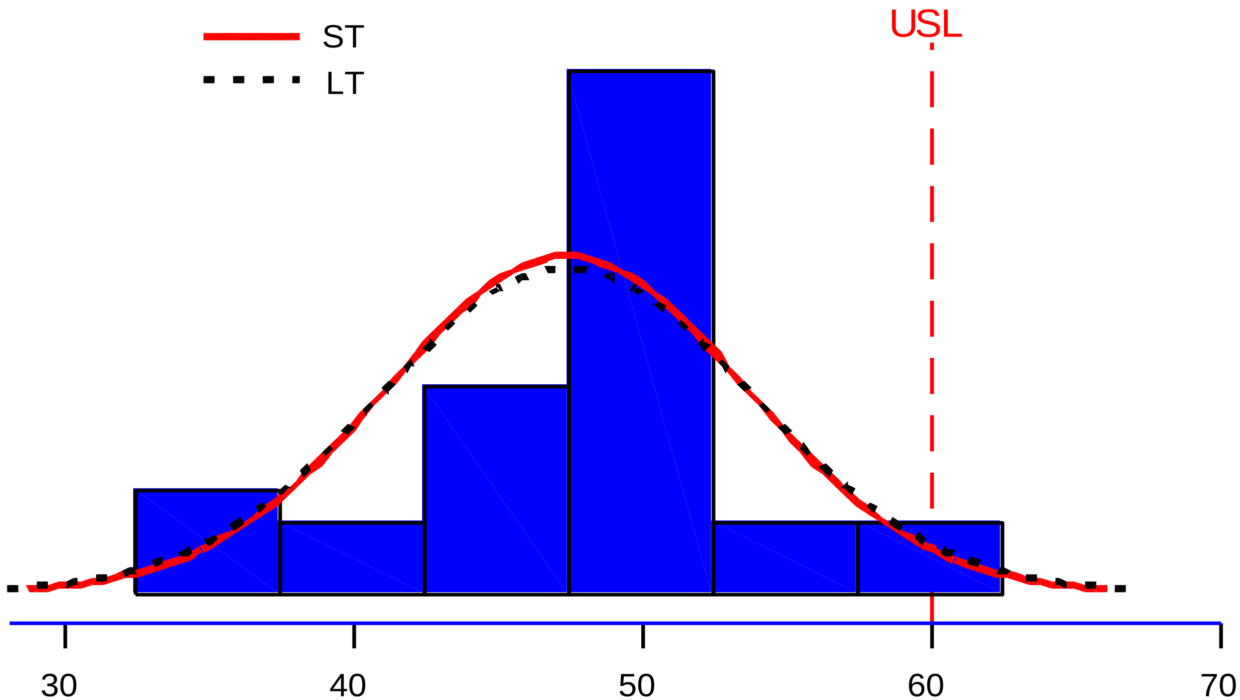
Cycle Time	Subgroup
48	1
49	1
48	1
53	1
58	1
50	1
46	1
50	1
49	1
47	1
50	2
48	2
36	2
50	2
50	2
62	2
45	2
47	2
51	2
44	2
49	3
48	3
39	3
49	3
34	3
33	3
57	3
48	3
47	3
39	3

Using Minitab for Continuous Data Z Calculation

Process Capability Analysis for time taken in pizza delivery

Process Data

USL	60.0000
Target	*
LSL	*
Mean	47.4667
Sample N	30
StDev (ST)	6.21507
StDev (LT)	6.44895



Potential (ST) Capability

Cp	*
CPU	0.67
CPL	*
Cpk	0.67
Cpm	*

Overall (LT) Capability

Pp	*
PPU	0.65
PPL	*
Ppk	0.65

Observed Performance

PPM < LSL	*
PPM > USL	33333.33
PPM Total	33333.33

Expected ST Performance

PPM < LSL	*
PPM > USL	21868.43
PPM Total	21868.43

Expected LT Performance

PPM < LSL	*
PPM > USL	25979.72
PPM Total	25979.72

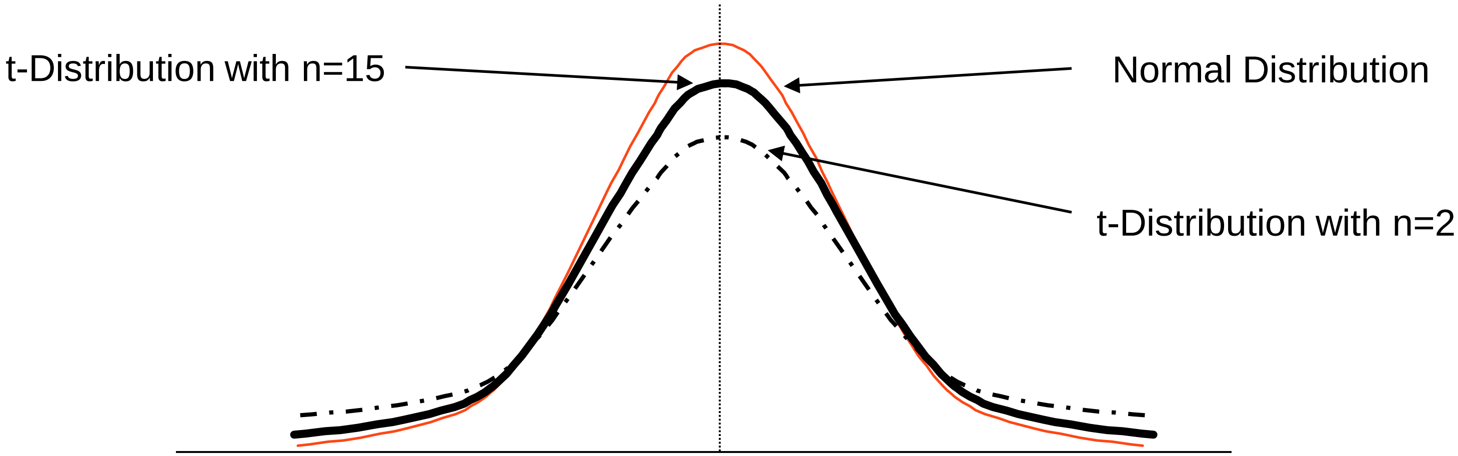
Introduction to t-distribution

DMAIC

Tool

t-Distribution

- A t-distribution is most appropriate to be used when
  - Sample size is <30
  - Population standard deviation is not known
  - Population is approximately normal
- t-distribution is symmetrical, but, flatter than the normal distribution
- As sample size increases, a t-distribution approaches normality
- There is a different t-distribution for every possible sample size (degrees of freedom)
- A t-distribution is lower at the mean & higher at the tails than a normal distribution



Using the t-distribution Table

DMAIC

- t-distribution table is more compact
- It uses areas & t-values for only a few percentages (10, 5, 2 & 1 percent)
- This is because unlike Normal table that focuses on area “within”, t table focuses on area “outside”
- If we are looking at a 10% chance of error, we must look at the table corresponding to 0.01 column
- We must specify the degrees of freedom while using the table (df = n - 1)

Perform Entitlement & Benchmarking Exercise

Key Concepts

- If the existing process has to be improved, then the improvement goal should be chosen only after proving statistically that it can be achieved only due to change, & not by noise
- If the improvement is possible even otherwise, discipline issues need to be addressed
- Verify if the targeted performance is really performing at a higher level
- However, project teams must not get over-ambitious, entitlement study should be completed

Introduction to Hypothesis Testing

DMAIC

Tool

Test of Hypothesis

- Suppose team management wants to see if Indian cricket team's performance has improved after the have recruited a new coach. Is there an improvement that can be proven statistically?

- What does the management need to do? It basically needs to make an assumption about the efficiencies of the two coaches A & B, & test it for significance

- Making such an assumption is called ***Forming a Hypothesis***

- Forming hypothesis is common around us
  - If I study for 8 hours a day, I can secure 90% marks
  - If we drop the price of the TV by 10%, we can increase sales by 25%

Null Hypothesis

DMAIC

- When a defendant is being prosecuted for a crime, the judge hears the proceedings assuming that the defendant has committed no crime
- The job of the prosecutor is to prove his assumption wrong
- In other words, the defendant is non-guilty till proven otherwise, i.e. status quo
- Assuming status quo is *Null Hypothesis*
- Considering the previous example, null hypothesis is that the two coaches have the same efficiency *(i.e. no difference in efficiencies till proven otherwise)*

Alternative Hypothesis

DMAIC

- Alternative hypothesis challenges the null hypothesis
- If null hypothesis is proven wrong, alternative hypothesis must be right
- The prosecutor believes in the alternative hypothesis, gives proofs to substantiate it & tries to give ***enough confidence*** to judge about alternative hypothesis
- Considering the previous example, alternative hypothesis is that coach B has a higher efficiency than coach A (*i.e. there is a difference in efficiencies)*

Type I Error

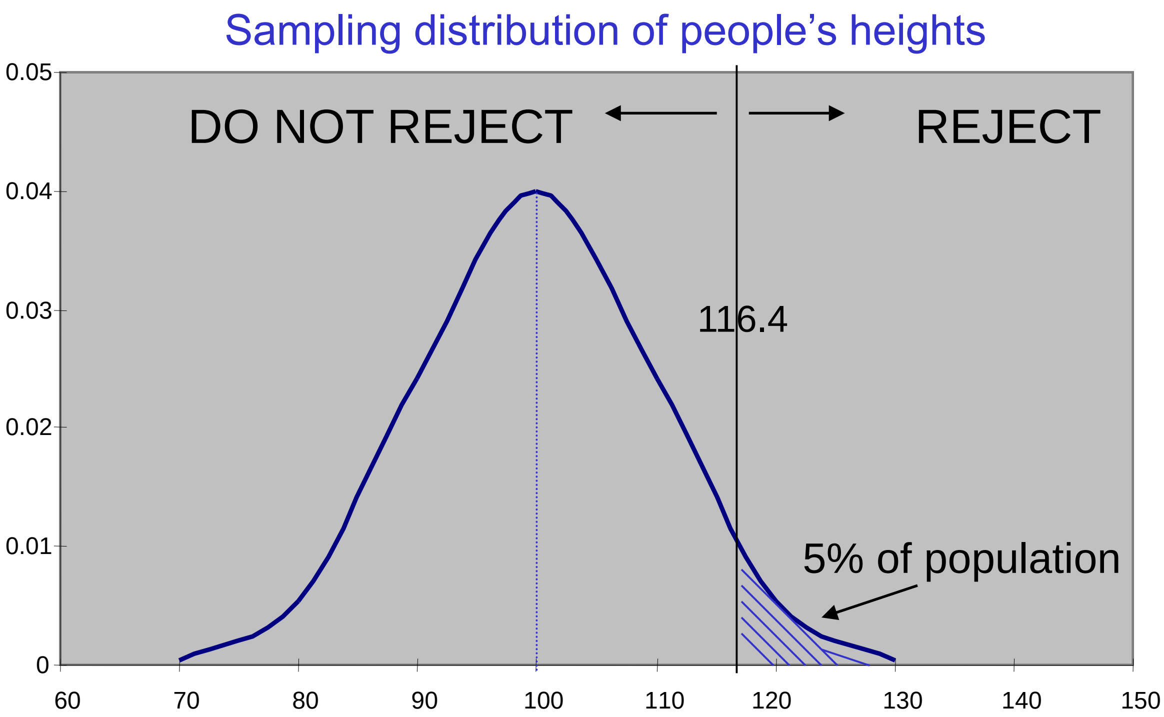
DMAIC

- *Rejecting* a null hypothesis when it was *true* is called *Type I error*
  - It is also called 'Producer's Risk' by drawing analogy with a part getting rejected by QA team when it was not defective, thereby bringing loss to producer
  - Thus, concluding that coach B is better than coach A when they are actually at the same level of efficiency, is making Type I error
- Minimizing Type I error requires rejection criteria to be very strict
- We reject a null hypothesis based on certain confidence obtained / error allowed
- We want to make an error not more than 'α' in *wrongly rejecting a true null hypothesis*
- Producer's Risk / Type I error / α error are used interchangeably

Interpreting the ‘α’ Error

DMAIC

- Below graph illustrates the concept of significance level, if α= 5%



Mean of heights	= 100
Std. error	= 10
Desired α	= 0.05
Critical Value	= 1.64
Cut-off Value	= 116.4

Does a sample with average height of 118 belong to a different population?

Interpreting the ‘α’ Error

DMAIC

Mean of heights	= 100
Std. error	= 10
Desired α	= 0.05
Critical Value	= 1.64
Cut-off Value	= 116.4

- Only 5% of the population falls beyond the 95% cut-off value of 116.4
- A sample with average height of 118 falls in the 5% region beyond 116.4
- & thus, conclusion that this sample belongs to a different population, would have maximum 5% error – *because there is a 5% chance of this sample belonging to the same population*
- Or, rejecting the null hypothesis that sample belongs to the same population will have an associated error of not more than 5%
- Actual error made is about 0.04, which is acceptable

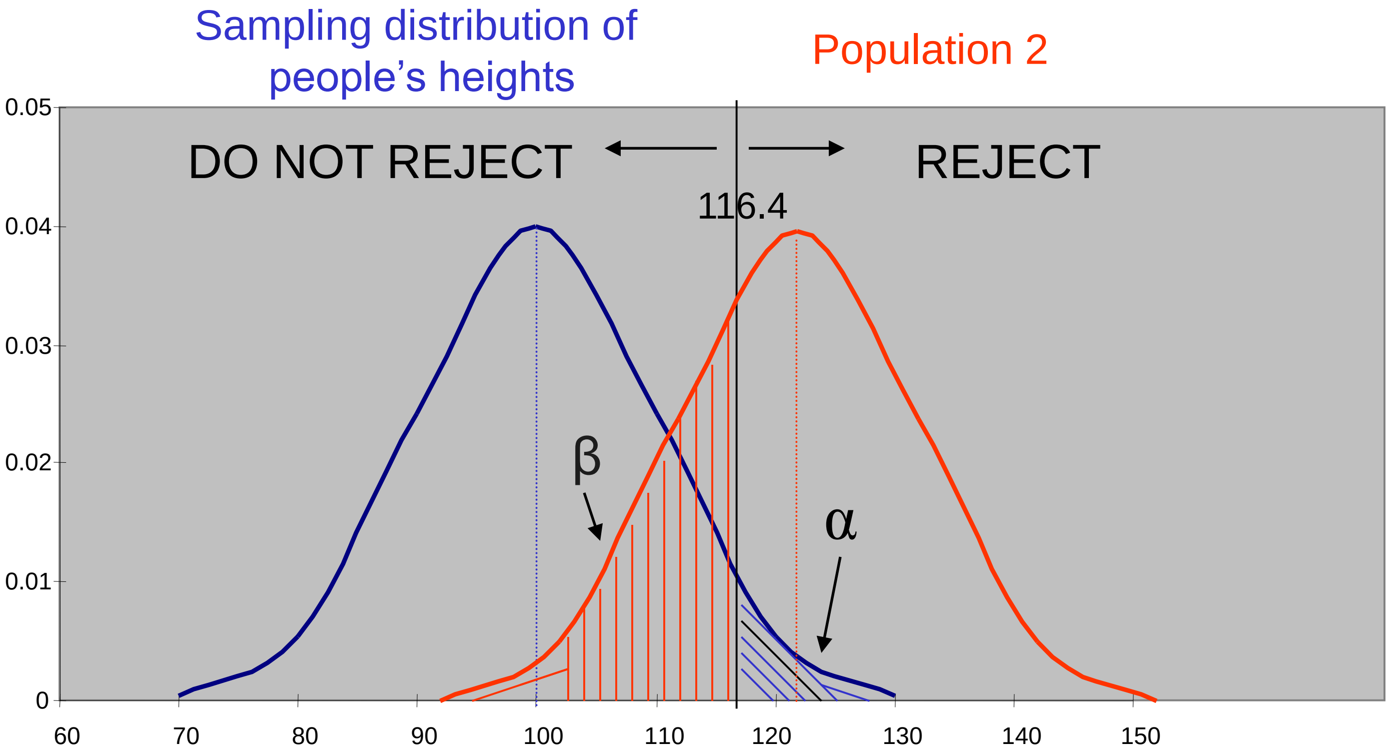
Type II Error

DMAIC

- *Accepting* a null hypothesis when it was *false* is called *Type II error*
  - It is also called ‘Consumer’s Risk’ by drawing analogy with a part getting accepted by QA team when it was defective, thereby bringing loss to consumer who will buy it
  - Thus, concluding that coach B is not better than coach A when he actually is, is making Type II error
- Minimizing Type II error requires acceptance criteria to be very strict
- We want to make an error not more than ‘β’ in *wrongly accepting a false null hypothesis*
- Consumer’s Risk / Type II error / β error are used interchangeably

Interpreting the β Error

- β exists for the alternate hypothesis, & not for given sample *(Rejecting the alternate hypothesis when it was true)*



Mean of heights	= 100
Std. error	= 10
Desired 'α'	= 0.05
Critical Value	= 1.64
Cut-off Value	= 116.4

Population 2 mean	= 122
Std. error	= 10
Desired β	= 0.29

Interpreting the β Error

DMAIC

- If we take a sample that has a mean of 110, it will fall under both populations
- If we go by ‘α’ error, we shall accept the null hypothesis that sample belongs to original population since 110 is < 116.4
- However, 110 also falls on the distribution of population 2, & hence we have made a Type II error in accepting a false null hypothesis
- Actual ‘β’ error made is on the left of 110 on curve 2 centered on 122

Type I & Type II Errors

DMAIC

- Probability of making one type of error can be reduced only when we are willing to accept a higher probability of making other type of error
- If we start accepting all null hypotheses because we do not want to reject a true null hypotheses by mistake (Type I error), even false null hypotheses would be accepted which is nothing but Type II error
- In the previous graph - If we fix $\alpha = 0.01$, corresponding decision point would be 123.3, that means β error will go up
- Typically, 'α' is set at 0.05
- Teams must decide which type of error should be less & set 'α' accordingly

Type I & Type II Errors

		Reality	
		Good	**Bad**
Conclusion	**Good**	**OK**	**Not OK** Type II Error Consumer’s Risk
	Bad	**Not OK** Type I error Producer’s Risk	**OK**

Test Criteria of the Hypothesis

DMAIC

- The purpose of hypothesis testing is not to question the calculated values, but to make a judgment about the *difference* in the values of the two data sets
- Next step after writing the hypotheses is to decide on the acceptance or rejection criteria of the null hypothesis
- ‘α’ is called the significance level for a hypothesis testing
- ‘1-α’ is called the confidence level for a hypothesis testing
  - We need a certain minimum confidence to reject the null hypothesis (prosecuting the defendant)

Key Concepts

DMAIC

- Essentially, when we are comparing two data sets, we want to see whether these two data sets have the same characteristics
- If we are comparing two samples (evidence), null hypothesis is that they belong to the same population (reality), i.e. there is no difference between the two sample characteristics
- If we are comparing a sample (evidence) with a given population (reality), null hypothesis is that this sample belongs to the population
- If we do happen to prove a difference, we are saying that there is more than $(1 – \alpha)\%$ confidence that this difference is genuine, & not due to chance

