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# Lean Six Sigma Green Belt training programme

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# Lean Six Sigma

# Lean Six Sigma Green Belt Training Flowchart

## DEFINE – Day 1

### Concept Building

- Six Sigma and Lean Overview
- History and Applicability of LSS
- Juran and Deming Contribution
- DMAIC vs. DFSS
- Definition of GB, BB, MBB, Champion and Sponsor

### Project Charter

- Business Case
- Problem Statement (Do's and Don'ts)
- Project Scope
- Milestone
- Roles & Responsibilities

(Group Exercise)

### VOC - CTQ

- VOC to CTQ
- Affinity Diagram
- Kano Model

(Group Exercise on the identified CTQs)

### Process Mapping

- SIPOC / COPIS
- As-Is (Till Uncontrollable)
- Observations
- Affirmations

(Group Exercise)

### Introduction to Lean

- Introduction to Lean



# Lean Six Sigma Green Belt Training Flowchart

## MEASURE – Day 2

### Understanding Data

- Types of data
- Data Distribution
- Sampling techniques

### Introduction to Minitab

- Introduction to Minitab

### MSA + Data Collection Plan

- Gage R & R
- % Study Variation
- 6 graphs (Minitab output)
- Attribute Agreement Analysis (only overview)

(Demonstration of GRR on Minitab with example)

- Data collection plan

### Understanding Variation

- Types of variation (Common and Special cause variation)
- Histogram
- Box Plot

(Demonstration of the graphical tools on Minitab with example)

### Checking Stability

- Run Charts
  - Causes
  - Patterns
- Normality
- 6 Sigma interpretation (99.999963%)

### Checking Capability

- Yield
- Sigma calculation (DPMO)
- Cp, Cpk

(Exercise to calculate DPMO, Cpk)

# Lean Six Sigma Green Belt Training Flowchart

## LEAN & ANALYZE – Day 3

### Causal Analysis

- Fishbone - 6M's
- 5 Why's
- Control Impact Matrix
- Pareto Chart / Analysis

(Group Exercise with 1 CTQ)

### Types of Waste

- Principles of Lean
- TIMWOOD
- 5 S

### Hypothesis Testing

- Introduction to Hypothesis
- Test of Means (1 sample t-test, 2 sample t-test, One way ANOVA, Paired t-test)
- Test of Proportion (1 proportion test, 2 proportion test, Chi Square test of association)

(Demonstration of Hypothesis Testing for above on Minitab with example)

### Correlation & Regression

- Introduction to Correlation and Simple Linear Regression

(Demonstration of Hypothesis Testing for above on Minitab with Salary vs. Experience example)



# Lean Six Sigma Green Belt Training Flowchart

## IMPROVE – Day 4

### Idea Generation

- TRIZ
- Brainstorming
- Channeling, Analogy, Anti-Solution, Brain writing etc.

### Solution Selection

- Payoff Matrix
- Nominal Group Technique
- Criteria Based Matrix

### Solutions with Lean

- Kanban
- Kaizen
- Poka Yoke

### Risk Proofing

- FMEA
- Example on FMEA

### Pilot

- Pilot implementation plan
- Cost Benefit Analysis (Pre CBA / Post CBA)

# Lean Six Sigma Green Belt Training Flowchart

**CONTROL – Day 4**

**Control** → **SPC** → **Project Closure**

**Control**
- Why Control?
- Control Response Document

**SPC**
- Introduction to Control Charts
- Types of Control Charts (Demonstration on Minitab with example)

**Project Closure**
- Process Management System
- Control Response Plan



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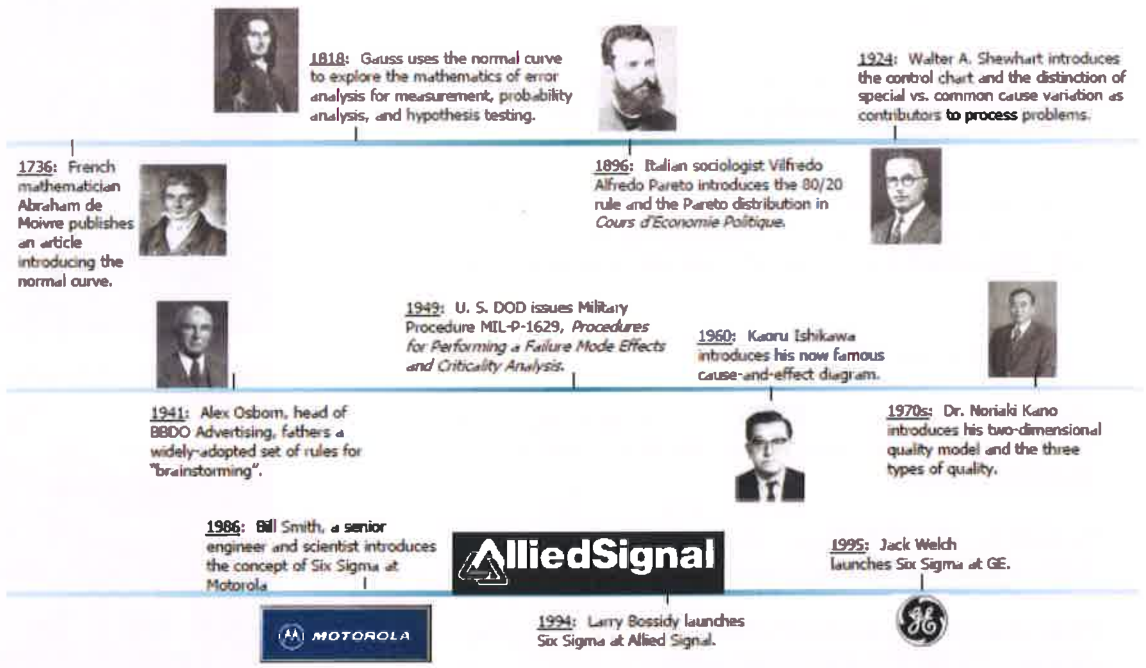
# Quality Gurus

# Quality Gurus




***Source: Slideshare.net***



# Quality Gurus

### Dr. Walter Shewhart (1891-1967)

- Known for framing the problems of failures in terms of "assignable causes" and "chance cause" variation.
- Known for the introduction of the SPC – control charts as a tool for distinguishing between assignable and chance cause variation.
- Invented control charts which are widely used across industries to monitor processes and to determine when there are changes in a process.
- Known for the introduction of the continuous improvement cycle – Plan –Do –Check –Act (PDCA)

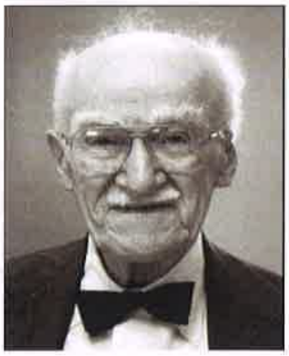
# Quality Gurus

### Dr. W Edward Deming (1900-1993)

- Made a significant contribution to Japan's reputation for innovative, high quality products and for its economic power.
- Championed the work of Walter Shewhart including statistical process control, operational definitions and "Shewhart Cycle" which had evolved into PDSA (Plan-Do-Study-Act).