Forming Hypothesis

DMAIC

- Null hypothesis is illustrated as H_0, Alternative hypothesis is illustrated as H_1
- Nomenclature of writing a hypothesis can be illustrated using the previous example:-

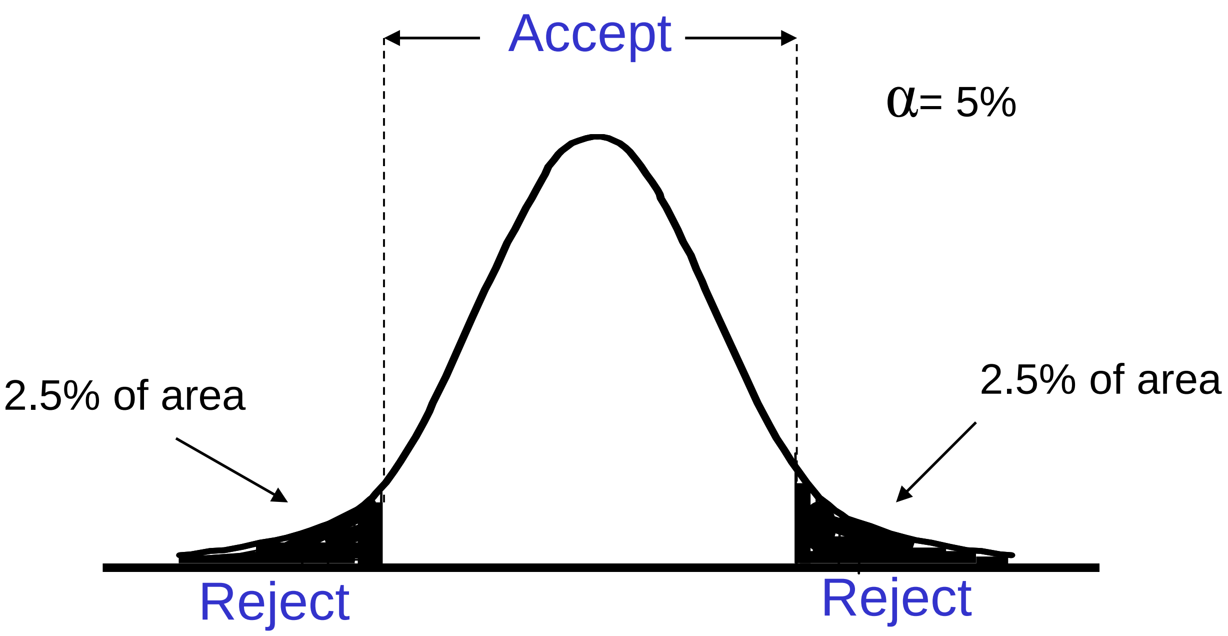
H_0 :	E (A) = E (B)	"The null hypothesis is that efficiencies of coaches A & B are same"

- We can write 3 possible alternative hypotheses for this null hypothesis:-

H_1 :	E (A) < E (B)	"The alternative hypothesis is that efficiency of coach A is less than that of coach B"	One-tailed test
H_1 :	E (A) > E (B)	"The alternative hypothesis is that efficiency of coach A is more than that of coach B"	One-tailed test
H_1 :	E (A) ≠ E (B)	"The alternative hypothesis is that efficiencies of coaches A & B are different"	Two-tailed test

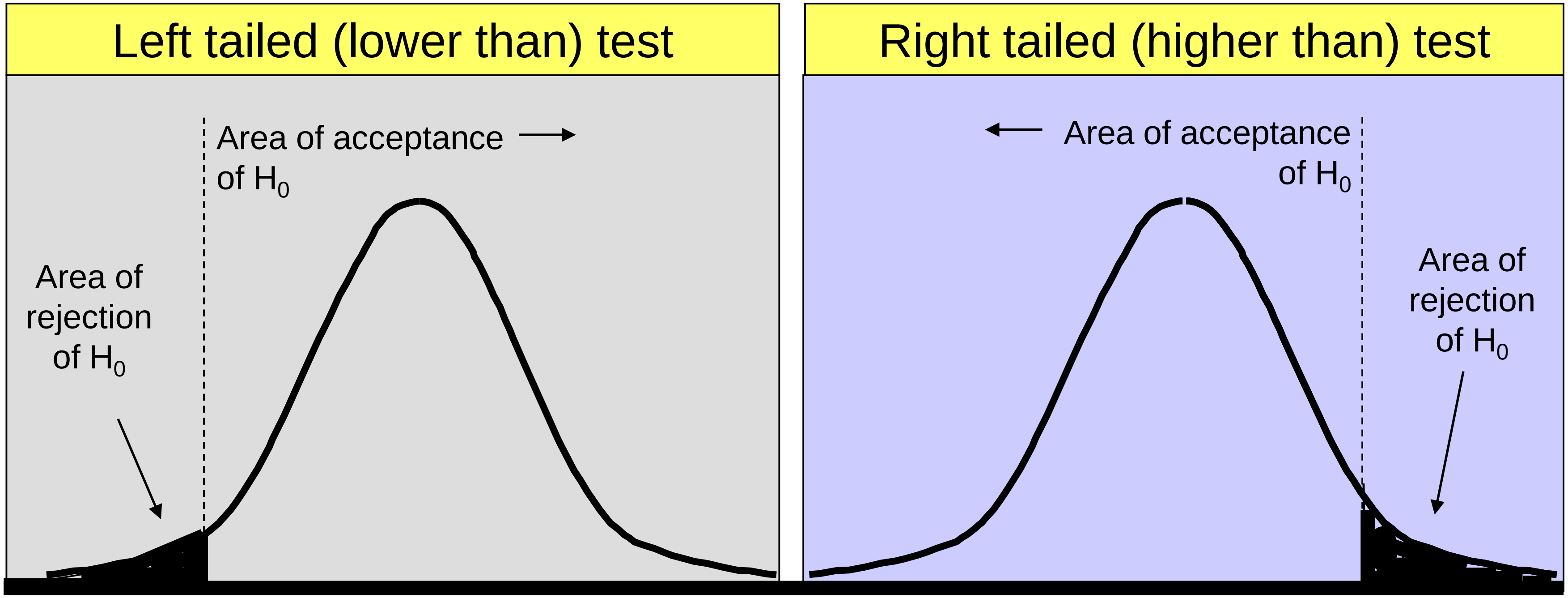
Two-Tailed & One-Tailed Tests of Hypothesis

- If we want to find out that two data sets are ***different from each other*** (e.g. efficiencies of two coaches are different (A could be higher or lower than B, but different), we use the two tailed test
  - A 2 tailed test would have 2 rejection regions, one in each tail of the corresponding distribution



Two-Tailed & One-Tailed Tests of Hypothesis

- If we want to find out that two data sets are ***either at a higher or a lower value compared to each other***, (e.g. efficiency of coach A is higher than that of B), we use the one tailed test
  - A 1 tailed test would have 1 rejection region, either in left or the right tail of the corresponding distribution depending upon the type of the test



Acceptance / Rejection Criteria for Hypothesis

DMAIC

- A null hypothesis can be accepted / rejected by using 3 methods

	Reject Null Hypothesis When...	Do Not Reject Null Hypothesis When...
1. Critical Value	The calculated value is greater than the tabular critical value for the corresponding distribution	The calculated value is not greater than the tabular critical value for the corresponding distribution
2. Probability	The p-value is less than α	The p-value is not less than α
3. Confidence Interval	The hypothesized parameter value is not in the calculated confidence interval	The hypothesized parameter value is within the calculated confidence interval

Interpreting Results

DMAIC

- Let’s understand the p-value method for accepting / rejecting the hypothesis
  - We need minimum (1- α)% confidence in rejecting a null hypothesis
  - Our actual confidence will be calculated by Minitab which is nothing but (1-p)%, based upon the data
  - When p-value is less than α, our actual confidence (1-p)% is more than required confidence (1- α)%
  - Hence, for p-value less than α, we reject the null hypothesis

Using Hypothesis Testing for Goal Setting

DMAIC

- One of the key steps in setting an improvement goal is to prove that the targeted / benchmarked performance is truly performing at a higher level *(different population)*

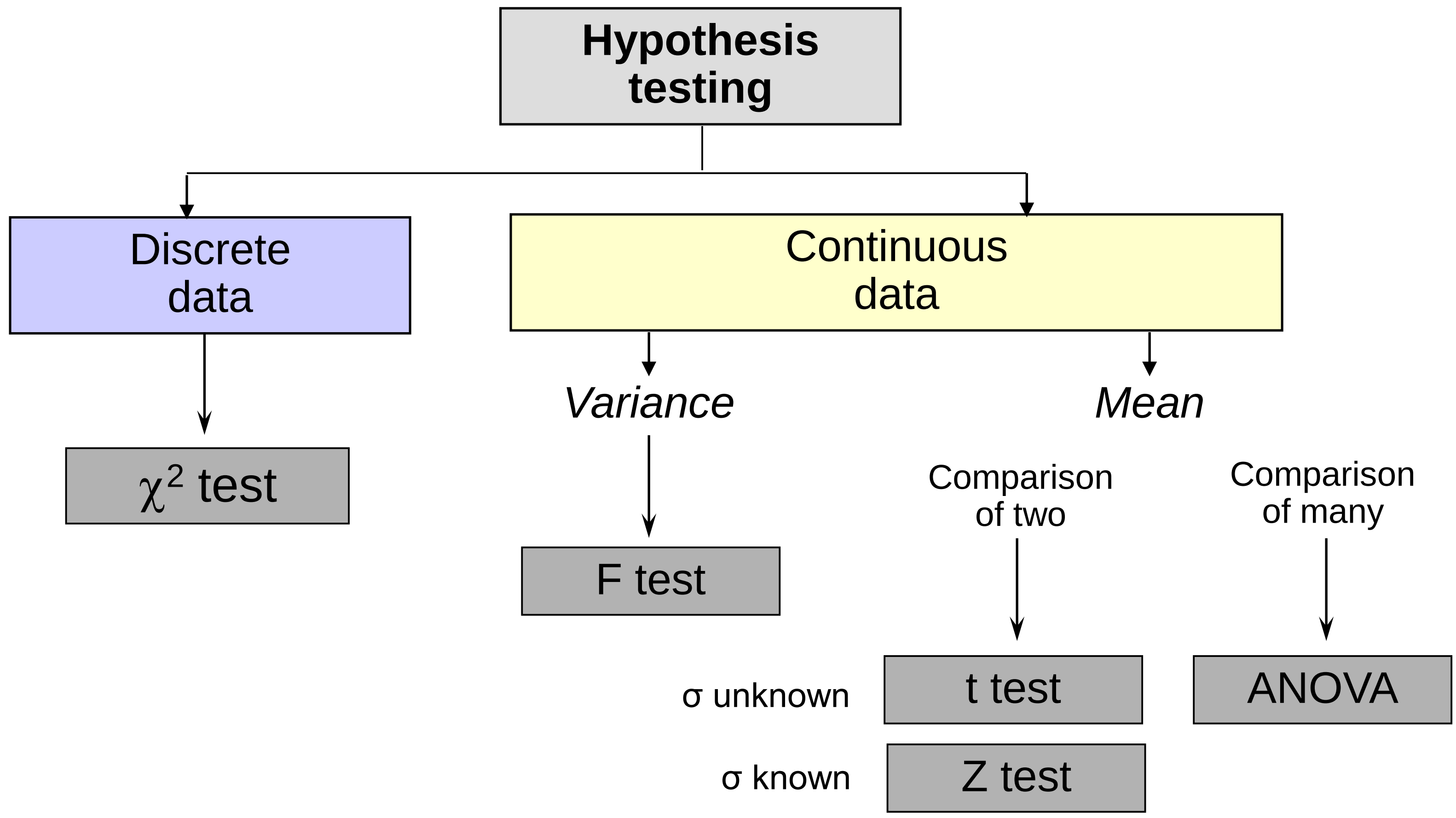
- In other words, a project team can set a target *hypothesizing* that this would be really an improved performance level

- Team must test this hypothesis statistically, otherwise it may end up setting either too easy or too stiff a target

Hypothesis Testing Roadmap

DMAIC

- Basic determinants of accepting or rejecting a hypothesis remains same, however, various tests are used depending upon the type of data



Using Hypothesis for Goal Setting – Discrete Data

DMAIC

Process Baseline

(Frequency of defects,

Proportion defects)

Test for
significant difference

Benchmarked Frequency

Benchmarked Proportion

Using Hypothesis for Goal Setting – Discrete Data

DMAIC

- A discrete data baseline can be treated as a frequency table for defects & non-defects
- In other words, we have data on proportions
- Many times, we need to know if the difference between the two proportions is significant or only due to chance
- Suppose we want to benchmark a particular proportion defective for our process, we must find out if benchmarked proportion is from a different population
- To test differences between frequencies / proportions, we use the ***chi-square test***

Chi-Square Test

DMAIC

Tool

Chi-Square Test

$$\chi^2_{\text{Calculated}} = \sum \frac{(f_o - f_e)^2}{f_e}$$

Where	f_o	=	An *observed* frequency
	f_e	=	An *expected* frequency, determined through a Contingency Table

Chi-Square Test

DMAIC

- Suppose, we are analyzing the centuries scored by an Indian cricket player in India & abroad, for 4 countries in 25 matches played against each country. We develop a contingency table as below:

Number of centuries scored in India & abroad, against various countries	England	Australia	Pakistan	Sri Lanka	Total
In India	3	6	5	7	21
Abroad	2	2	4	2	10
Total	5	8	9	9	31

- The data has two classifications
- This table is called 2 x 4 contingency table (2 rows, 4 columns)

Chi-Square Test

DMAIC

- Let's hypothesize that proportion of centuries in India or abroad is equal irrespective of the country played against

- In other words, proportion of centuries in India & abroad is ***independent*** of the country played against

  i.e.

H_0 :	"Proportion of centuries scored in India or abroad is independent of country played against
H_1 :	"Proportion of centuries scored in India or abroad is dependent on country played against

Chi-Square Test

DMAIC

- If null hypothesis is to be rejected, then there should be a relationship / dependence among the various centuries scored

- We can calculate the *expected frequencies assuming there is a relationship*

- Expected frequency for each of the observed frequency

$$\left(\frac{\text{Row total}}{\text{Grand total}}\right) * \left(\frac{\text{Column total}}{\cancel{\text{Grand total}}}\right) * \cancel{\text{Grand total}}$$

For example

Observed frequency of 3 against England in India, would convert to expected frequency as (21 / 31) * 5 = 3.39

Preparing a Contingency Table

DMAIC

		Number of centuries scored in India & abroad, against various countries				
		England	Australia	Pakistan	Sri Lanka	
In India	Observed	3	6	5	7	**21**
	Expected	3.39	5.42	6.10	6.10	**21**
Abroad	Observed	2	2	4	2	**10**
	Expected	1.61	2.58	2.90	2.90	**10**

Sample Statistics

Estimated
Population Parameters

Preparing a Contingency Table

DMAIC

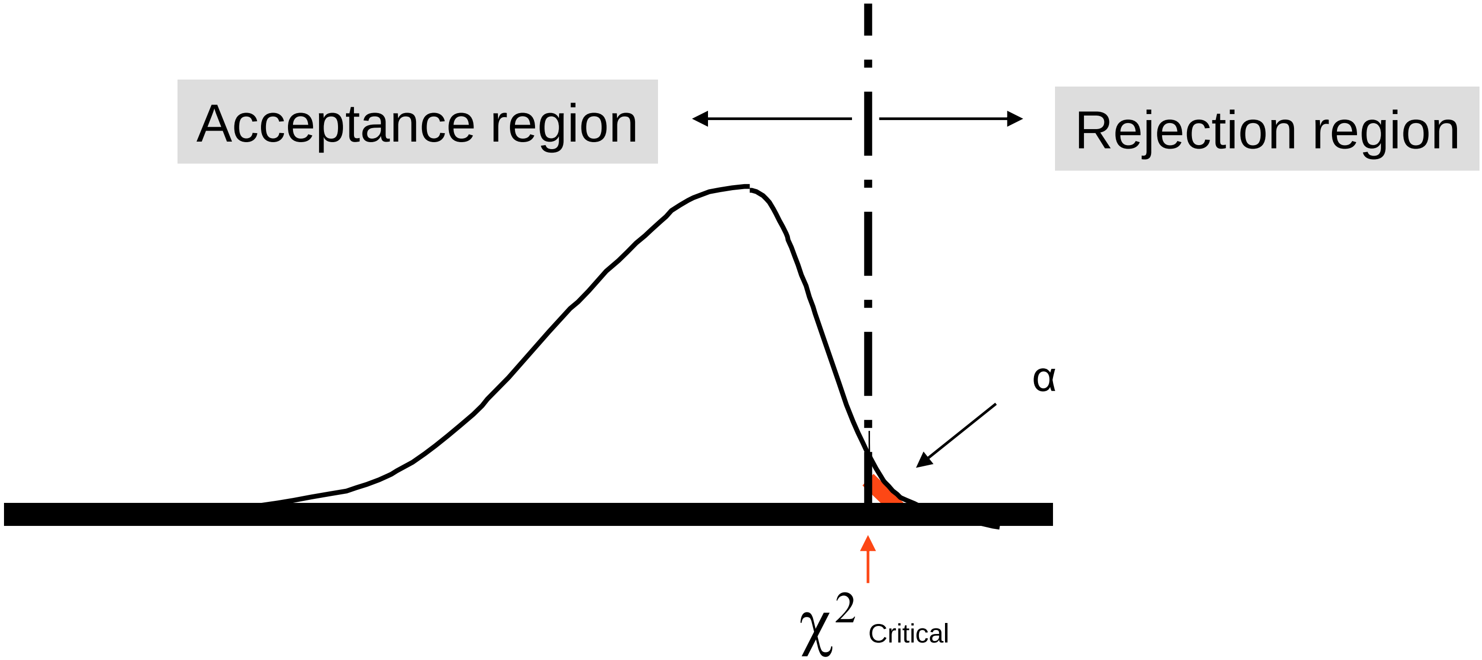
- Combining all the information

f_o	f_e	$(f_o - f_e)^2$	$\frac{(f_o - f_e)^2}{f_e}$
3	3.39	0.15	0.04
6	5.42	0.34	0.06
5	6.10	1.20	0.20
7	6.10	0.82	0.13
2	1.61	0.15	0.09
2	2.58	0.34	0.13
4	2.90	1.20	0.41
2	2.90	0.82	0.28
			1.36

$$\chi^2_{Calculated} = \sum \frac{(f_o - f_e)^2}{f_e} = 1.36$$

Calculating Critical Value (χ^2 Critical)

DMAIC



- We calculate χ^2 Critical from the chi-square distribution for given 'α' & degrees of freedom (df)
- If calculated statistic from the contingency table χ^2 Calculated , is greater than χ^2 Critical , it means difference between the 2 populations exists in more than (1 – α)% of the area & hence null hypothesis is rejected

Interpreting Results

DMAIC

- When calculated value is greater than critical value, it means there is more than (1 – α) % of chance that there is a significant difference between given sample proportions & estimated population proportions

- That means samples given do not belong to the same population, & hence we reject the null hypothesis

- Similarly, when calculated value is less than critical value, it means there is less than (1 – α) % of chance that there is a significant difference between given sample proportions & estimated population proportions

- That means samples given belong to the same population, & hence we accept the null hypothesis

One Sample One Sided t-Test Example

DMAIC

- Suppose pizza delivery time has the following output spread over a few days. Would it be an improved process if we target a mean delivery time of 42 minutes?

Let's assume that true population mean $\mu_T = 42$

H_0 :	$\mu_T = \overline{Y}$	"The null hypothesis is that true population mean is equal to the given sample mean"
H_1 :	$\mu_T < \overline{Y}$	"The alternative hypothesis is that true population mean is less than the given sample mean

Time taken in minutes
50
47
45
54
56
55
45
43
46
48
57

- We will have to use the lower tailed test, assuming $\alpha = 0.05$

- Computing the mean & standard deviation of given sample $\overline{Y} = 49.6, \quad s = 5$

One Sample One Sided t-Test Example

- Method 1: CRITICAL VALUE

- Using the central limit theorem, let's assume that we have picked a sample from a sampling distribution whose mean is 42 *(mean of means equals the population mean)*

- If the given sample mean 49.6 is part of the same sampling distribution, it must lie on the same distribution that has a mean of 42 & standard error of 1.52

- Df = n – 1 = 10 $t_{0.05,\,10} = 1.812 = t_{critical}$

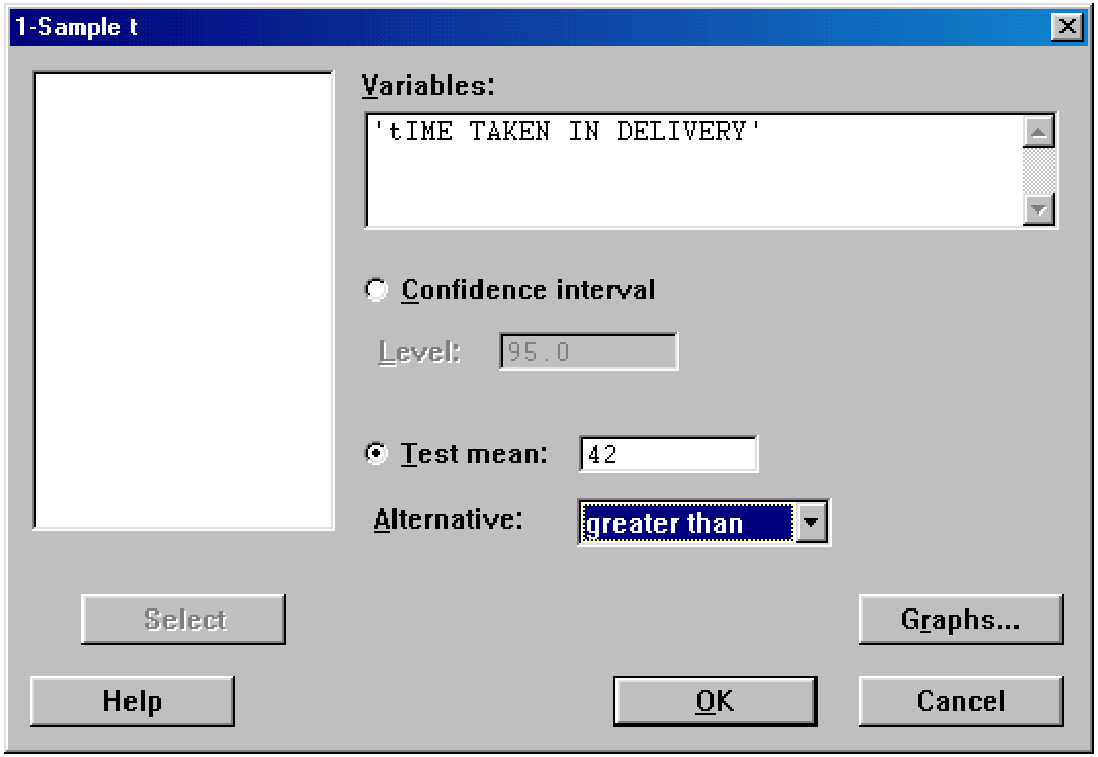
- $t_{calculated} = \dfrac{\bar{Y} - \mu_T}{s / n^{0.5}} = \dfrac{49.6 - 42}{1.52} = 5.03$

- Since $|t_{calculated}|$ is more than $|t_{critical}|$ we reject the null hypothesis

One Sample One Sided t-Test Example

- Method 2: P VALUE

- STAT > BASIC STATISTICS > 1 SAMPLE T



One Sample One Sided t-Test Example

DMAIC

- Method 2: P VALUE

- Using the Minitab, we get the following output

T-Test of the Mean

Test of mu = 42.00 vs mu > 42.00

Variable	N	Mean	StDev	SE Mean	T	P
C1	11	49.64	5.03	1.52	5.04	0.0003

- Since p-value is less than 0.05, we reject the null hypothesis

- Minitab is the most user-friendly method

Two Sample t –Test

DMAIC

Tool

Two Sample t-Test

- As explained earlier, two sample tests are performed to compare two samples & discover if they belong to different populations
- In benchmarking, we often want to compare the existing process with a benchmarked process
- Having understood the basic concepts, we shall straight-away use Minitab for this exercise as manual calculations can be tedious

Two Sample t –Test Example

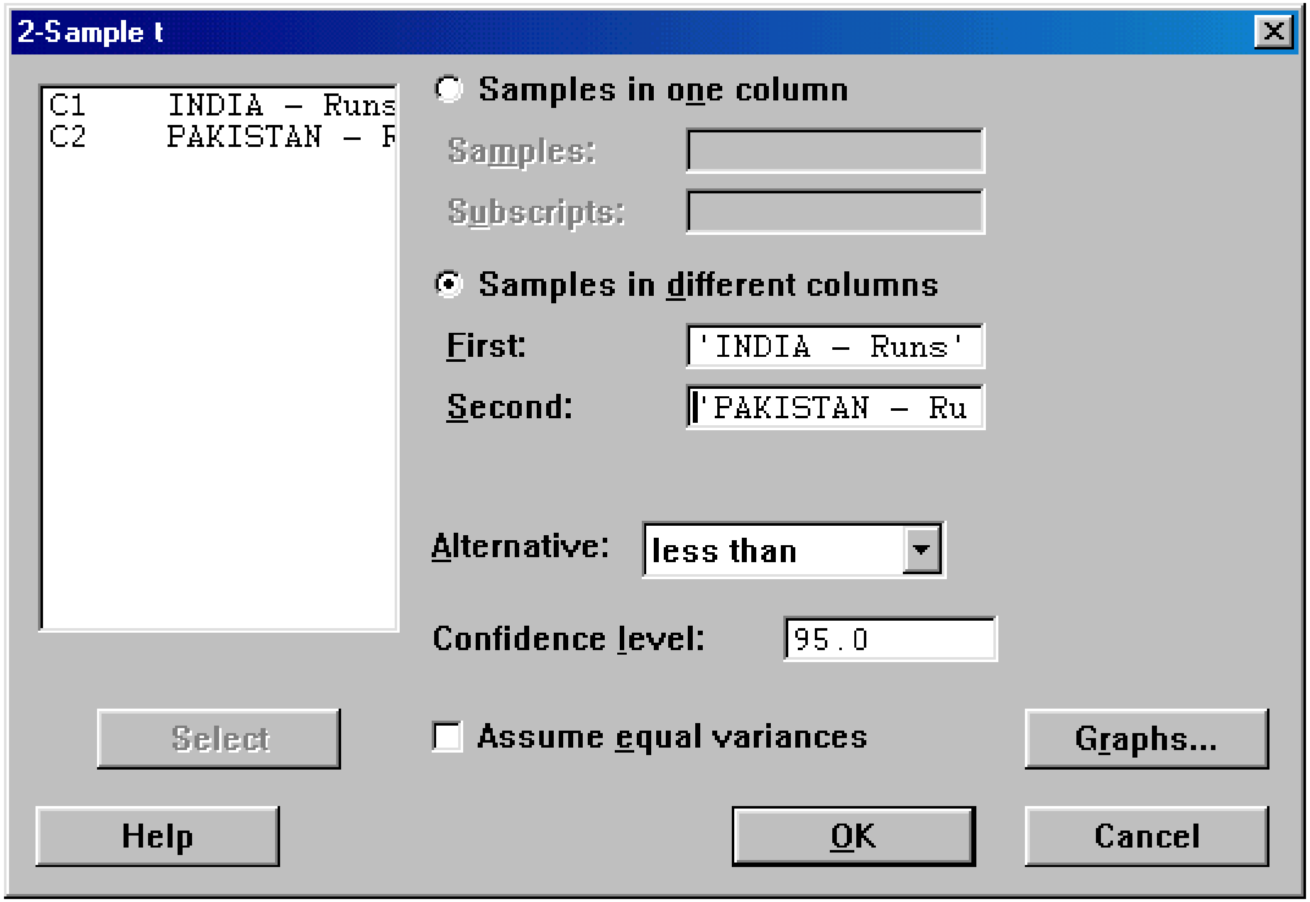
DMAIC

Runs scored by India	Runs scored by Pakistan
298	203
299	210
298	265
303	154
308	236
300	302
296	236
300	265
299	301
297	315
300	265
298	212
286	288
300	213
300	225
312	301
295	269
297	300
301	217
294	238
299	325
298	201
289	291
299	301
284	286
283	315
307	309
298	300
297	220
289	265
289	289

- Alongside is the data given on runs scored by Indian & Pakistani cricket teams while batting first in a one-day match. Is there enough evidence to believe that Pakistani team's performance is better? In other words, should their performance be benchmarked?

Two Sample t –Test Example

- STATS > BASIC STATISTICS > 2 SAMPLE T



Two Sample t –Test Example

- Assuming α = 0.05, we get the following Minitab output

Two sample T for India vs Pakistan

	N	Mean	StDev	SE Mean
India	31	297.19	6.47	1.2
Pakistan	31	261.8	43.7	7.9

95% CI for mu India - mu Pakistan: (19.2, 51.5)

T-Test mu India = mu Pakistan (vs <): T = 4.46 P = 1.0 DF = 31

- Since p-value is more than α, we accept the null hypothesis & conclude that Pakistani team is not performing better than Indian team

Key Concepts

- While using Minitab, we may assume that the two samples have equal variance
- In that case, Minitab uses a common standard deviation for calculation
- Before making any conclusion, we can use the F-test to test this assumption

ANOVA (Comparison of more than two means)

DMAIC

Tool

ANOVA

- We learnt earlier that we can use a t-test only for 1-sample & 2-sample tests for comparing the difference between two means
- If we want to compare the means of more than two samples, we use ANOVA
- ANOVA is nothing but **AN**alysis **O**f **VA**riance
- However, ANOVA does not tell us which mean is better, it only tells us that *all the sample means are not equal*
- Based upon ANOVA output, short listed samples can be further tested

ANOVA Example

DMAIC

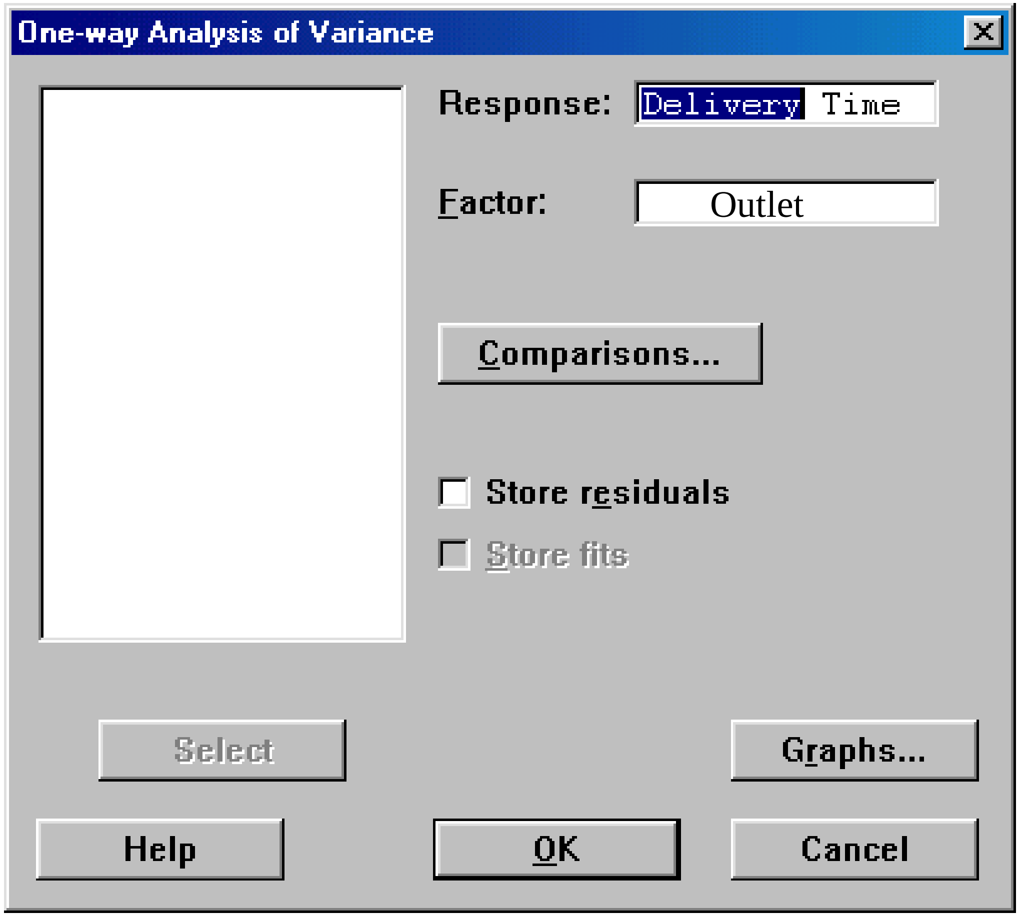
- Let's consider the pizza delivery time of three different outlets

Pizza Delivery Time (Minutes)		
Outlet 1	**Outlet 2**	**Outlet 3**
48	50	49
49	48	48
48	36	39
53	50	49
58	50	34
50	62	33
46	45	57
50	47	48
49	51	47
47	44	39

- Is there any evidence that the averages for 3 outlets are not equal? In other words, can the delivery time be benchmarked upon the outlet?
- Null hypothesis is that $\mu_1 = \mu_2 = \mu_3$
- If we end-up rejecting the null hypothesis, it would mean that there are at least two outlets that are different in their average delivery time

Using Minitab for ANOVA

- STAT > ANOVA > 1 WAY



Using Minitab for ANOVA

- Feeding the same data into Minitab, we get the following output

One-way Analysis of Variance for time taken

Source	DF	SS	MS	F	P
Outlet	2	161.7	80.8	2.13	0.138
Error	27	1023.8	37.9		
Total	29	1185.5			

```
                                Individual 95% CI's For Mean
                                Based on Pooled St Dev
Level      N     Mean    St Dev ----------+---------+---------+---
OL 1      10   49.800    3.458                (---------*--------
OL 2      10   48.300    6.550            (---------*---------)
OL 3      10   44.300    7.675  (---------*---------)
                                ----------+---------+---------+---
Pooled St Dev =    6.158                44.0      48.0      52.0
```

Interpreting Minitab Results

DMAIC

- Since p-value is more than 0.05 (Minitab default), we accept the null hypothesis that there is no significant difference between means of delivery time for 3 outlets
- Looking at the confidence intervals, you will find that intervals are too overlapping which means that there is little that separates the means of three samples
- Previous example was of one-way ANOVA where there was only one factor to be benchmarked, i.e. the outlet of delivery
- If there are two such factors, we may use the two-way ANOVA

Two-Way ANOVA

DMAIC

- Suppose apart from delivery being made from 3 different outlets, we also use another benchmarked factor, say, a transport agency, then there could be two possible factors contributing to the variation

response	Outlet	agency
48	1	a
49	1	a
48	1	a
53	1	a
58	1	a
50	1	b
46	1	b
50	1	b
49	1	b
47	1	b

response	Outlet	agency
50	2	a
48	2	a
36	2	a
50	2	a
50	2	a
62	2	b
45	2	b
47	2	b
51	2	b
44	2	b

response	Outlet	agency
49	3	a
48	3	a
39	3	a
49	3	a
34	3	a
33	3	b
57	3	b
48	3	b
47	3	b
39	3	b

Two-Way ANOVA

- Minitab output will be as follows

Analysis of Variance for response

Source	DF	SS	MS	F	P
Outlet	2	161.7	80.8	1.98	0.160
agency	1	1.2	1.2	0.03	0.865
Interaction	2	43.4	21.7	0.53	0.594
Error	24	979.2	40.8		
Total	29	1185.5			

```
              Individual 95% CI
Outlet      Mean  ------+---------+---------+---------+-----
1        49.8             (-----------*-----------)
2        48.3          (-----------*-----------)
3        44.3  (-----------*----------)
              ------+---------+---------+---------+-----
                42.0      45.5      49.0      52.5
```

```
                   Individual 95% CI
agency      Mean  -+---------+---------+---------+---------+
     a       47.3  (----------------*----------------)
     b       47.7   (----------------*----------------)
                  -+---------+---------+---------+---------+
                  44.0      46.0      48.0      50.0      52.0
```

Interpreting Minitab Results

DMAIC

- P-value for benchmarked practice 1 - *Outlets*, is more than 0.05, thus there is no significant difference in average delivery times from different outlets, thus, *benchmarking a particular outlet may not be appropriate*

- P-value for benchmarked practice 2 - *Agency*, is more than 0.05, thus there is no significant difference in average delivery times of different agencies, thus, *no agency should be benchmarked*

Class Exercise

DMAIC

- Production team in a steel manufacturing company XYZ wants to study if the production yield is different for various input raw material combinations. It collects data on yields for two raw material combinations from rival companies A & B. Combination C is what XYZ company presently uses:

A: *Pure DRI* **B:** *Pure Hot Metal* **C:** *40:60 ratio of DRI to Hot Metal*

Use ANOVA to find if average yield differs for these three samples? Should XYZ company benchmark the company A or B based upon yield?