### Dr. Joseph M Juran (1904-2008)

- Made a significant contribution to Japan's reputation for innovative, high quality products and for its economic power.
- Known for Juran Trilogy – *quality planning, quality control and quality improvement*
- First to apply the work of Vilfredo Pareto to quality issues - *"vital few and trivial many".*





# Quality Gurus

### Dr. Kaoru Ishikawa (1915-1989)

- Considered as a key figure in the development of quality initiatives in Japan, particularly the quality circle.
- Best known for the Ishikawa or fishbone or cause and effect diagram often used in the industrial processes analysis.
- Translated, integrated and expanded the management concepts of W. Edwards Deming and Joseph M. Juran into the Japanese system.

### Philip B Crosby (1928-2001)

Philip Crosby is known for his four absolutes of quality management

- Quality means conformance to requirements
- Quality comes from prevention
- Quality performance standard is zero defects
- Quality measurement is the price of non-conformance

# Six Sigma History

## Evolution of Six Sigma

What does Quality Mean?

- Detecting and correcting mistakes in the product such that it meets compliance standards.

OR

- Preventing defects in the first place through manufacturing controls and product design such that it meets performance standards.

# Evolution of Six Sigma

"The real problem at Motorola is that our quality stinks"

……1979, Art Sundry

"A product found defective and corrected during manufacturing had high probability of failing during early use by customer"

……1985, Bill Smith


- Late 1970s - Motorola started experimenting with problem solving through statistical analysis
- Motorola started Six Sigma approach to achieve it's one of the top ten corporate goal of improving the quality by ten times within five years in 1981.
- The term "Six Sigma" was coined by Bill Smith, an engineer with Motorola
- 1987 - Motorola officially launched it's Six Sigma program as follows:
  - Improve quality 10 times by 1989
  - Improve quality 100 times by 1991
  - Achieve six sigma (3.4 DPMO) performance by 1992
  - Motorola won the first Malcolm Baldridge National Quality Award in 1988.



# Origin of Six Sigma

Beginning of a new era at Motorola..

- Improve the quality
- Lower production cost
- Lower production time
- Focus on how the product was designed and made

***Motorola gained a return of USD 800 million in two years***

# Growth of Six Sigma - GE

- Jack Welch launched Six Sigma at GE in Jan,1996
- 1998/99 - Green Belt exam certification became the criteria for management promotions at GE
- 2002/03 - Green Belt certification became the criteria for promotion to management roles at GE
- Scope of six sigma initiative has changed from 'manufacturing' to the entire business – service, product design and innovation.

***Source: Internet***



# Focus of Six Sigma

- Reduce Variation
- Reduce Defects
- Delighting Customer
- Reduce Cost
- Reduce Cycle Time

# Sigma Levels and PPM


| Six Sigma | Part per Million (PPM) |
|---|---|
| σ 2 | 3,08,000 |
| σ 3 | 6,6800 |
| σ 4 | 6,210 |
| σ 5 | 230 |
| σ 6 | 3.4 |

**Mumbai's Dabbawala are at more than Six Sigma level**



# Six Sigma - Its significance

| 99 % Good (2.8 Sigma) | 99.99967 % Good (6 Sigma) |
|---|---|
| 20,000 lost articles of mail/ hour | Seven articles lost per hour |
| Unsafe drinking water for almost 15 minutes each day | One unsafe minute every seven months |
| 5,000 incorrect surgical operations per week | 1.7 incorrect operations per week |
| Two short or long landings at most major airports each day | One short or long landing every five years |
| 200,000 wrong drug prescriptions each year | 68 wrong prescriptions per year |
| No electricity for almost seven hours each month | One hour without electricity every 34 years |

# What is Six Sigma?

**Sigma is a letter in the Greek alphabet**

## Metric

A **metric** that demonstrates quality levels at 99.99967 per cent performance for processes

## Benchmark

A **benchmark** for product and process capability on a quality basis

## Tool

A practical application of statistical **'tools'** to help define, measure, analyze, improve, and control the processes

## Commitment

A **commitment** to customers to offer the highest quality, reduced cost products



# Multiple meanings of Sigma

## Standard deviation

- The Greek symbol 'sigma' which means standard deviation.
- Is a measure of variation

## Process capability

- A statistical measure of a process's ability to meet customer requirements (CTQs).
- Process Sigma= 6σ equates to 3.4 defects per million opportunities

## Management philosophy

- View processes/measures completely from a customer point of view
- Continual improvement
- Integration of quality and daily work
- Satisfying customer needs profitably

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# Six Sigma Organization

## Six Sigma Team

- Apex Council
- Champion or Sponsor
- Process owner
- Master Black Belt
- Black Belt
- Green Belt
- Team Members

# Apex Council

**Top Management:**

- Accountable for Six Sigma business results
- Develop a strong case for Six Sigma
- Plan and actively participate in implementation
- Create a vision and market "change"; Become a powerful advocate
- Set clear (SMART) objectives
- Hold itself and others accountable
- Demand specific measures of results
- Communicate results (including setbacks)
- Helping to quantify the impact of Six Sigma efforts on bottom line.



# Champion or Sponsor

**Senior Manager:**

- Oversees a Six Sigma project
- Is accountable to the Apex Council
- Sets rationale and goal for project
- Be open to changes in project definitions
- Find resources (time, support, money) for team
- Help the team overcome roadblocks; smoothen implementation
- Focus on data-driven management
- Identify and recruit other key players
- Assist in identifying and developing training materials

# Process Owner

**Functional Head:**

- Implements solutions through Black Belts and project teams
- Provide resources and helps resolve conflicts
- Accountable to the Apex Council
- Owns end-to-end process
- Sets goals for projects
- Project review: timeline and project is on track
- Responsible for holding the gains.