Yield with Combination A	Yield with Combination B	Yield with Combination C
90.00%	78.90%	99.80%
89.00%	79.60%	99.60%
91.00%	84.70%	99.50%
89.50%	85.60%	98.70%
91.00%	87.10%	97.50%
92.00%	82.50%	99.00%
88.50%	81.70%	95.50%
97.60%	89.70%	98.70%
98.70%	79.30%	96.30%
99.00%	82.50%	99.80%
98.70%	86.90%	99.50%
95.80%	90.10%	99.00%
89.00%	87.20%	96.80%
94.10%	87.90%	99.80%
97.80%	85.00%	99.20%

Means & Ends of a Process

$$Y = \mathbf{f}(X_1, X_2, X_3 \ldots\ldots X_n)$$

Y	X
Dependent	Independent
Process Output	Process Input / Step
Effect	Cause
Symptom	Problem
Monitor	Control

Means & Ends of a Process

DMAIC

- So far, we have focused on the process output ‘Y’
  - Unit
  - Specifications
  - Defects
  - Baseline
  - Target
- Variation / Change in ‘Y’ is due to X’s
- In other words, defect observed in output ‘Y’ is due to some X’s not being controlled
- In this step, we identify the factors that contribute to variation in the process output ‘Y’
- Another objective of this step is to separate the *vital few* X’s from *trivial many*

Generating & Prioritizing X's

DMAIC

- Identifying & prioritizing X's could be done using both non-statistical & statistical tools
- Identification tools include *(non-statistical basis)*
  - Experience of process doers
  - Brainstorming & Multi-voting
  - Process mapping

  → Focus on identifying problem areas
  - Fishbone

  → Focus on identifying potential root causes
- Prioritization tools include
  - Pareto Diagram
  - Correlation (for a single X)
  - Regression (for multiple X's)
  - Chi-square test
  - ANOVA
  - Failure Mode & Effect Analysis (FMEA)

  → Focus on prioritizing potential root causes

Identify Potential X's that Cause Variation in 'Y'

Identification Tools

DMAIC

- Brainstorming & Multi-voting is a structured methodology to collect responses from a group & arrive at a short-list
  - Even though it provides a short-list, it's not an effective prioritization tool because short-listing is not done on any mathematical basis
- Use of process mapping requires studying the micro as-is process mapped in step 2 earlier & walking through it
- Fishbone relates an 'effect' to its 'cause' by drawing a tree diagram

Brainstorming & Multi-voting

DMAIC

- Identify a focus group that possess knowledge & experience about the process being improved
- Brainstorm & generate a list of X's that may cause variation in the process
- Let's assume that number of members in the focus group is 5 & they generate 20 X's
- Each member can give one vote each to each of the 20 X's (he may not give votes to some X's)
- Count the number of total votes given, say, it's 60
- Take 50% of 60, i.e. 30 & list top X's whose vote count adds upto 30
- Say there are 7 X's whose votes count upto 30
- Give each member 4 votes (50% of ideas short-listed in the previous step) & repeat the exercise of casting votes upto this step
- Stop when number of X's comes to 4-5, or a pre-determined level

Tool

Brainstorming & Multi-voting

Multi-voting Example

DMAIC

- Below table illustrates the number of group members & total ideas (X's) generated

Team Members	Ideas
A B C D E	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

- Now each member gives votes to ideas (maximum one vote to each idea) & below is the vote distribution for ideas

Idea	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Votes	2	5	5	2	3	1	2	2	1	4	3	5	3	3	4	4	5	2	2	2	**60**

- Top ideas whose vote count adds upto 32 are as below (30 is not possible), there are 7 such ideas

Idea	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Votes	2	5	5	2	3	1	2	2	1	4	3	5	3	3	4	4	5	2	2	2	**60**

Multi-voting Example

- Take these 7 ideas for further round of multi-voting

Idea	2	3	10	12	15	16	17
Votes	5	5	4	5	4	4	5

- Give each member 4 votes (round off 50% of 7 to next higher integer) & ask them to distribute these 4 votes among these 7 ideas. Below could be the distribution in this fresh round of voting

Idea	2	3	10	12	15	16	17	
Votes	3	1	3	1	2	3	4	**17**

- Take top ideas wh

Idea	2	3	10	12	15	16	17	
Votes	3	1	3	1	2	3	4	**17**

- This list is manage

Points to Remember in Brainstorming

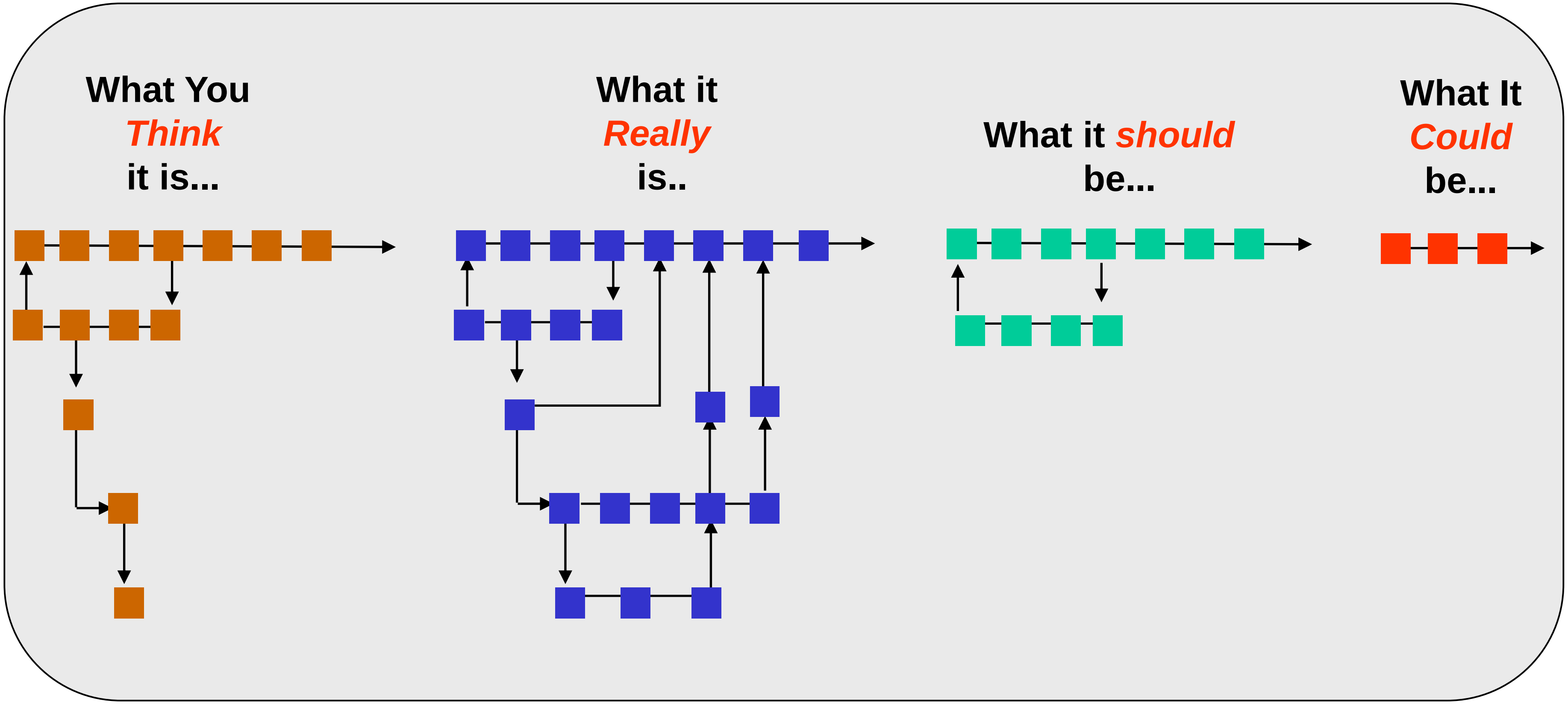
DMAIC

- All ideas are important, don’t out rightly reject any idea
- Participation should be ensured from all team members
- To ensure this, project teams could use the round-robin method of idea generation
- It’s advised to use the Black Belt as the facilitator here

Use of Process Mapping for Defect Identification

DMAIC

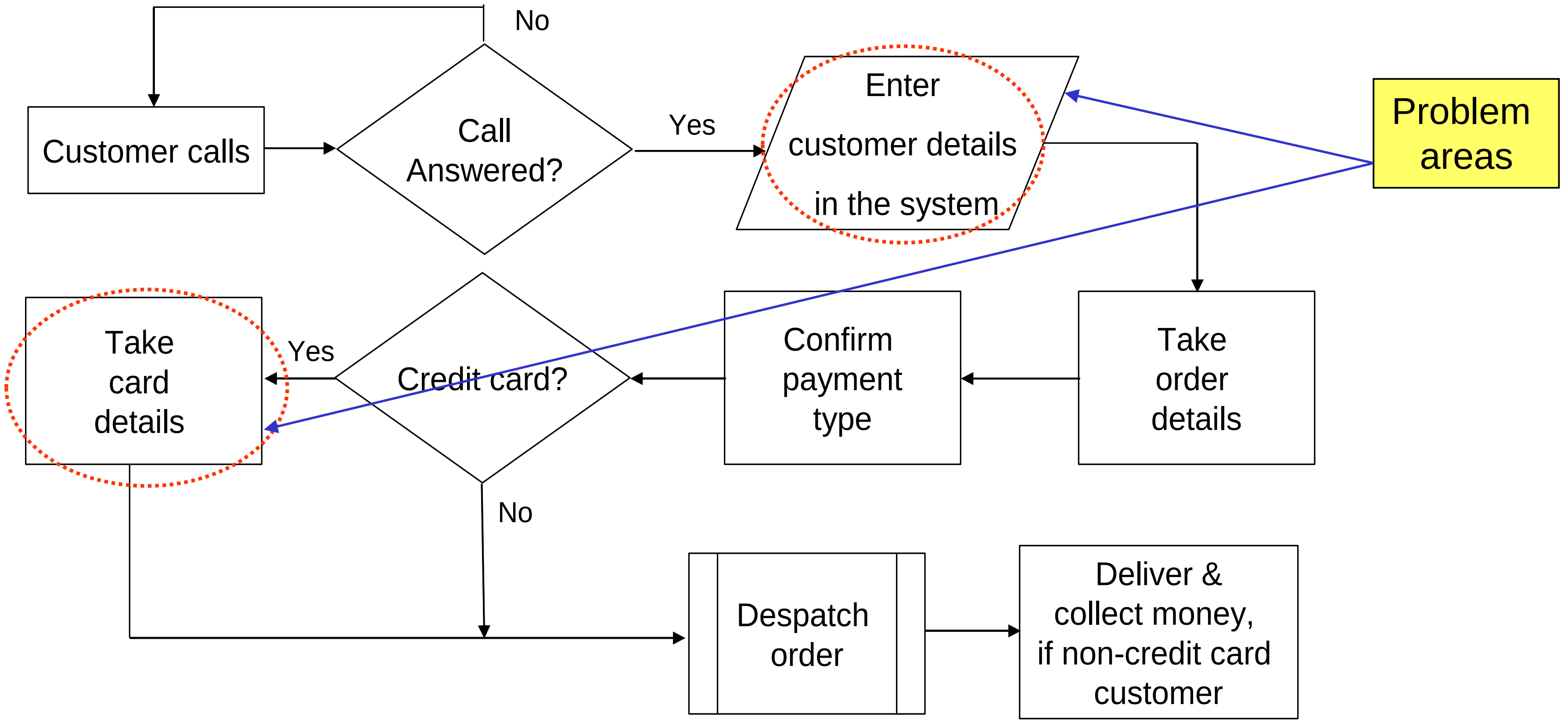
Versions of a Process



Use of Process Mapping for Defect Identification

DMAIC

- Below is the macro process mapped for pizza home delivery. However, project teams would have created a micro process map in step 2 which should be used for this exercise



Fishbone

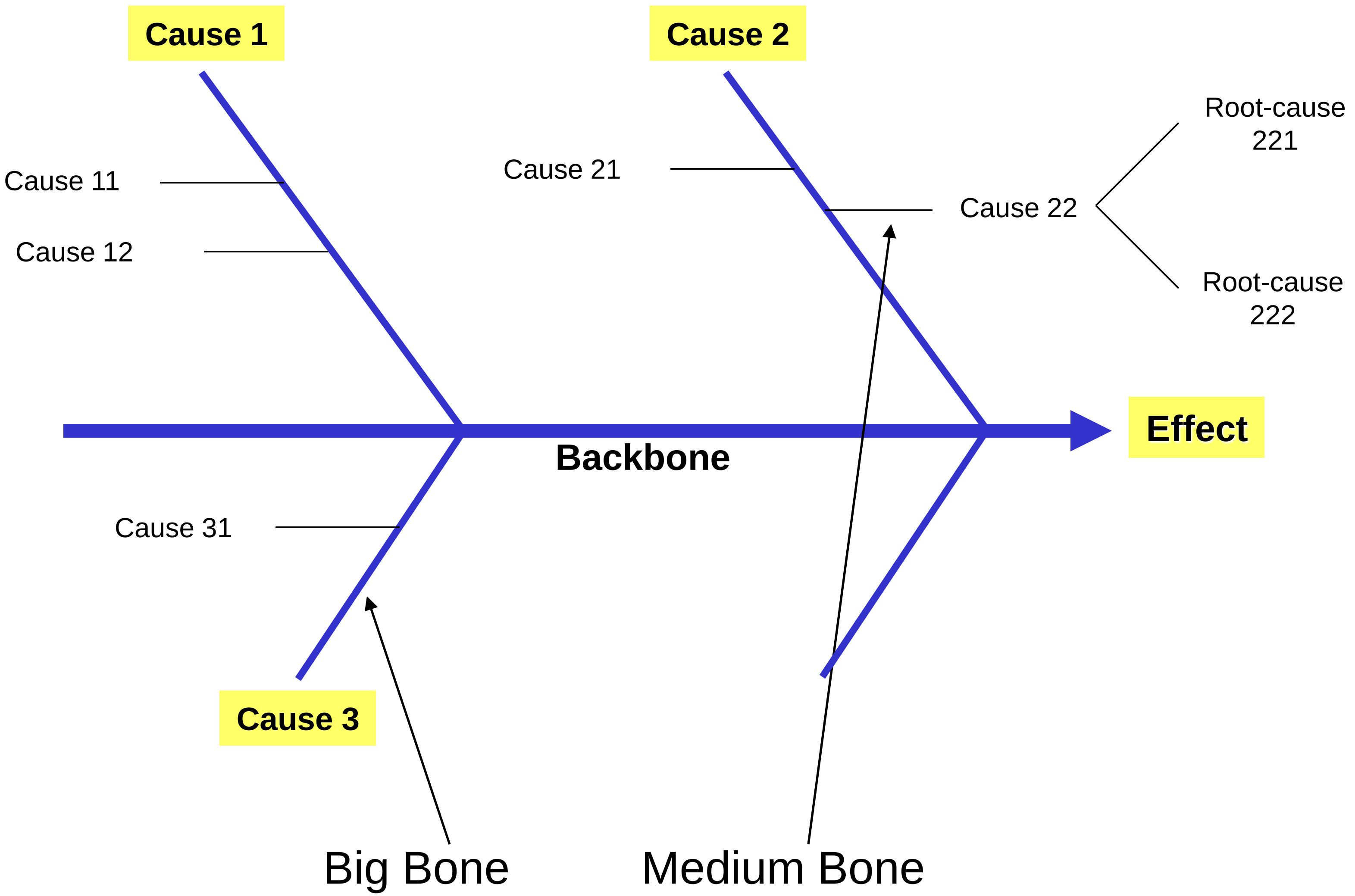
DMAIC

- Also called "Cause & Effect' or 'Ishikawa' diagram
- Focus of Fishbone is to arrive at the root causes of the problem areas identified through multi-voting / process mapping
- It works on the principal of asking 'why' to each cause till you reach the 'root cause'
- For example, if one of the problem areas identified in the pizza delivery process was 'Wrong customer details' for the defect of 'Order not paid for', a fishbone can be prepared on identifying the root cause for this problem
- Why was the building getting yellow?

Tool

Fishbone

Fishbone Structure



Separate Vital Few from Trivial Many for Further Screening

Prioritization Tools

DMAIC

- Some teams may do a multi-voting here, at the output of root-cause analysis
- Pareto diagram works on the 80:20 rule of 20% causes contributing to 80% of defects
- Co-relation & Regression help in identifying the movement of continuous ‘Y’ with respect to continuous ‘X’
- ANOVA & Chi-square help in identifying the movement of continuous / discrete ‘Y’ with respect to discrete ‘X’
- Failure Mode & Effect Analysis (FMEA) identifies the process failure modes & assigns a number to it that helps to prioritize the actionables

Success of all prioritization tools depends upon data collection

Pareto Diagram

DMAIC

Tool

Pareto

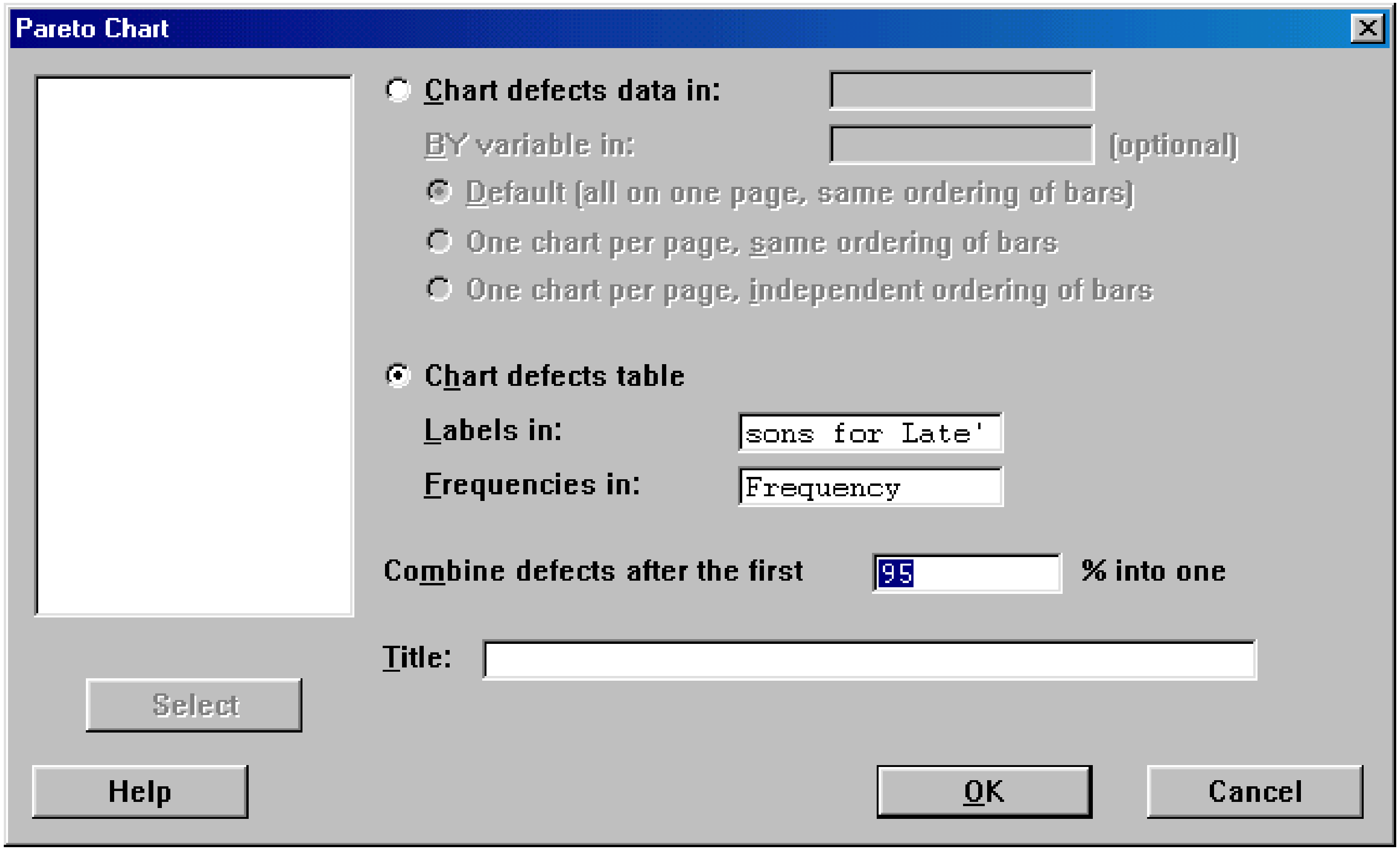
- Suppose a person identifies multiple root-causes of reaching his office late. Now he is not sure where to focus so that he reduces the occurrence of reaching late by minimum 50%.

- He has identified following root causes
  - Woke up late
  - Clothes not ready
  - Breakfast not ready
  - Bus not coming on time
  - Traffic jam
  - Bus waiting for other employees

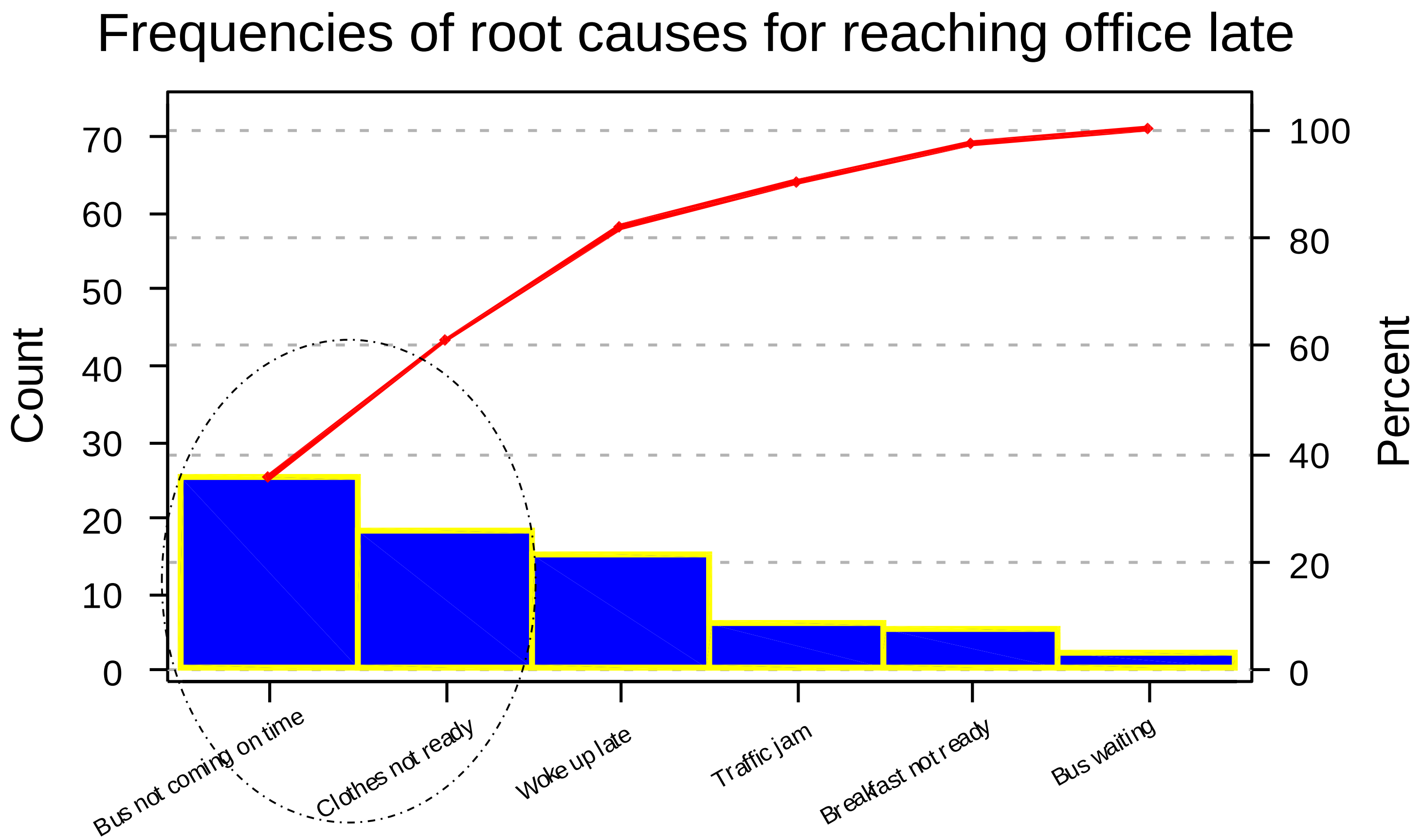
- He collects data on how frequent each of the root cause is & constructs a Pareto

Constructing a Pareto in Minitab

- STAT > QUALITY TOOLS > PARETO CHART



Pareto Diagram



Count	25	18	15	6	5	2
Percent	35.2	25.4	21.1	8.5	7.0	2.8
Cum %	35.2	60.6	81.7	90.1	97.2	100.0

Pareto Diagram

DMAIC

- Essentially, Pareto is used to prioritize the problem areas / root-causes
- However, it can also be used to segment project defects to get clues about the process behavior
- Common factors used for segmentation are as below:

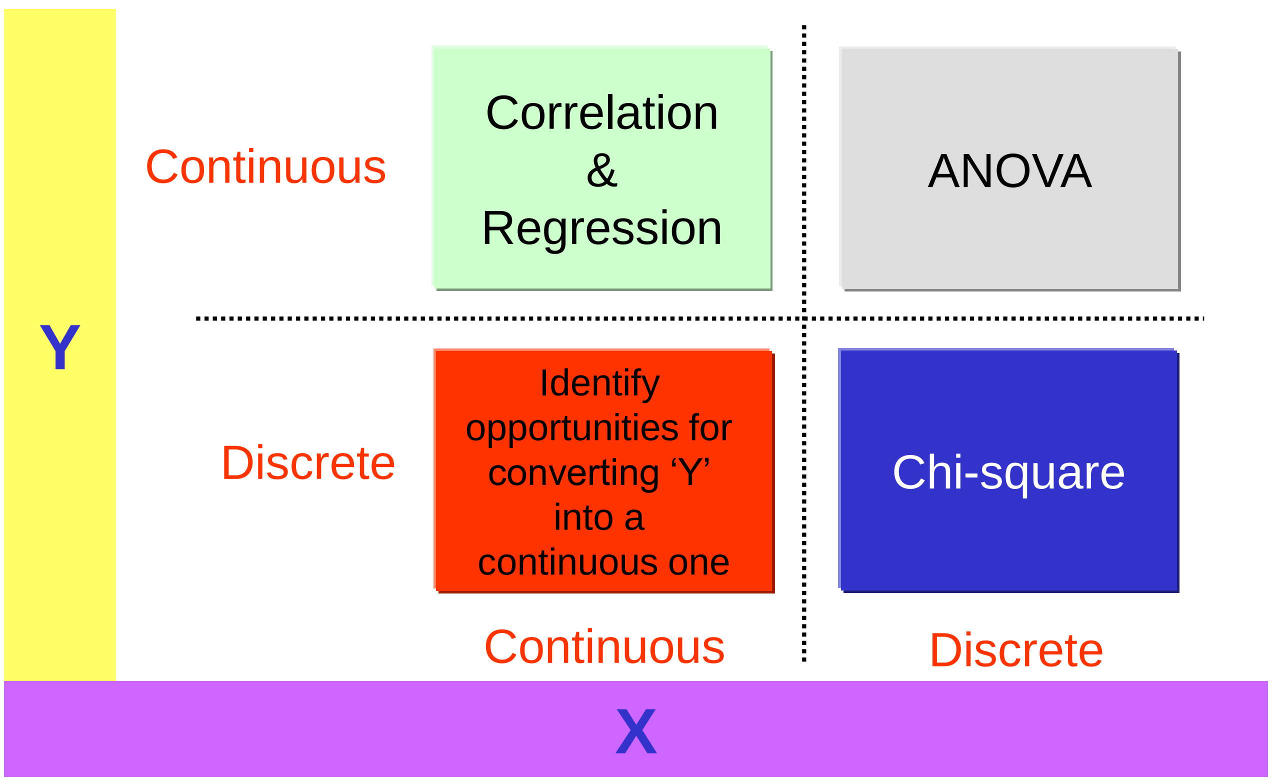
Factor	Example
What	Complaints, Defects, Problems
When	Year, Month, Week, Day
Where	Country, Region, City, Work Site
Who	Business, Department, Individual

Summary of Pareto

- Pareto diagram can be used even in step 4 when we establish the process baseline
- It can also be used in prioritizing problem areas (before RCA), if data is available
- If a process has multiple defect definitions, project teams can use the Pareto to see where to focus first for defect reduction, & set improvement targets accordingly
- Even for single defect definitions, if there are multiple defect categories (different products, different geographies, etc.), Pareto could be useful
  - For example, if late delivery for products is the defect definition, one can use the Pareto to see if the frequency of late delivery is higher in product A, B or C, & focus accordingly

Key Concepts

- So far, we have not used any statistical tool to prioritize X's.
- Depending upon the data characteristics of Y & X, we can choose the appropriate tool



Correlation – Association between Variables

DMAIC

Tool

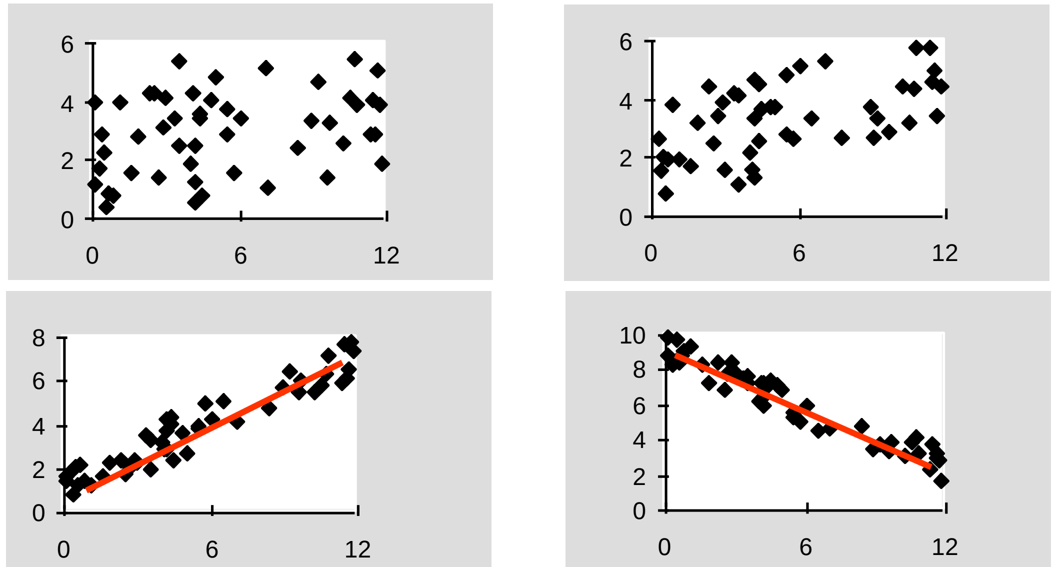
Correlation

- If we want to associate 'Y' with a *single* 'X', we can use correlation
- Correlation is about predicting the movement in values in 'Y' when 'X' changes
- Statistical significance of that movement is denoted by correlation coefficient 'r'
- 'r' is always between –1 & +1
  - Positive value of 'r' means direction of movement in both variables is same
  - Negative value of 'r' means direction of movement in both variables is inverse
  - Zero value of 'r' means no correlation between the two variables
- Higher the value of 'r', stronger the correlation between 'Y' & 'X'
- An 'r' value of > + 0.85 or < - 0.85 indicates a strong correlation

Correlation Levels

DMAIC

r = 0.05 r = 0.50



r = 0.95 r = – 0.95

- Correlations of 0.5 or below are hard to see
- Correlation measures the *linear association* between the output (Y) and one input variable (X) only

Regression

DMAIC

Tool

Regression

- While correlation tells us only about the direction of movement, it does not throw much light on *degree of movement* in one variable with respect to movement in another
- Regression of 'Y' on 'X' results in a transfer function equation that can be used to *predict* the value of 'Y' for given values of 'X'

$$Y = \mathbf{f}(X)$$

- 'Y' can be regressed on one or more X's simultaneously
  - Simple linear regression is for one X
  - Multiple linear regression is for more than one X's
  - Regression by subsets is to choose the best model when there are many X's
  - Polynomial regression is to explore the curvilinear relationship between variables

Key Concepts

DMAIC

- Even though we get a transfer function Y = f(X) as an output of the regression in step 6, this is not the correct transfer function to control ‘Y’
- Main thrust of regression in this step is only to discover whether a substantial relationship exists between ‘Y’ & a particular ‘X’, i.e., whether it is a vital ‘X’ or not, by looking at p-values
- The correct definition of transfer function will be arrived at in step 8 in *Improve* phase when we perform optimization experiments only on vital X’s

Regression

DMAIC

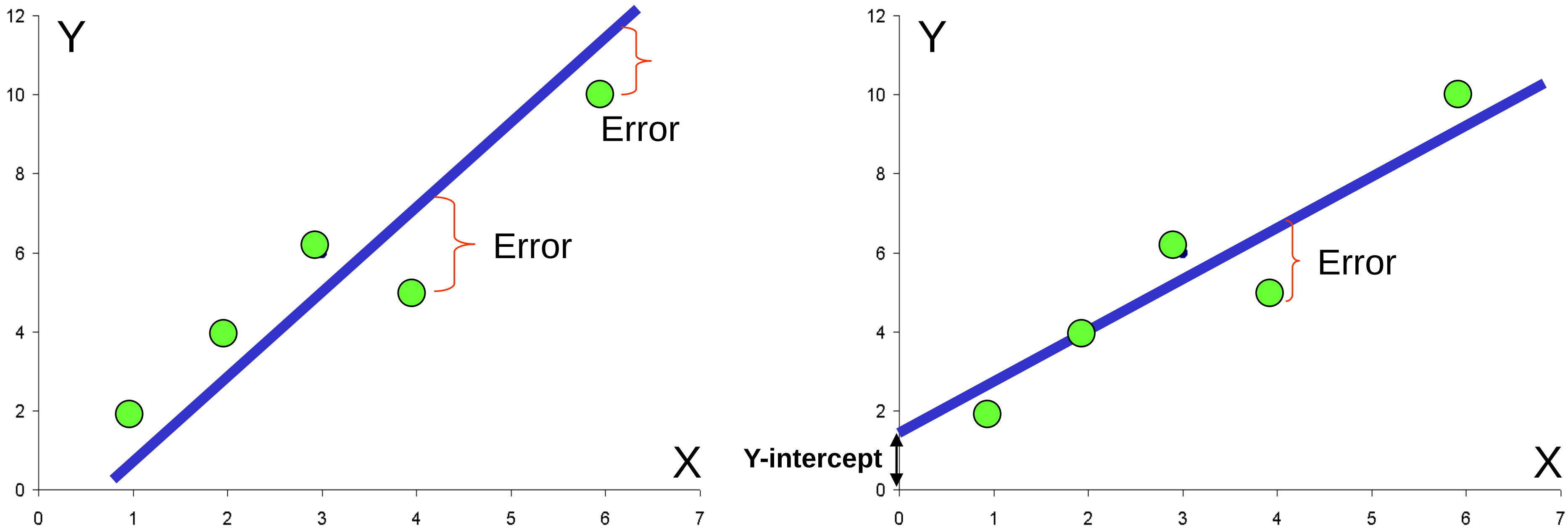
- A regression equation is nothing but a ***fitted linear equation*** between 'Y' & 'X' that looks as follows:

$$Y = A + BX + C$$

where	Y =	Dependent variable / output / response
	X =	Independent variable / input / predictor
	A =	Intercept of fitted line on Y axis
	B =	Regression coefficient / Slope of the fitted line
	C =	Error in the model

Least Squares method

- If ‘Y’ & ‘X’ are not perfectly linear (r = ± 1), there could be several lines that could be fitted



- Minitab fits the line which has the least value of errors squared & added

Example

DMAIC

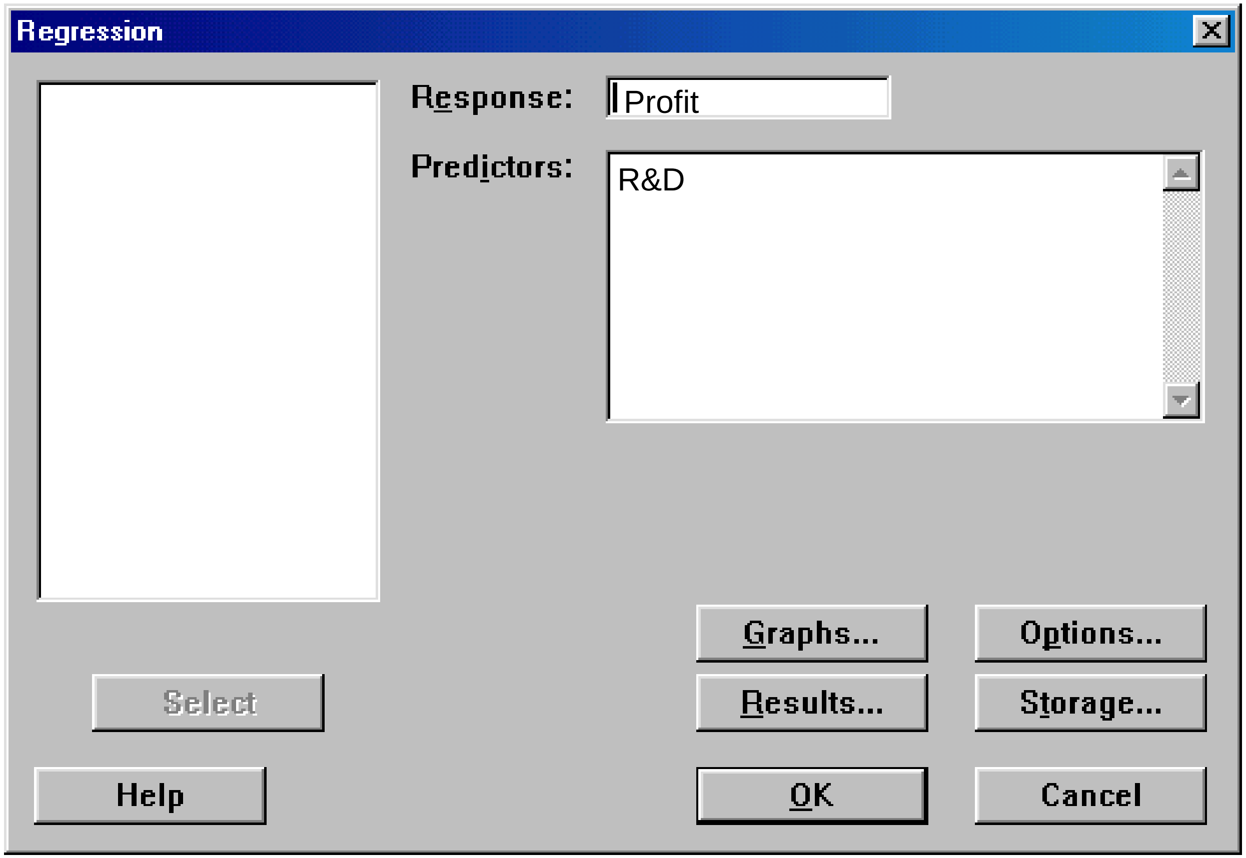
- Suppose R&D department of a company wishes to predict the relationship between amount spent on R&D & annual profit generated. It collects the following data for last few years & wants to give a R&D budget for this year based on the targeted company profits. Company has targeted a profit of INR 32 Million this year.