# Master Black Belt

**Six Sigma Coach:**

- Advise and mentor Black Belts and teams
- Communicate with champions and apex council
- Establish and adhere to a schedule for projects
- Deal with resistance to Six Sigma
- Resolve team conflicts
- Estimate, measure, and validate savings
- Gather and analyze data on team activities
- Plan and execute training
- Help teams promote and celebrate successes
- Document overall progress of Six Sigma.

# Black Belt

**Facilitator:**

- Six Sigma implementation experts with the ability to develop, coach, and lead multiple cross-functional process improvement teams
- Use tools to quickly and efficiently drive improvement
- Facilitate to keep team focused on the project objective
- Ensure that the Six Sigma methods are followed
- Help teams learn and understand Six Sigma tools and techniques through regular project reviews
- Responsible for the ultimate success of the project
- Trains and develops Green Belts
- Spread Six Sigma awareness throughout the organization.



# Green Belt

**Project Team Leaders:**

- Lead and Execute Six Sigma as part of their daily jobs
- Keep the project team focused on the project goal
- Extract equal participation from all team members. Counsel non participating team members and motivate them to participate
- Ensure discipline of Team Meetings is followed and that every meeting starts with an Agenda. Ensure MOM is distributed the same day
- Regularly follow up with team members to ensure that assigned tasks are completed on time
- Manage conflicts and seek intervention of Process Owner / Champion if necessary
- Dual responsibility of being process experts as well as trained resource on Six Sigma methods and quality tools

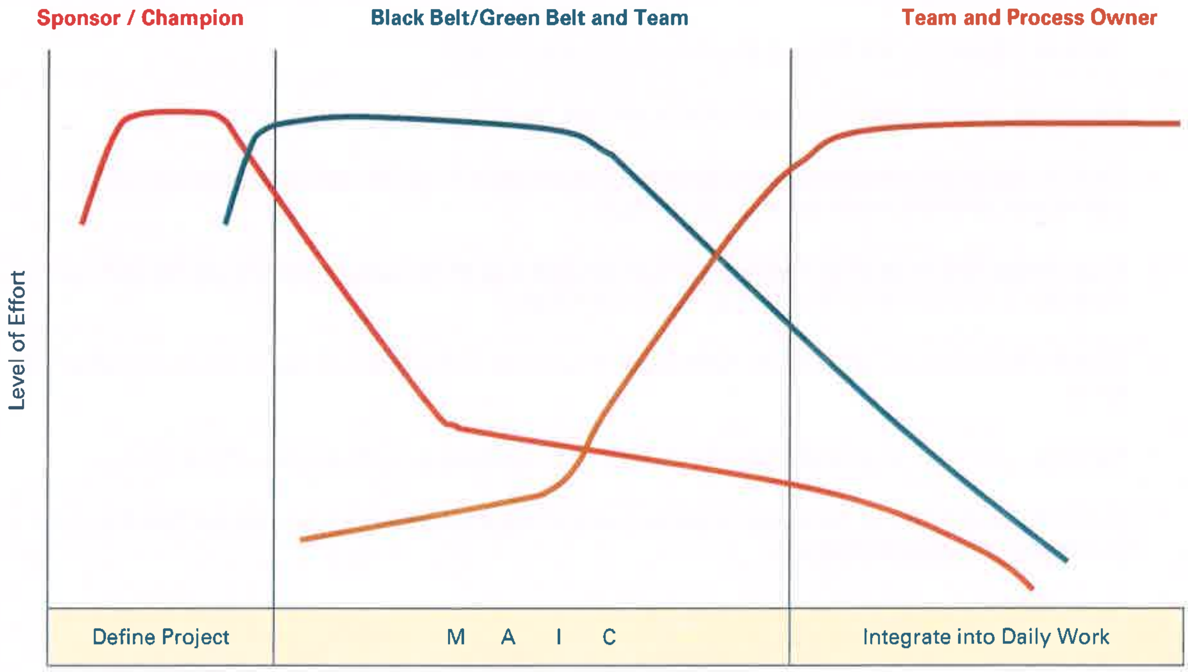
# Team Members

**Process Experts:**

- Team members are vital for success
- Good knowledge of product, process, customer
- Willing to work in teams
- Time to work on projects
- Active in Data collection
- Responsible for improvement
- High Participation.



# Typical Project Life Cycle and Effort



# Six sigma team roles and responsibilities

## Champion

- Leadership: overall initiative
- Project funding and resources
- Felicitate with rewards and recognition


## Master Black Belt

- Strategize on Six Sigma
- Mentor Black Belts
- Train resources on Six Sigma

## Black Belt

- Lead multiple Six Sigma project teams
- Provide insights on data collection and analysis
- Advise on the appropriate tools for each phase of DMAIC

## Green Belt

- Learn / Use Six Sigma Tools
- Work on Six Sigma Projects
- Integrate Six Sigma with their daily jobs

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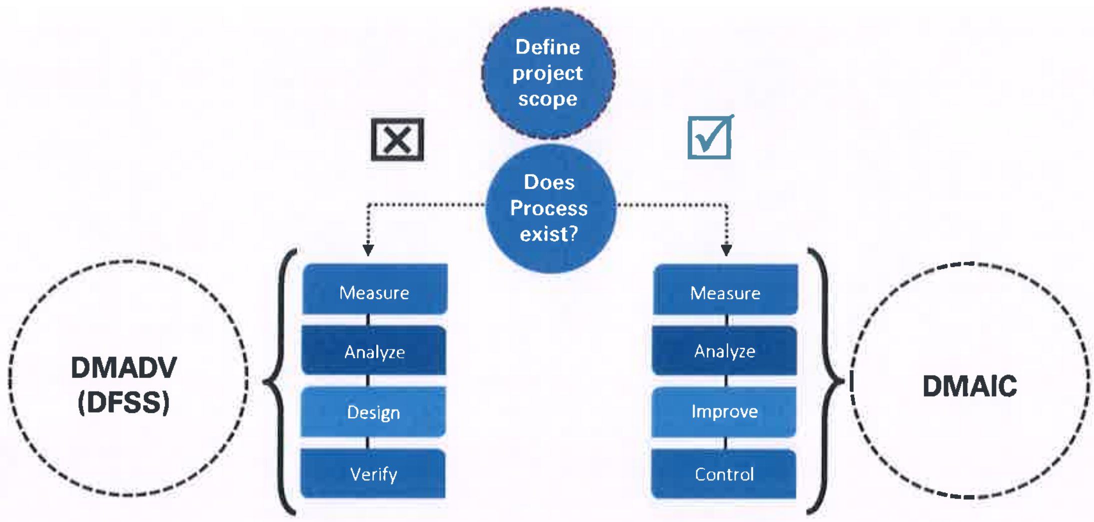
# DMAIC vs DMADV