	X	Y
	INR Millions spent on R&D	Annual profit in INR Million
1995	5	31
1994	11	40
1993	4	30
1992	5	34
1991	3	25
1990	2	20

Using Minitab Example

DMAIC

- STAT > REGRESSION > REGRESSION



Regression Example

DMAIC

- Minitab gives the following output

Regression Analysis

The regression equation is

Annual Profit = 20.0 + 2.00 * R&D expenditure

Predictor	Coef	StDev	T	P
Constant	20.000	2.646	7.56	**0.002**
R&D expenditure	2.0000	0.4583	4.36	**0.012**

S = 3.240 R-Sq = 82.6% **R-Sq(adj) = 78.3%**

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	200.00	200.00	19.05	**0.012**
Residual Error	4	42.00	10.50		
Total	5	242.00			

- For a targeted profit of INR 32 Million, R&D could be budgeted for INR 6 Million

Interpreting Results

DMAIC

- P-value of 0.012 for R&D expenditure denotes that expenditure is statistically significant to have a *non-zero* regression coefficient

- R-Sq = 82.6% = r^2. This is called the *coefficient of determination*

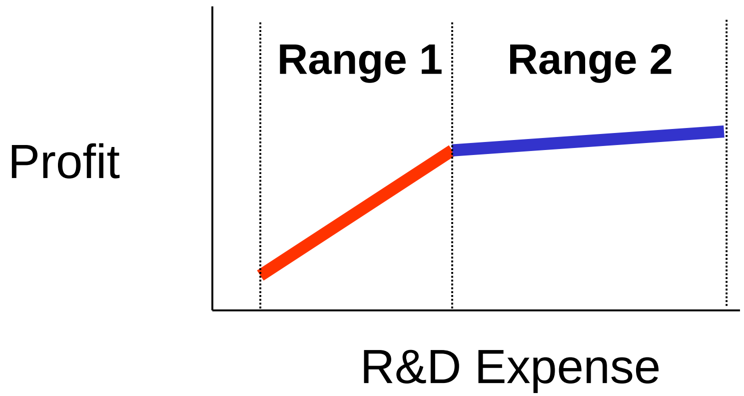
- Also, R-Sq = $SS_{Regression} / SS_{Total}$

- The R-Squared value is the proportion of variability in the Y variable accounted for by the predictors. In other words, 82.6% of *linear* variation in 'Y' is explained by 'X' in the fitted model

	R&D Spend (X)	Actual Profit (Y)	Fitted Model's Predicted Profit (Y_P) (20 + 2X)	Error in Prediction
1995	5	31	30	-1
1994	11	40	42	2
1993	4	30	28	-2
1992	5	34	30	-4
1991	3	25	26	1
1990	2	20	24	4
	Sum of Squares	242	200	42
	R^2	82.64%		= 200 / 242

Points to Remember in Regression

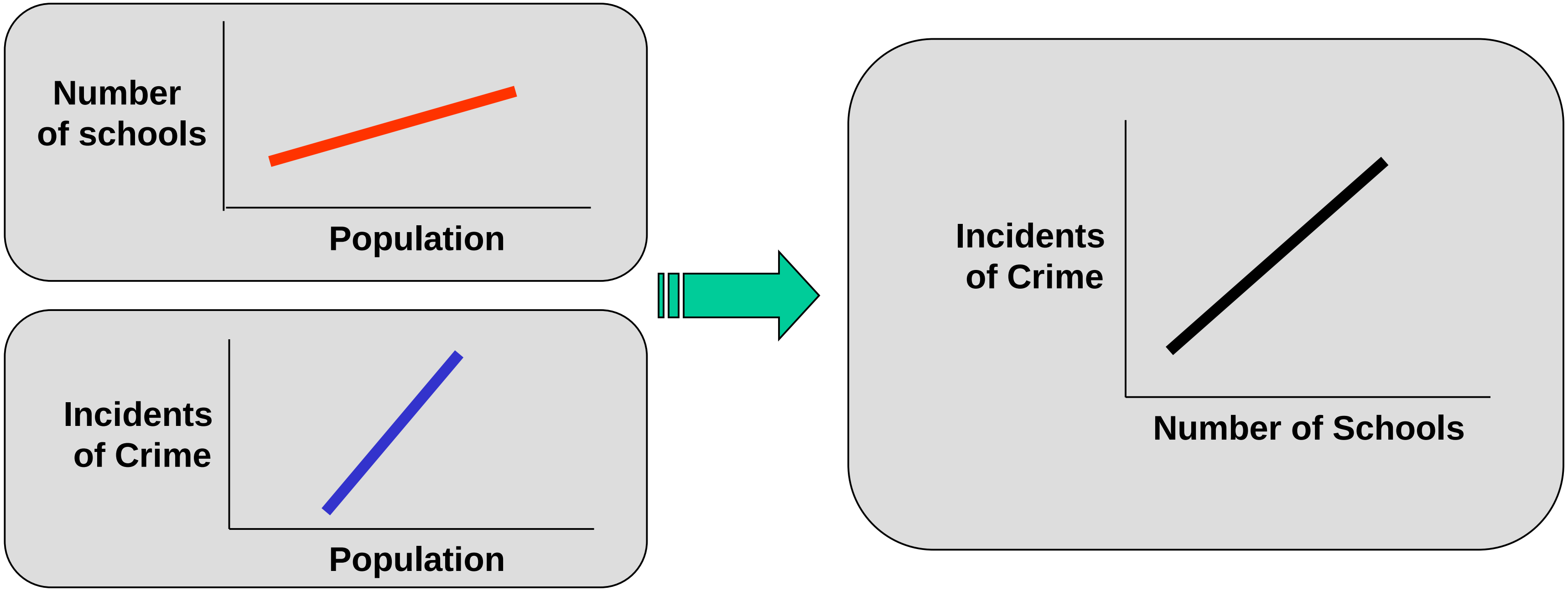
- Don’t extrapolate beyond the range
  - Project teams get tempted to extrapolate the results beyond the range of collected data. In one of the previous examples, higher R&D expenditures may not see same increase in profits, & hence, the regression equation between profit & R&D expense may change



Points to Remember in Regression

DMAIC

- Don't assume causation
  - Regression equation denotes a relationship only. This in no way means that a change in one variable <u>*causes*</u> change in another. If number of schools & incidents of crime in a city go up together, there may be a relationship, but no causation. The increase in both factors could be due to third factor – population.
  - In other words, both of them may be dependent variables themselves



Points to Remember in Regression

DMAIC

- Regression may not give you a good R^2 :
  - If Xs chosen in the model are not the 'real' ones – *you may need to look at residual plots*
  - If X's have interactions
  - In case of multiple X's having a curvilinear relationship with 'Y'

- Regression results that defy theory / conventional logic, should be re-validated with DOE in next phase of *IMPROVE*

ANOVA

DMAIC

- ANOVA is used to short-list potential discrete X's for a continuous 'Y'
- We can use one-way ANOVA & see the variation in 'Y' for one 'X' at a time
- We can use two-way ANOVA for more than one X

Failure Mode & Effect Analysis (FMEA)

DMAIC

- FMEA is a simple tool to prioritize the failure modes & actions
- By understanding why and how we fail, we can plan for success
- It works on the belief that proactiveness saves time
- Typically, FMEA is applied on the output of root-cause analysis, & is a better tool for focus / prioritization as compared to multi-voting
- We shall focus on Process FMEA *(Design FMEA is used in designing products)*

Tool

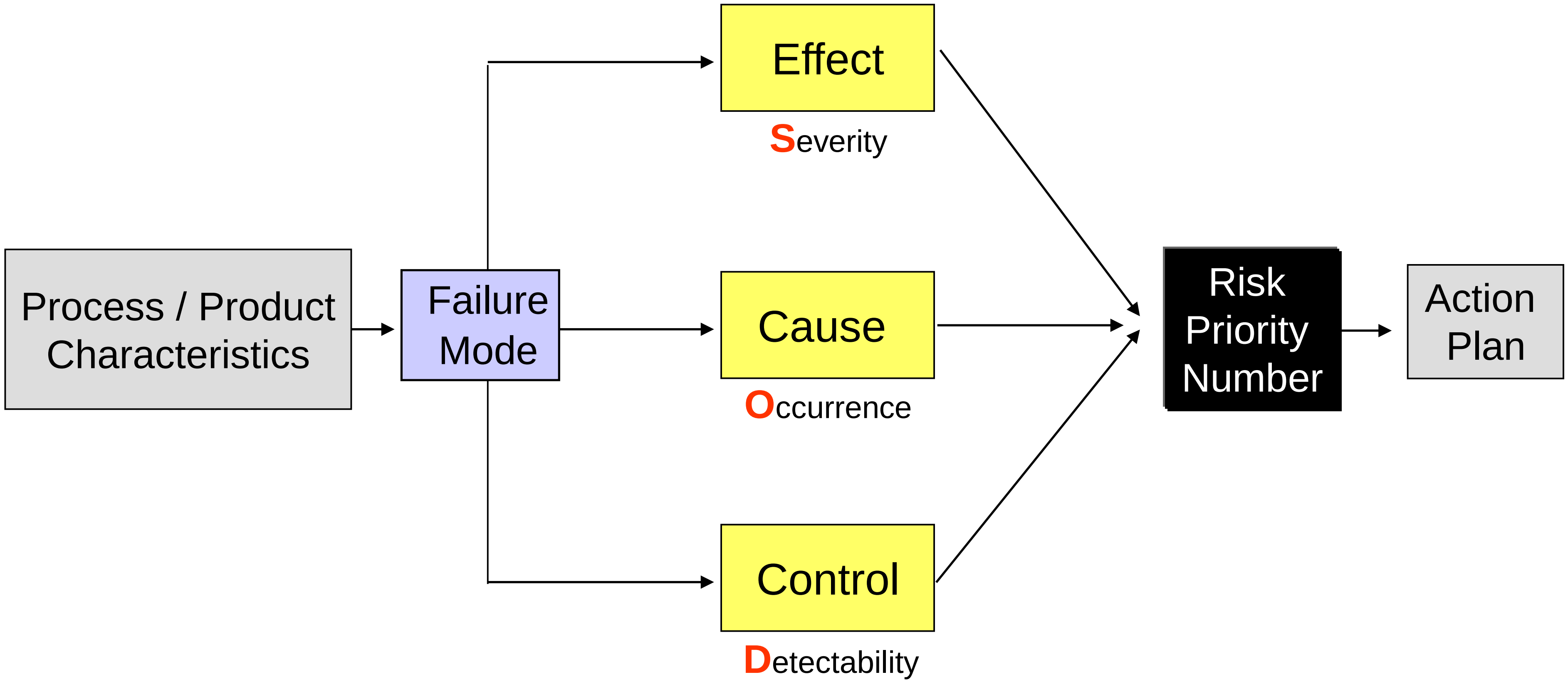
FMEA

Process FMEA Torchbearers

DMAIC

- Product Developer
- Process Technologist
- R&D
- Black Belts
- Sourcing Team
- Equipment Supplier
- Customer
- Environment Health & Safety
- Legal - Intellectual Property

FMEA Concept & Output



- Risk Priority Number (RPN) = S * O * D
- Severity, Occurrence & Detectability are measured on a scale of 1-10

FMEA Concept & Output

DMAIC

- Process / Product characteristics - *Purpose of the product or Process*
- Failure Mode - *How can the product / process fail to function?*
- Effects - *Which effects are most severe to customer?*
- Causes - *Which causes are most likely to occur?*
- Controls - *Ability for current controls to detect causes?*
- RPN - *Which high risk cause we work on first?*
- Action Plan - *Recommended actions & responsibilities*

FMEA Example

DMAIC

FMEA Table

Process / Product Characteristics	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev (S)	Potential Cause(s) of Failure	Occ (O)	Current Design Controls	Det (D)	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	New Sev (S_N)	New Occ (O_N)	New Det (D_N)	New RPN (RPN_N)
Playing a cricket match	Losing	Loss of money	9	Lack of fitness	9	Fitness report from any doctor	3	243	Panel of certified doctors	Management	2 doctors have been nominated to certify fitness	9	7	1	63
				Betting	7	None	9	567	Audit bank accounts of players, control external interaction	Management	Audit procedure has been designed		5	5	225
				Lopsided team due to bias	5	Selection committee selects	5	225							

Repeat the same exercise for another failure mode – ***match abandoned***

FMEA Summary

DMAIC

- Usually, FMEA is used to prioritize root-causes for discrete defect definitions on ‘Y’ where Regression / ANOVA are not possible
- Typically, final part of the FMEA table in terms of ‘recommended actions’ & improved SOD rating gets filled during *IMPROVE* & *CONTROL* phases
- Recommended action is nothing but a counter-measure to eliminate/ transition a root-cause that will be studied in step 9 of DMAIC
- New SOD ratings shall be given only at the time of project closure when counter-measures would have been implemented & effect seen on “failure mode”
- Project teams must review the RPN’s periodically

Key Concepts

DMAIC

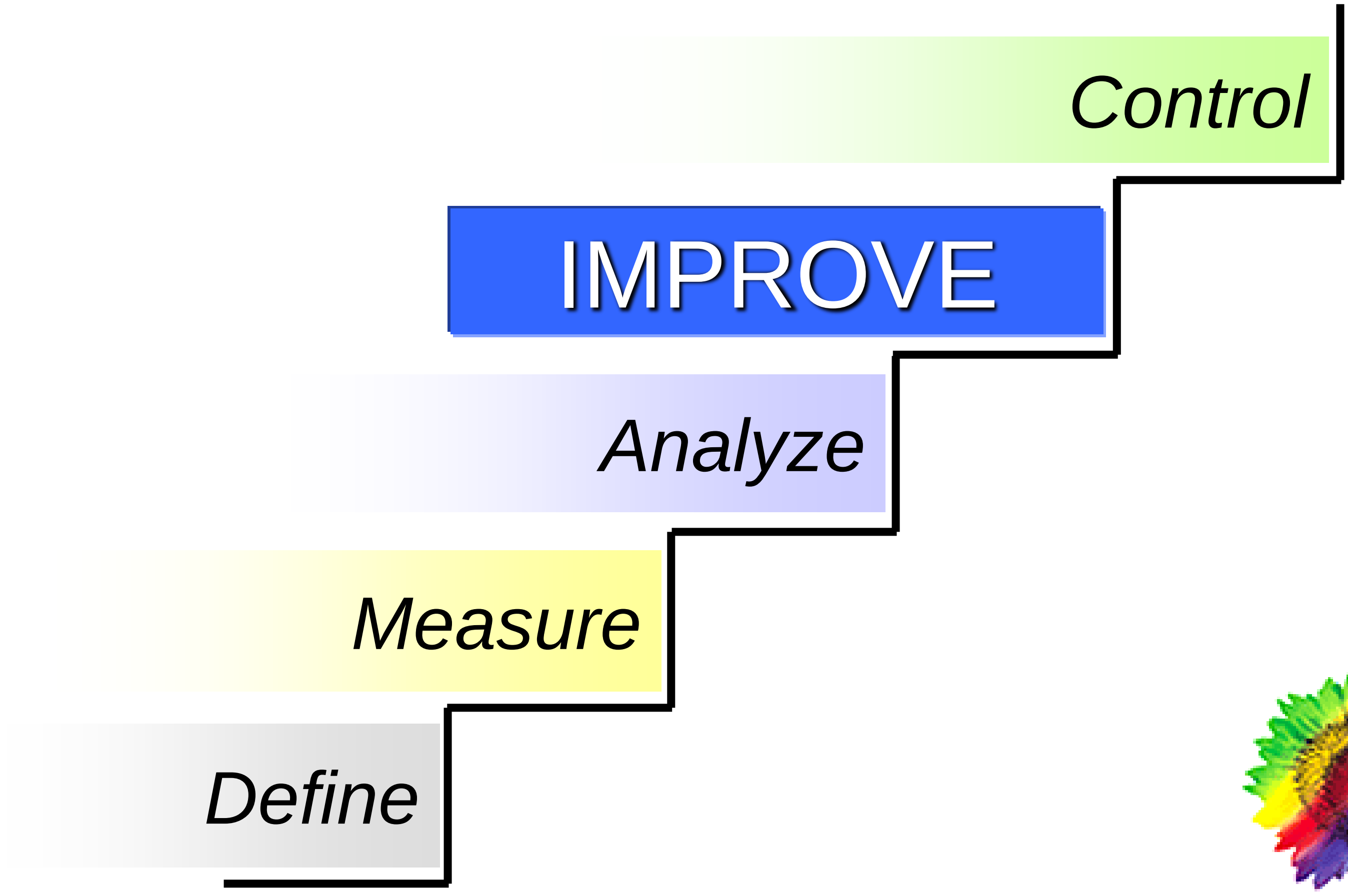
- Even though, project teams may *identify* potential X's using Brainstorming / Fishbone, & use Regression / ANOVA / Chi-square to *prioritize* potential X's, they may still end up with X's that explain the variation in 'Y', but do not really cause that variation
- However, they may just be the real causes
- The real output of this step is to short-list potential X's that *may have* a causal relationship with 'Y', because a relationship between 'Y' & 'X' is a *necessary but not sufficient condition* for cause & effect
- If an 'X' is not a significant factor for 'Y', it should not be explored further, it is one of those *trivial many X's* project team would have identified
- A good job done in this step reduces the work in further steps
- We check for causation in the first step of *Improve* module through experimentation techniques

Tollgate - Analyze

- Baseline Process Sigma multiple / DPMO / Mean / Variance
- Target Process Sigma multiple / DPMO / Mean / Variance with statistical significance
- Prioritized list of potential X’s that contribute to variation in ‘Y’