# DMAIC Vs. DMADV






# DMAIC methodology

**Define**
Selection of performance characteristics critical in meeting customer requirements

**Measure**
Creation and validation of a measurement system

**Analyze**
Identification of sources of variation from the performance objectives

**Improve**
Discovery of process relationships and establishment of new procedures

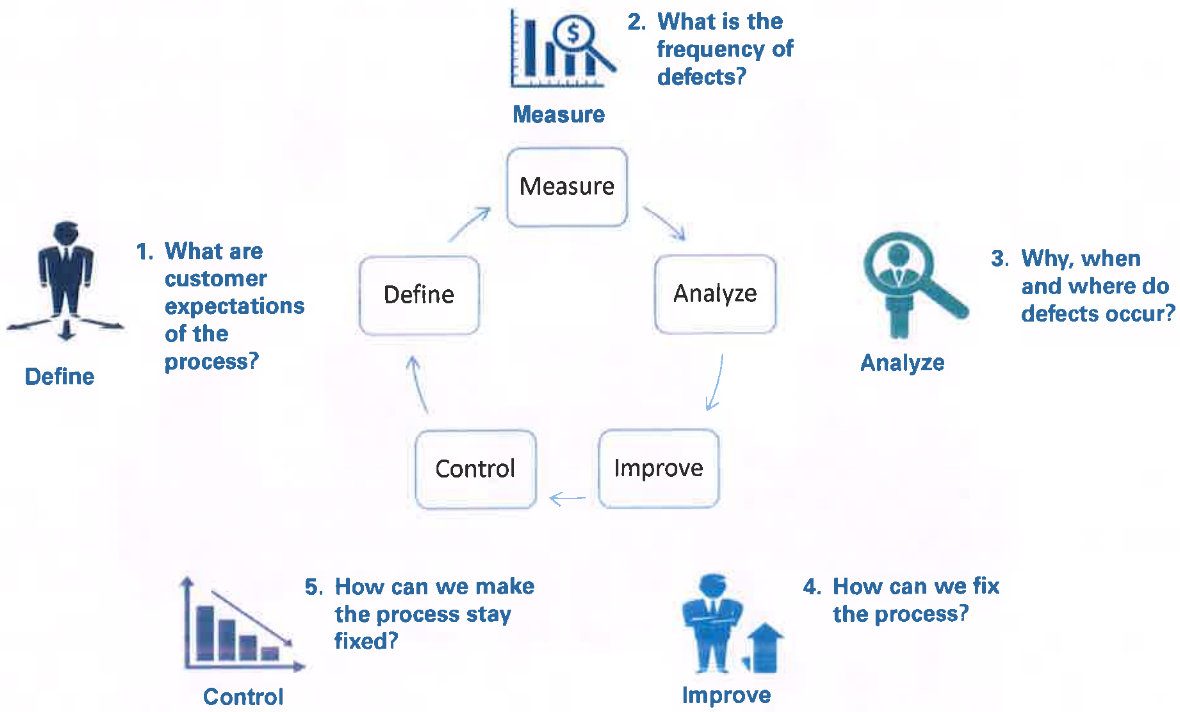
**Control**
Monitoring of implemented improvements to maintain gains and help ensure corrective actions are taken when necessary

# DMADV methodology

- **Define**
  Initiate, scope and plan the project
- **Measure**
  Understand customer needs and specify the CTQs
- **Analyze**
  Develop design concepts and high-level design
- **Design**
  Develop detailed design and control/test plan
- **Verify**
  Test design and implement full-scale processes



# DMAIC approach



# Define Phase

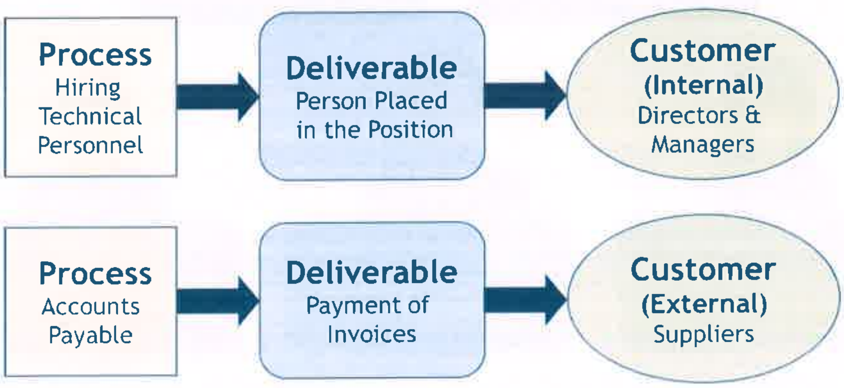
## Define Phase - Roadmap

Voice of Customer (VOC) → Determine Critical To Quality (CTQ) → Develop Project Charter → Map the process

# Voice of Customer (VOC)

## Who is your customer?

- Define products or services provided to customer
- Identify related process
- Are your customers – External and (or) Internal ??




**Customers can be Internal or External**

# What does your customer need?

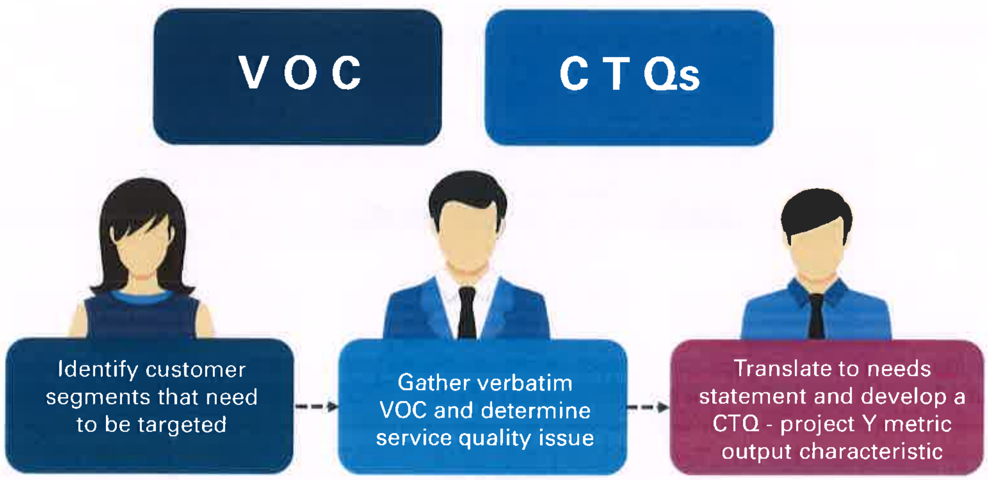
Before you approach to a business problem, ask these questions:

- How does the customer view my process?
- What does the customer look at to measure my performance?
- What does the customer need from me to fulfill his process?

The approach towards any problem must be ***"Outside-In"***, that is view the problem from customer's perspective.



# Translating VOC into CTQs




**CTQs**: Critical To Quality Characteristics

A specific measurable attribute of the output that is a key requirement for customer satisfaction

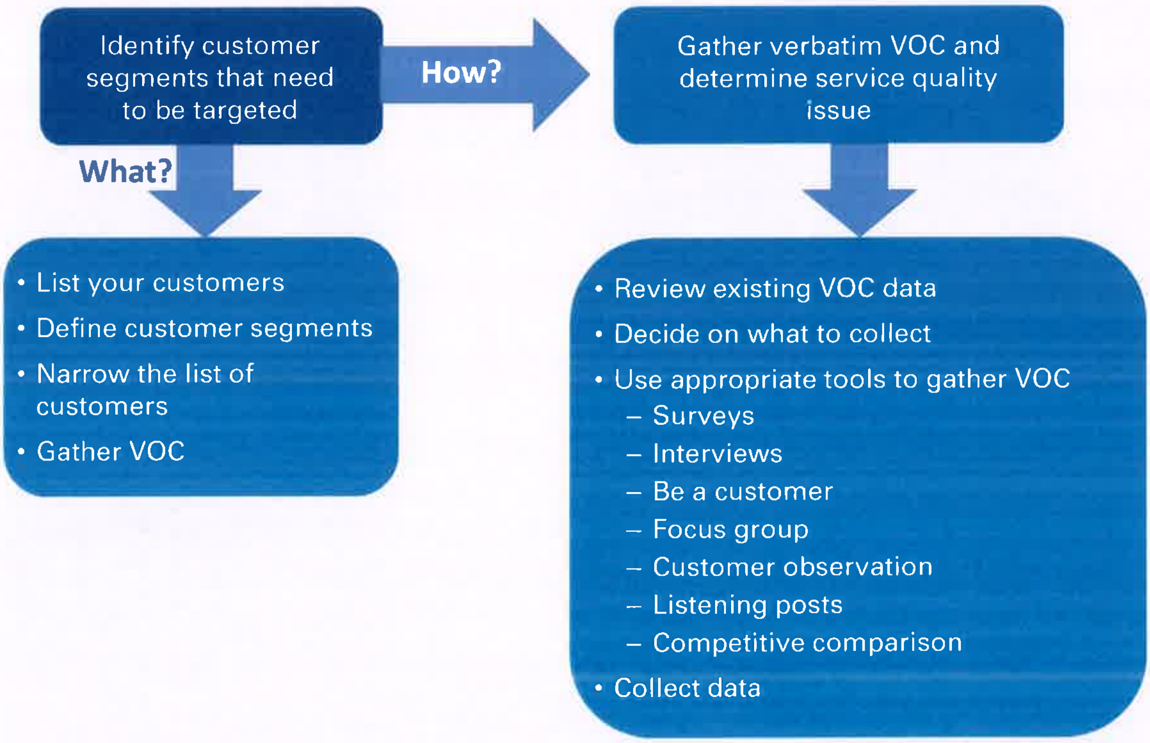
## Gather Voice Of Customer (VOC)

Key Considerations In Collecting Customer Data:

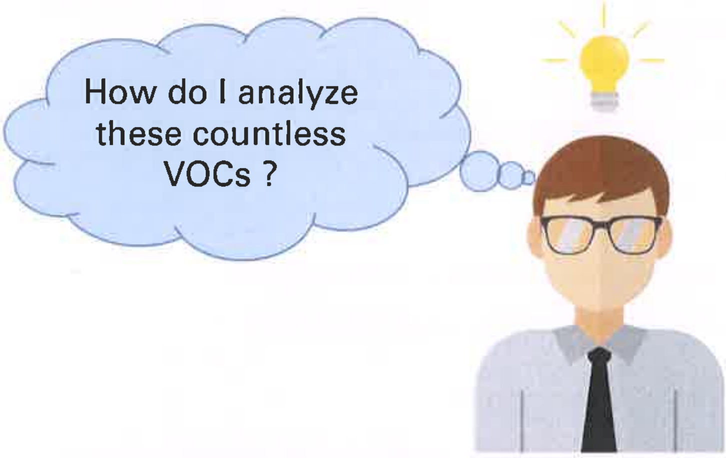
- Collector's bias may affect what is heard
- What contact/relationship do you have with the customer?
- What are your time constraints?
- What budget is available?
- How much certainty to do you need to move forward with the project?
- Ensure customer expectations are aligned with our intentions/actions



## Gather Voice Of Customer (VOC)

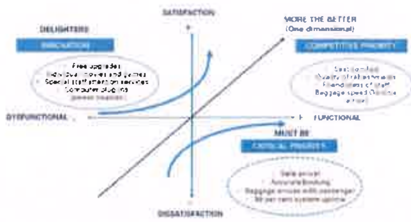


# Tools for analyzing VOC




**Affinity Diagram (> than 10 VOC)**


**Kano Model (up to 10 VOC)**



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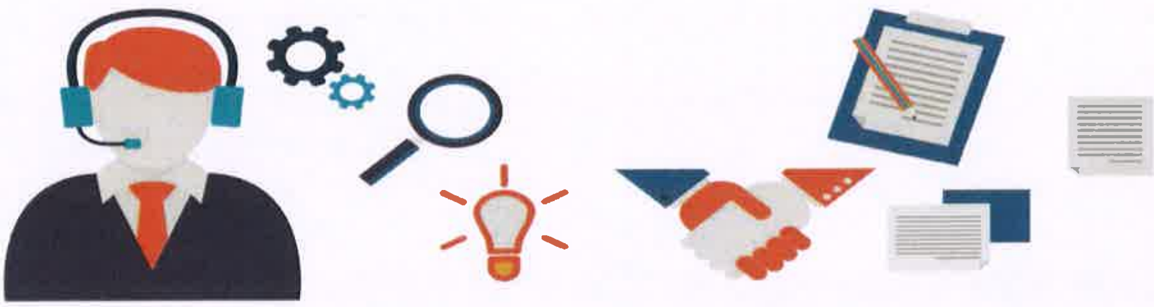
# Voice of Customer (VOC)