Tollgate - Analyze

Six Sigma



WIPRO
Applying Thought

Means & Ends of a Process

DMAIC

- We have studied the transfer function in steps 4 & 5

$$Y = \mathbf{f}(X_1, X_2, X_3 \ldots\ldots X_n)$$

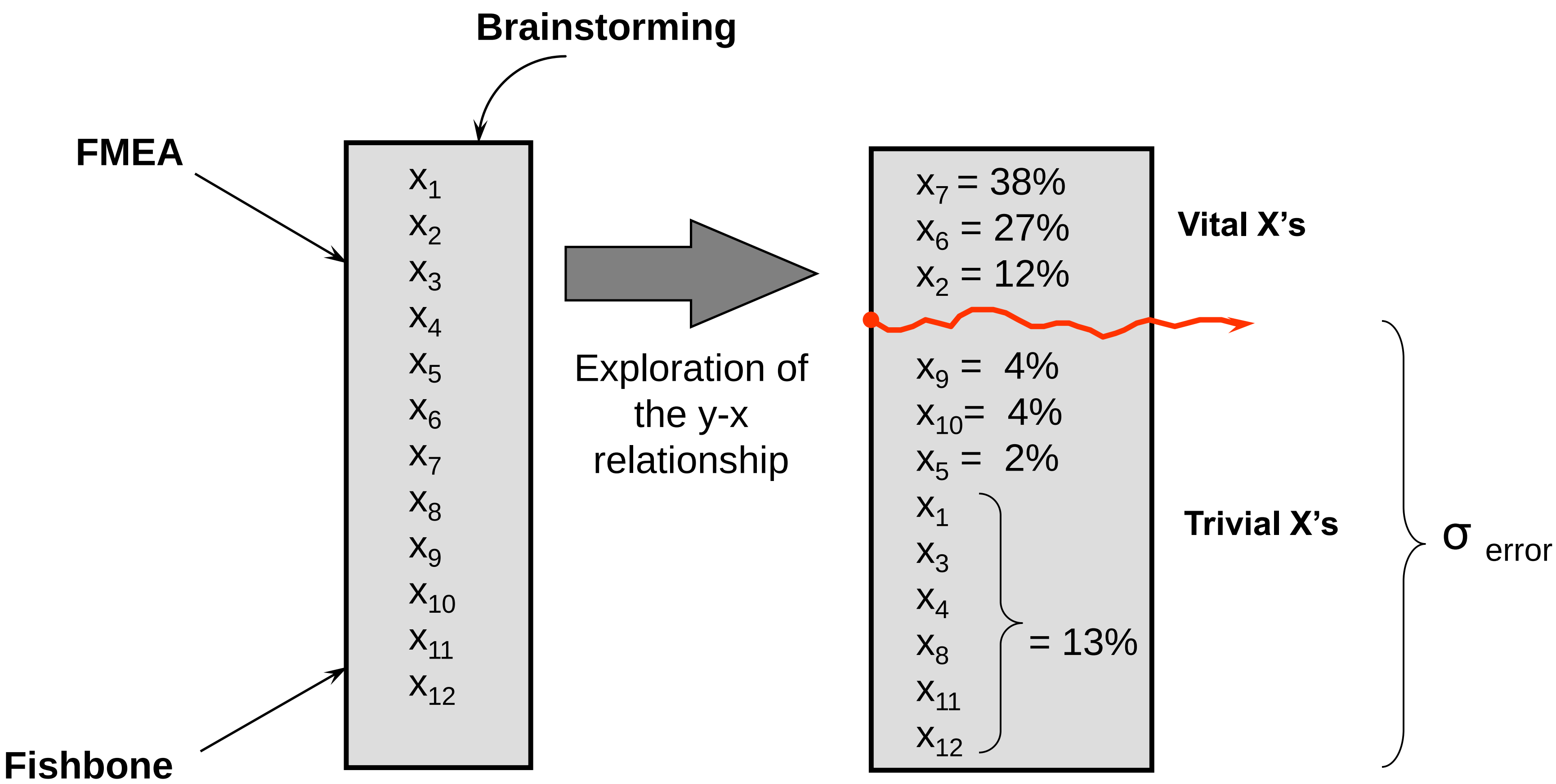
Y	X
Dependent	Independent
Process Output	Process Input / Step
Effect	Cause
Symptom	Problem
Monitor	Control

Deliverables of Improve Phase

- Quantitatively segregate the vital few X's
- Determine optimum levels of Vital Few X's
- Determine operating limits of vital few X's
- Map the new process
- Perform resistance analysis

Quantitatively Segregate the Vital Few X's

Creating a List of X's



Design of Experiments (DOE)

DMAIC

Tool

Design of experiments (DOE)

- Definition
  - Experimental Design is a structured proactive process for investigating the relationship between input and output factors. Multiple input factors are considered and controlled simultaneously to ensure that the *effects on the (multiple) output responses are causal and statistically significant*
- Origin
  - 1920’s with Sir R Fisher
  - Has an agriculture based nomenclature, e.g. treatments

Design of Experiments (DOE)

- Strategy of DOE
  - Define the Problem
  - Establish the Objective
  - Select the Response (Y)
  - Select the Factors (X's)
  - Choose the Factor Levels
  - Select the Experimental Design
  - Collect the Data
  - Analyze the Data
  - Draw Conclusions
  - Run Additional Experiments, if necessary
  - Achieve the Objective
- Experimental design is more than just analyzing data. It is a structured process for achieving an objective

Key Concepts

DMAIC

- Process experience must be used to design the experiment
  - Factors
  - Operating range
  - Number of levels
  - Repetition of experiments

DOE Nomenclature

DMAIC

DOE

Experiment Design

Factors

Response

Design

Level

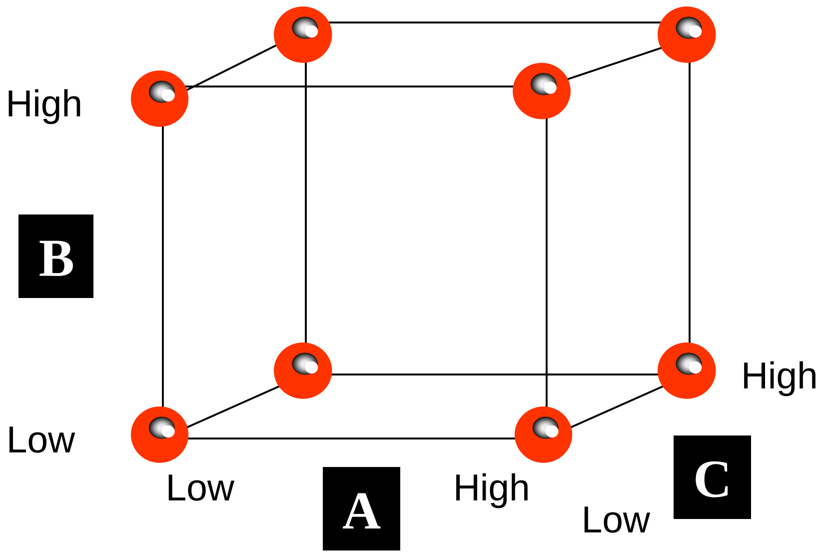
DOE Nomenclature

- Experiment Design
  - The formal plan for conducting the experiment is called the “experiment design” (also the “experiment pattern”)
  - It includes the choices of the responses, factors, levels, blocks, and treatments and the use of certain tools called planned grouping, randomization, replication
- Factors
  - A factor is one of the controlled or uncontrolled variables whose influence upon the response is being studied in the experiment. Factors are also known as the X’s
  - A factor may be quantitative, e.g., temperature in degrees, time seconds
  - A factor may also be qualitative, e.g., different machines, different operator, clean or not clean

Two Level & Three Factor Design

DMAIC

Graphical Illustration



Tabular Illustration

Trial	A	B	C
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

Creating Designs in Minitab

DMAIC

- Consider a washing machine whose cleaning efficiency is being studied. Three factors have been identified that affect the extent of cleaning:
  - Temperature of water (W)
  - Time elapsed in running the machine (T)
  - Concentration of cleaning agent (C)
- 2 levels are chosen for each of the factors
  - W Warm (-1) Hot (+1)
  - T Shorter (-1) Longer (+1)
  - C Lower (-1) Higher (+1)
- Response being measured is left out ‘dirt’ content in the clothes measured through a standard evaporation procedure

Creating Designs in Minitab

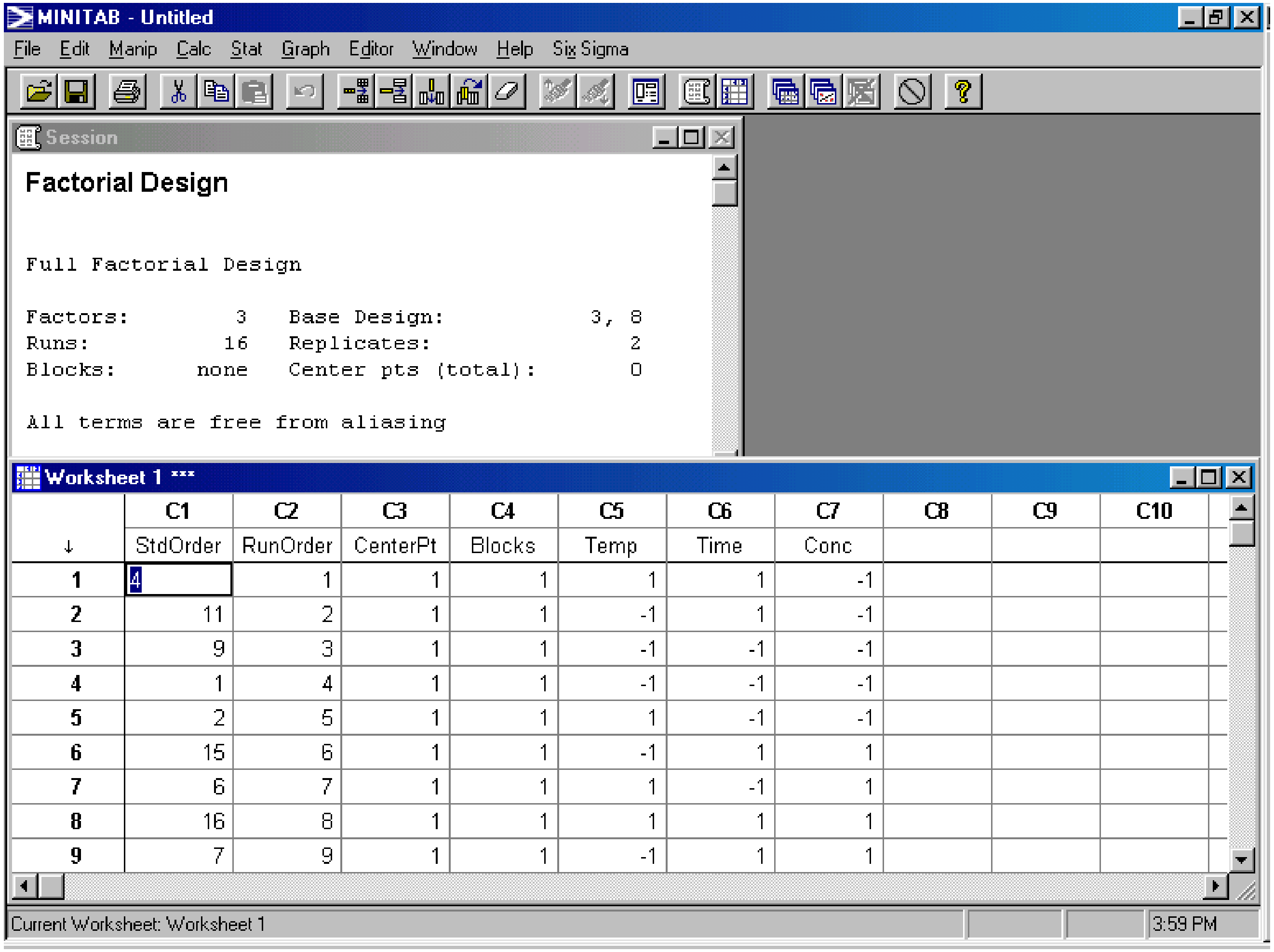
- Considering a full factorial 2^3 design, following is the ***design matrix:***

Trial	Temp (W)	Time (T)	Conc. (C)
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1

- Verify that it is a balanced & orthogonal design matrix
- The design matrix can be constructed in ***Minitab itself***
- Each trial can be replicated a number of times to provide an estimate of the error in the experimental process

Creating Designs in Minitab

- Completion of the design of the experiment results in following output:



Factorial Design

```
Full Factorial Design

Factors:         3    Base Design:         3, 8
Runs:           16    Replicates:             2
Blocks:       none    Center pts (total):     0

All terms are free from aliasing
```

↓	C1 StdOrder	C2 RunOrder	C3 CenterPt	C4 Blocks	C5 Temp	C6 Time	C7 Conc	C8	C9	C10
1	4	1	1	1	1	1	-1			
2	11	2	1	1	-1	1	-1			
3	9	3	1	1	-1	-1	-1			
4	1	4	1	1	-1	-1	-1			
5	2	5	1	1	1	-1	-1			
6	15	6	1	1	-1	1	1			
7	6	7	1	1	1	-1	1			
8	16	8	1	1	1	1	1			
9	7	9	1	1	-1	1	1			

Creating Designs in Minitab

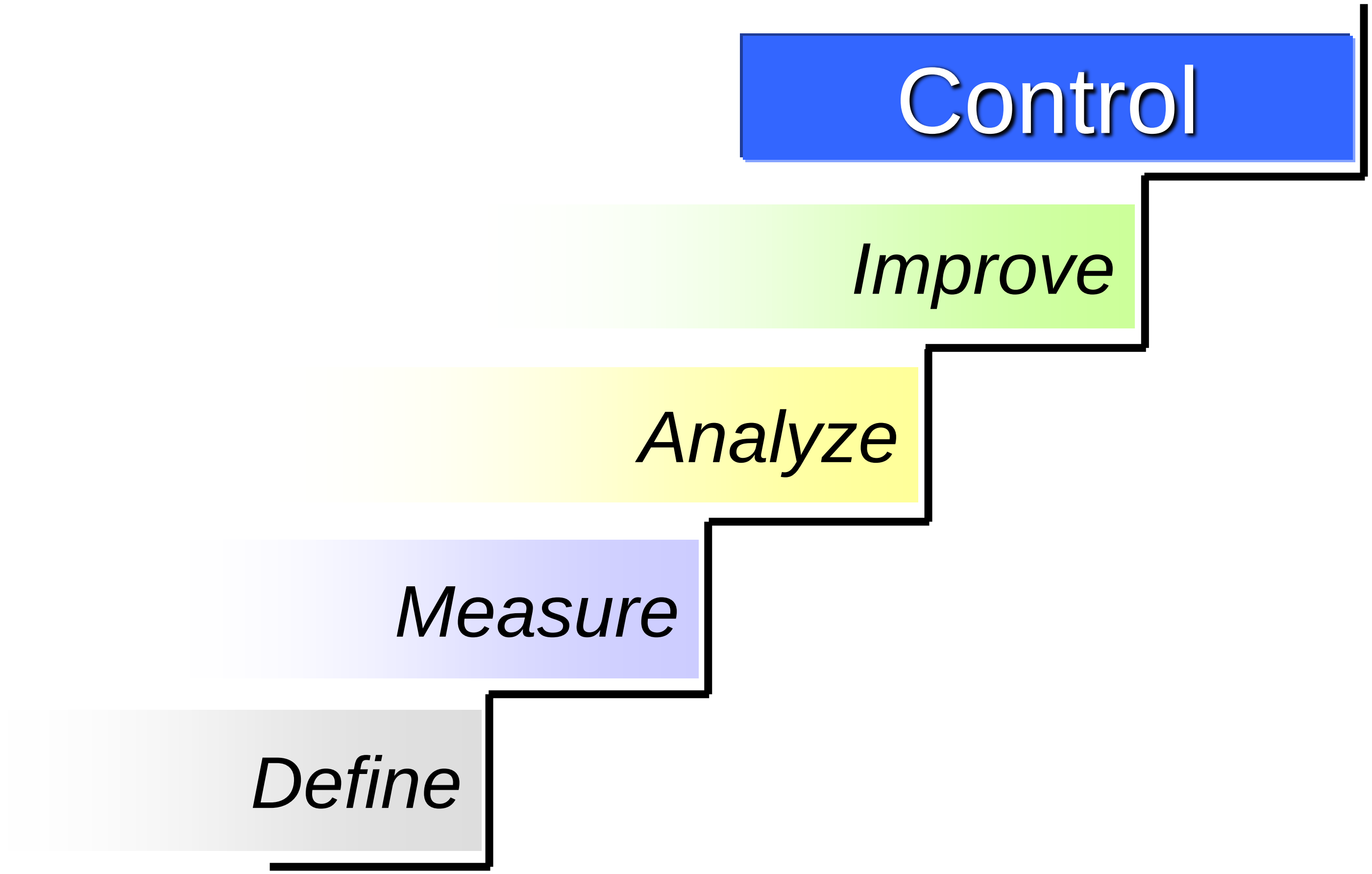
DMAIC

- Experiment is run as per the ***randomized run order*** as suggested by Minitab & following response is observed

Trial	Temp (W)	Time (T)	Conc. (C)	Dirt
1	1	1	-1	41
2	-1	1	-1	50
3	-1	-1	-1	65
4	-1	-1	-1	65
5	1	-1	-1	44
6	-1	1	1	50
7	1	-1	1	45
8	1	1	1	41
9	-1	1	1	52
10	-1	-1	1	58
11	-1	-1	1	61
12	1	1	-1	45
13	1	1	1	47
14	1	-1	-1	42
15	-1	1	-1	43
16	1	-1	1	43

- Data for ‘dirt’ is entered in Minitab

Six Sigma



Steps in Mistake-Proofing

DMAIC

Step		
1	Identify Problems	▸ Brainstorming ▸ Customer complaints ▸ Error reports ▸ Rejection analysis
2	Prioritize Problems	▸ FMEA ▸ Cost & Effort estimate ▸ COPQ
3	Identify Root-cause	▸ Don’t cover-up ▸ Don’t treat symptoms ▸ Correct errors at source
4	Find Solutions	▸ Make it impossible to go wrong ▸ Be creative – think out of the box
5	Measure Outcome	▸ Have errors been eliminated? ▸ What is the financial impact?