## Affinity Diagram

# Affinity Diagram

- Record each VOC on a post it note in bold letters
- Without talking sort the ideas simultaneously as a team into 5 –10 related groupings
- For each grouping create summary or header cards using consensuses
- Draw the final affinity diagram connecting all finalized header cards with their grouping





# Affinity diagram - An Example

| Flexible product | Easy process | Availability | Personal interface | Advice/consulting |
|---|---|---|---|---|
| Low interest rate | Easy application | Will come to my facility | Knowledgeable reps | Knows about my finances |
| Variable terms | Easy access to capital | Available outside normal business hours | Professional | Knows about my business |
| All charges clearly stated | Quick decision | Available when I need to talk | Friendly | Makes finance suggestions |
| Pay back when I want | Can apply over phone | Responsive to my calls | Make me feel comfortable | Cares about my business |
| No prepayment penalties/ charges | Know status of loan during application | Talk to one person | Patient during process | Has access to experts |
| Pre-approved credit | Know status of loan (post-approval) | Will come to my facility | Knowledgeable reps | Provides answers to questions |
| Variable terms | Preference if bank customer | Available outside normal business hours | Professional | Calls if problems arise |

**Organize VOC into broad categories**

# Voice of Customer (VOC)

## Kano Model

## Kano Model

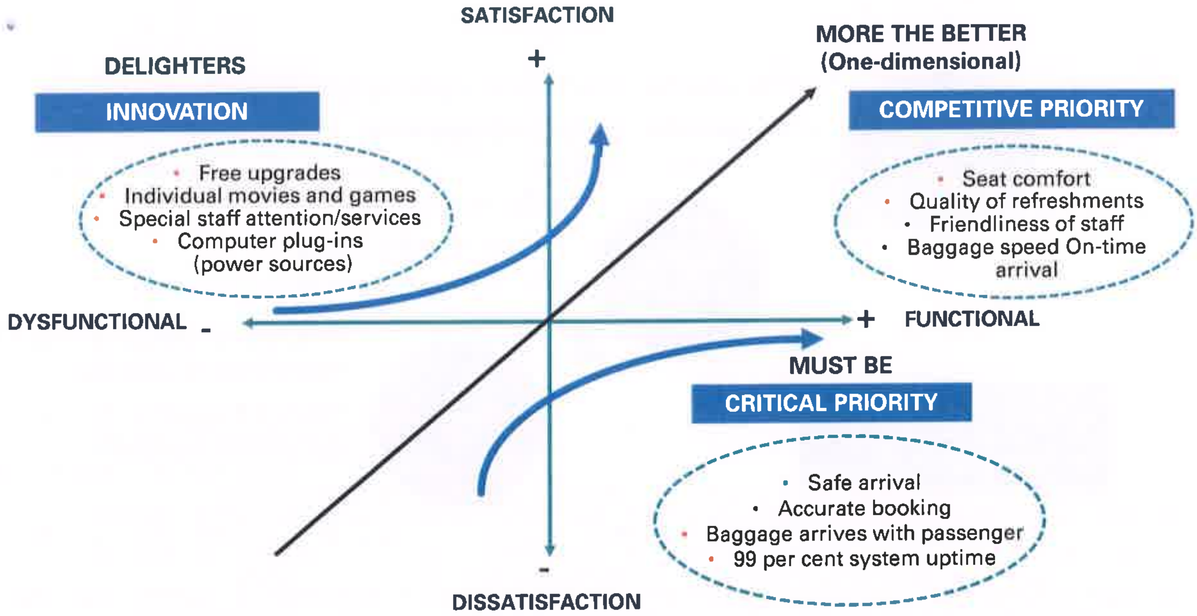
**Purpose:**

- To identify & prioritize the full range of the customers needs
- Kano model helps to describe which needs, if fulfilled contribute to customer dissatisfaction neutrality or delight
- Kano Model Identifies
  - Must be needs - Critical to customer expectation
  - More is better – Critical to customer satisfaction
  - Delighter – Converting wants to needs

**How to built ?**

- Gather sorted customer needs
- Classify the needs into 3 Categories
  - Must be
  - More the better
  - Delighters
- If there is insufficient data to enable the classification, collect addition data on VOC
- Prioritize the customer needs to develop the CTQ

# Prioritizing VOC for CTQ Identification - Kano model




**KANO MODEL HELPS TO PRIORITIZE OUR EFFORTS TOWARDS SATISFYING CUSTOMERS**



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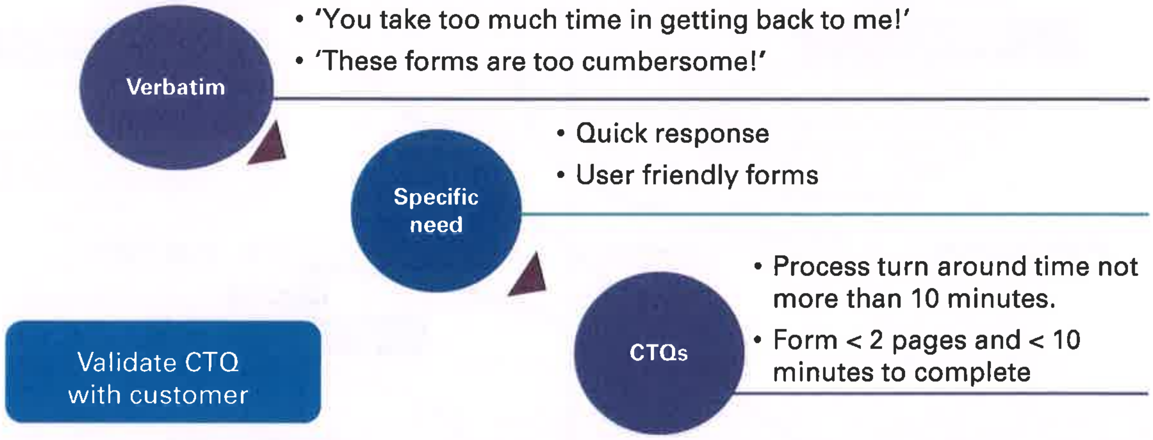
# Determine Critical To Quality (CTQ)

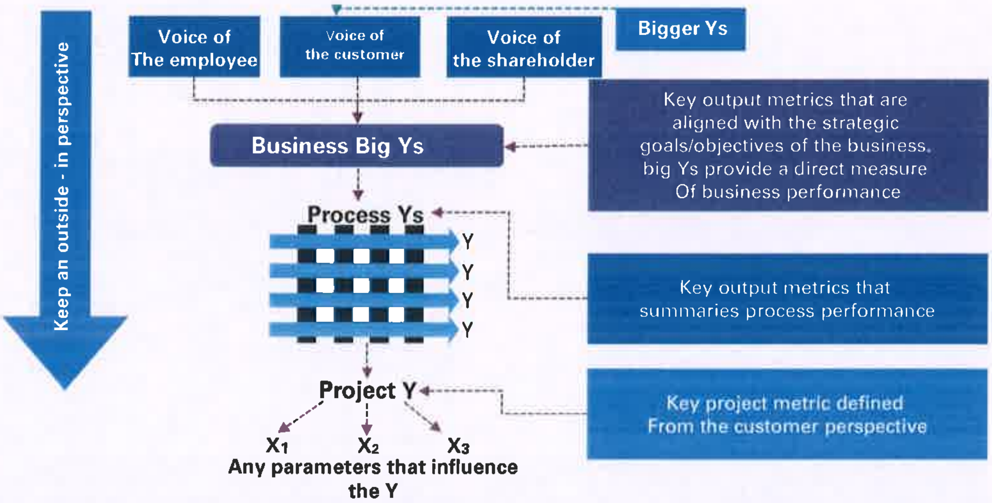
# Example: Translating VOC to CTQs




**What gets measured gets managed... help ensure measurable CTQs**



# Drivers of project selection




**Strong linkage between projects and big Y is important**

# Develop Project Charter

## What is a Charter?

One of the most important things necessary to get a team started on a footing is a charter

A Charter:

- Clarifies what is expected of the project
- Keep the team focused
- Keeps the team aligned with organizational priorities
- Transfers the project from the Champion to the Improvement Team
- Used as a tool by the Apex Council to review project progress

# Business case

- Why is this project worth doing?
- Why is it important to do now?
- What are the consequences of **not** doing this project?
- What activities have higher or equal priority?
- How does it fit with business initiatives and targets?



# Problem Statement

The purpose of the Problem Statement is to describe what is wrong

**Description of the "pain"**

- What is wrong or not meeting our customer's needs?
- When and where does the problem occur?
- How big is the problem?
- What's the impact of the problem?

# Problem Statement

### Key Points / Potential Pitfalls

- Is the problem based on observation (fact)
- Does the problem statement prejudge a root cause?
- Can data be collected by the team to verify and analyze the problem?
- Is the problem statement too narrowly or broadly defined?
- Is a solution included in the statement?
- Is the statement blaming any person or function?
- Would customers be happy if they knew we were working on this?



# Problem Statement - Examples

### Example 1

**Poor Statement**
*Because our customers are dissatisfied with our service, they are late paying their bills.*

**Improved Statement**
*In the last 6 months (when) 20% of our repeat customers – not first timers (where) – were over 60 days late (what) paying our invoices. When surveyed, all of these customers reported extreme dissatisfaction with our service (what). The current rate of late payments is up from 10% in 1990 and represents 30% of our outstanding receivables (how big). This negatively affects our operating cash flow (impact)*

### Example 2

**Poor Statement**
*Customers are unable to access the call center half the time leading to high revenue losses.*

**Improved Statement**
*During the year 2003, (when) 40% of our customers (extent) were unable to access the call center at the first attempt (what). This causes dissatisfaction to our customers and a loss of revenue opportunities to the organization (impact).*

# Goal Statement

- The Goal Statement defines the team's improvement objective
- Define the improvement the team is seeking to accomplish
- Must not assign blame, presume cause, or prescribe solution!
- Goal Statement has four parts:
  - Start with a verb (e.g., reduce, eliminate, control, increase)
  - Focus of project (cycle time, accuracy, etc.)
  - Has a definite Target (by 50%, by 75%)
  - Has a definite deadline (completion time)



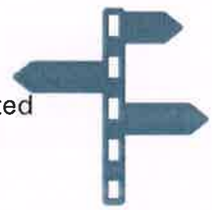

# Project Scope and Milestones / Project Plan

**Project Scope**

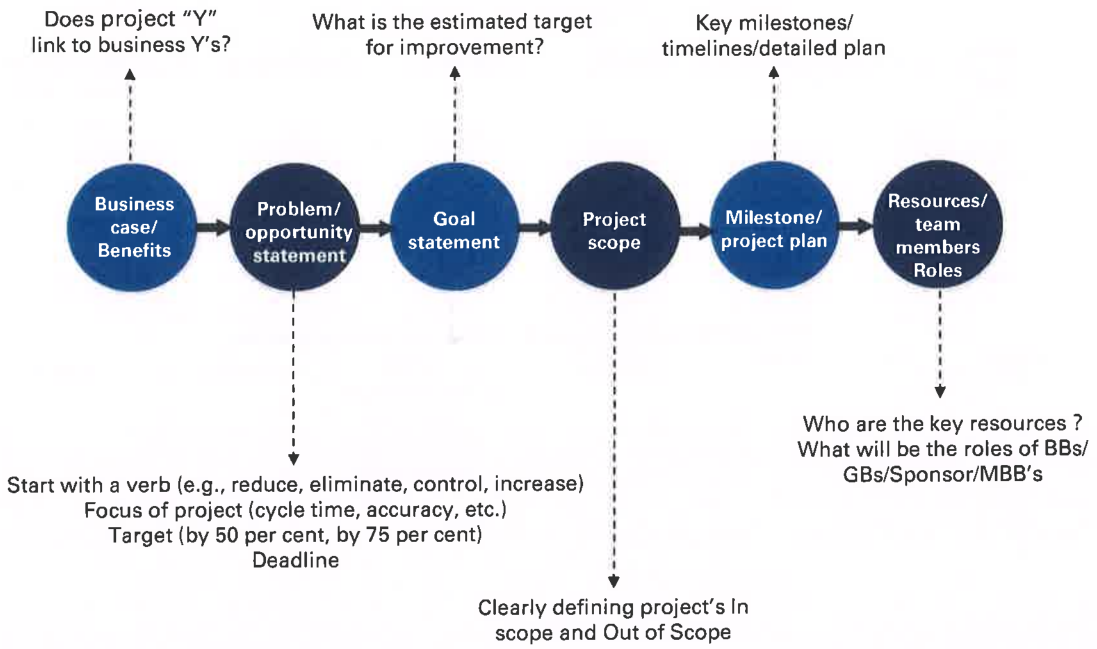
- What process will the team focus on?
- What are the boundaries of the process we are to improve? (Start and End points of the process)
- What (if anything) is out of bounds for the team?
- What (if any) are the possible constraints?
- What is the time commitment expected of team members?
- What will happen to our 'regular jobs' while we are doing the project?