Mistake-Proofing Techniques

Technique	Prevention	Detection
SHUTDOWN	A mistake is about to be made	A mistake has been made
CONTROL	Defects are impossible	Defective parts can't move to next process step
WARNING	Something is about to go wrong	Something has just gone wrong

Mistake-Proofing Techniques - *Examples*

DMAIC

Technique	Prevention	Detection
SHUTDOWN	Cameras that don't click if the shutter is on	Air-conditioners trip when detect slight over-heating
CONTROL	ATM does not accept a card inserted wrongly	Quality check at each point in the assembly
WARNING	Car security system alerting the driver that all doors are not closed	Smoke detectors

Statistical Process Control (SPC)

DMAIC

- SPC was developed by Walter A. Shewhart in 1924
- Historically, SPC has been used to monitor & control output 'Y'
- In DMAIC, we apply SPC to control X's (remember 'Y' is only monitored)
- However, sometimes applying SPC to 'Y' can also be beneficial in detecting trends
- About SPC
  - Aids visual monitoring & controlling
  - Depends heavily on data collection

Tool

Statistical Process Control

Key Concepts

DMAIC

- SPC tools - control charts, are used to monitor the vital few X's on an ongoing basis to ensure that 'Y' improvement is sustained

- SPC uses statistical tools to help the operator visualize, analyze and control the process in a consistent manner

- SPC is best applied to proactively manage process X's, rather than as a means of detecting and reacting to process 'Y'

- While SPC is an effective for managing a process, the data collection scheme is the key to effective application.

Foundation of SPC

- It forms data into patterns which can be statistically tested and, as a result, leads to information about the behavior of process output / control variable characteristics

- It graphically represents output / control variable performance

- It detects assignable causes which affects the central tendency and/or variability of the cause system

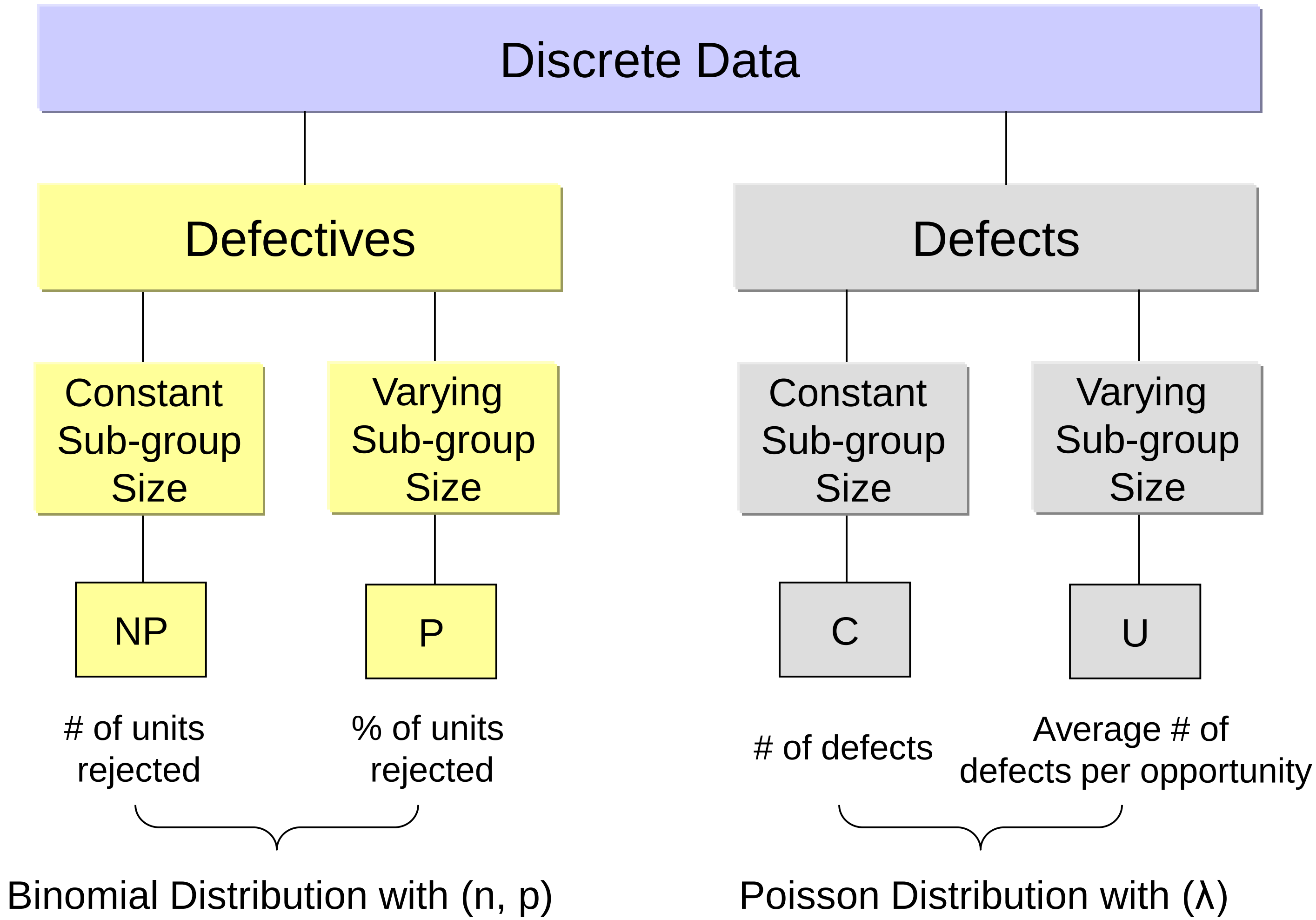
- It serves as a probability-based decision making tool

- It points out where action can be taken with known degrees of risk and confidence

Benefits of SPC

SPC applied on 'Y'	SPC applied on 'X'
Separates special & common cause variability	Recognizes unintended change in process activities quickly
Recognizes unintended change in process output quickly	Enables maintenance within operating limits
Identifies stable zone for calculating process capability	Provides useful internal information for continuous improvement
Provides useful external information	

Choosing An Appropriate Control Chart



I & MR Control Chart

DMAIC

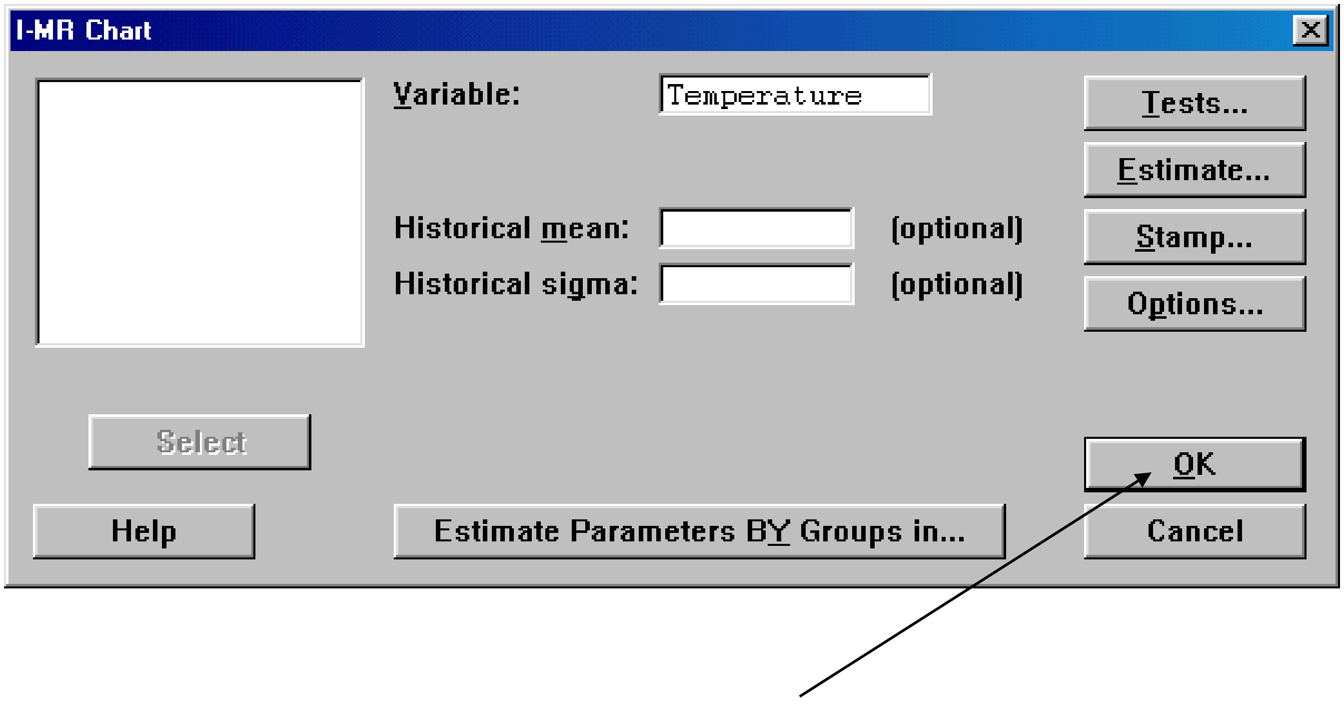
- Temperature of the cleaning agent is a vital ‘X’ to successfully meet the requirements of t cleaning efficiency. This is monitored periodically to keep it within desired operating range.

- Data on temperature (in ^{0}C) is collected over several hours

Hour	Temperature
1	65
2	69
3	67
4	66
5	63
6	70
7	71
8	68
9	64
10	69
11	63
12	68
13	84
14	81
15	68

I & MR Control Chart

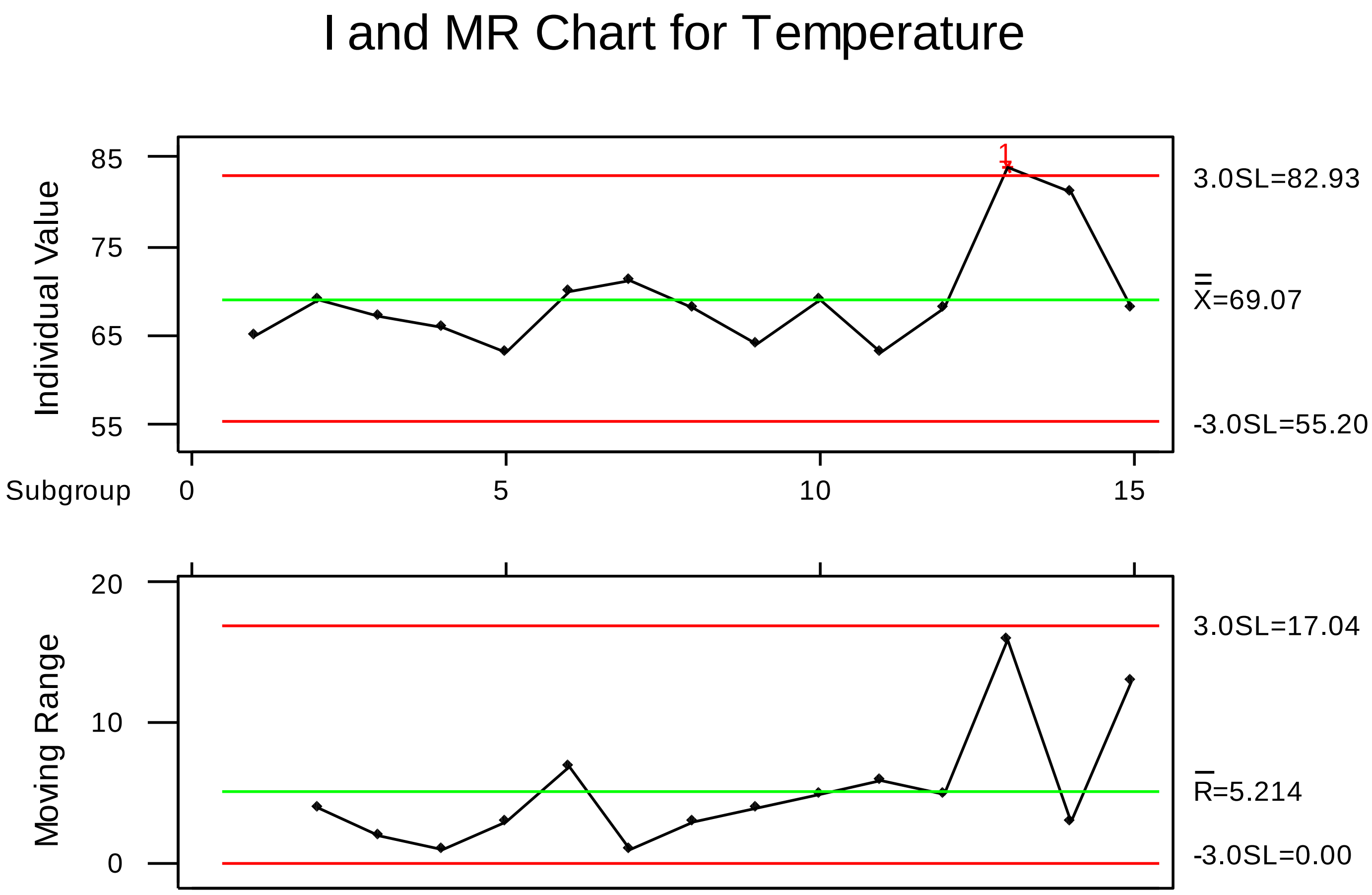
- STAT > CONTROL CHARTS > I-MR



Click on OK

I & MR Control Chart

- Minitab gives the following output:



I & MR Control Chart

DMAIC

- Interpreting Results
  - Mean of the given data points is 69.07 which is the central line of the top chart
  - Standard deviation of the data is 4.62 (S_{ST}) which results in three sigma control limits of
    UCL = 69.07 + 13.86 = 82.93 & LCL = 69.07 – 13.86 = 55.21
  - Note that S_{ST} can not be calculated from usual standard deviation formula since there are no sub-groups (you can use capability analysis)
  - First point in the lower chart is the absolute difference between first & second data point
    = I 69 – 65 I = 4
  - Second point in the lower chart is the absolute difference between second & third data point
    = I 67 – 69 I = 2…….& so on. Mean of all such differential points is 5.21
  - Test fails at point 13 (value 84) that is outside the upper control limit
  - However, it seems to be an outlier & hence, some more readings must be taken to observe the trend

I & MR Control Chart

DMAIC

- Interpreting Results
  - If we specify the population mean as known historically, Minitab treats that as the center line
  - Similarly, we can also specify population standard deviation
  - S_{ST} can also be calculated in a different way --

$$S_{ST} = \frac{\overline{R} / d_2}{n^{0.5}} = \frac{5.21 / 1.128}{1} = 4.62$$

  - In other words, LCL & UCL can be calculated as

$$LCL = \overline{X} - \frac{3 * \overline{R} / d_2}{n^{0.5}} \qquad UCL = \overline{X} + \frac{3 * \overline{R} / d_2}{n^{0.5}}$$

  - We can replace $3 / (d_2 * n^{0.5})$ as A_2
  - Control limits on moving range are calculated as

$$LCL = D_3\overline{R} \qquad UCL = D_4\overline{R}$$

Summary of I & MR Control Chart

DMAIC

$LCL_X = \bar{X} - A_2 \bar{R}$

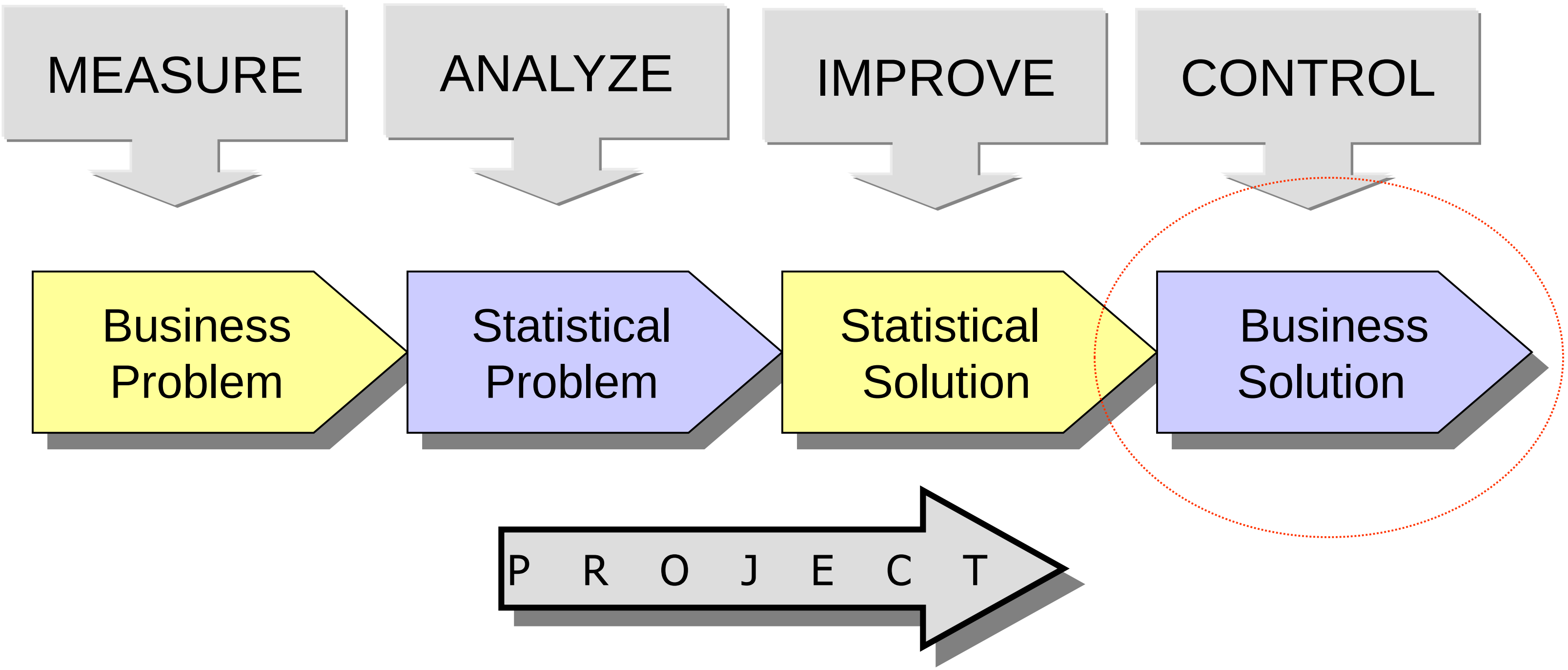
$UCL_X = \bar{X} + A_2 \bar{R}$

$LCL_{MR} = D_3 \bar{R}$

$UCL_{MR} = D_4 \bar{R}$

subgroup-size (n) = 1

Problem Solving Flow



Business Problem:	Low production yield
Statistical Problem:	Low mean, high deviation
Statistical Solution:	Change raw material spec's
Business Solution:	Develop new vendor

Sign-off The Project Closure Form

Project Closure

DMAIC

- All Six Sigma projects must be closed with sign-offs

DMAIC Project Closure Form

(Tick / fill all that apply)

Project Title:			
Champion:			
Green Belt:		**Black Belt:**	
Customer CTQ:		**Internal CTQ:**	

Baseline	**Target**	**Achieved**	**Open Action Items**	
			Description	*Owner*

Vital X's	**Best Setting**	**Lower Operating Limit**	**Upper Operating Limit**

Realised Financial Benefits:		(attach details)
Process Sustenance Owner:		

Signatures:

Champion: ____________________

Black Belt: ____________________

Finance: ____________________

Green Belt: ____________________

Tool

Project Closure Template