**Milestones (Project Plan)**

- It is a detailed project plan with key steps and target completion dates
- Tied to phases of DMAIC process, with defined tollgate reviews
- Aggressive and Realistic (no ready-made solution)
- Documented, shared with all project team members and Champion, and updated regularly



# Elements of a project charter






# Sample project charter

| Project Name | Improving Accuracy of Payments Processing | | |
|---|---|---|---|
| Process name | Accounts Payables Process for Malaysia | | Project Number |
| Sub Process Name | Black Belt | H T | |
| | Sponsor | H K | |

| Business Case | Problem/Opportunity Statement | Goal Statement |
|---|---|---|
| The Malaysian team is presently handling the trade creditor payments for Bank of Malaysia. Average lines processed being in the range of 15,000 to 16,000 per month.<br>Many a time, there are few errors which if passed on to the customers which may have a financial impact thus incurring a monetary loss and high Customer dissatisfaction. Such errors also have an impact on the TAT as it results in rework. | The data for the month of October 2002 shows that 65 errors which were corrected during processing and there were seven errors identified by the Customers which led to Customer Complaints during the month. | To reduce the number of errors to less than 10 errors (both first pass and second pass) per month by end of 31st December 2002 |

| Project Scope Includes | Project Excludes |
|---|---|
| Includes vendor payments, staff claims. | Project Excludes Fixed Assets batch run, Daily Batch run and Account reconciliations. |

| Project Milestones | | | |
|---|---|---|---|
| Start Date: 28-Oct-02 | | End Date: 31-Dec-02 | |
| | Target Date | Actual Date | TG Review Date |
| Define | 01-Nov-02 | 01-Nov-02 | 01-Nov-03 |
| Measure | 16-Nov-02 | 29-Nov-02 | 29-Nov-03 |
| Analyze | 23-Nov-02 | 29-Nov-02 | 29-Nov-03 |
| Improve | 30-Nov-02 | 31-Jan-03 | 31-Jan-03 |
| Control | 07-Dec-02 | 28-Feb-03 | 26-Mar-03 |

| Project CTQ Details | | | |
|---|---|---|---|
| Process CTQs | Unit | USL | Target |
| Accuracy | # | 10/month | 5/month |
| | | | |
| | | Current | Target |
| | sigma | 5.04 | 5.29 |

| Project Comments | |
|---|---|
| | |
| **Project Charter Sign Off ( With date)** | |
| Sponsor | |
| GB/BB | |
| BB/QL | |

| Project Translation Plans | Project Benefits Estimate |
|---|---|
| Possible to roll out the model to other AP shops in BOM | |

## Sample project charter

| Roles and responsibilities | | | | | |
|---|---|---|---|---|---|
| Name | Approver | Resource | Member | Interested party | Time commitment |
| Jack | X | | | | 2 hours a month |
| Harry | X | | | | 2 hours a month |
| Louis | | X | | | 2 hours a month |
| Amanda | | | X | | 4 hours a week |
| Jude | | | X | | 4 hours a week |
| Elsa | | | X | | 4 hours a week |
| Anna | | | | X | 1 hour a month |

| Estimated benefits (Enter details for columns whichever are applicable) | | | | | | |
|---|---|---|---|---|---|---|
| Hard gains | Unit | Amount | Assumptions | Soft gains | Unit | Assumptions |
| | | | | End customer satisfaction | | |
| | | | | Sigma increase | | |
| | | | | Employee satisfaction | | |
| | | | | Shareholder satisfaction | | |
| | | | | | | |
| | | | | | | |



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# Create a Project Charter

## Work out session

# Great project

- **Be clearly bound with defined goals**
  - If it looks too big, it is
- **Be aligned with critical business issues and initiatives**
  - It enables full support of business
- **Be felt by the customer**
  - There should be a significant impact
- **Work with other projects for combined effect**
  - Global or local 'beta themes'
- **Show improvement that is locally actionable**
- **Relate to your day job**



# Project selection

**Success factors**

- Project scope is manageable
- Project has identifiable defect
- Project has identifiable impact
- Adequate buy-in from key stakeholders

**To be successful**

- Set up project scope charter and have it reviewed
- Measure where defects occur in the process
- Assess and quantify potential impact up-front
- Perform stakeholder analysis

**Common pitfalls**

- Resourcing of project is inadequate
- Duplicating another project
- Losing project momentum
- Picking the easy X, not the critical X

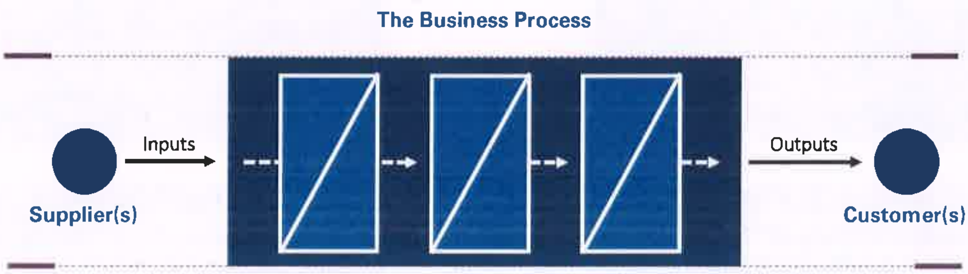
**Avoiding pitfalls**

- Identify and get committed resources up-front
- Research database and translate where possible
- Set up milestones and communications plan

# Map the Process

## Process definition and elements

Process is a collection of activities that takes one or more **inputs** and transforms them into **outputs** that are of value to the **customer**




Types of Process Maps

- SIPOC (Supplier-Input-Process-Output-Customer) (L1)
- Sub Process Map (L3,L4,L5)
- Value Stream Mapping (L1,L2)

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# Map the Process

## SIPOC

## SIPOC

**Supplier:** The provider of inputs to your process

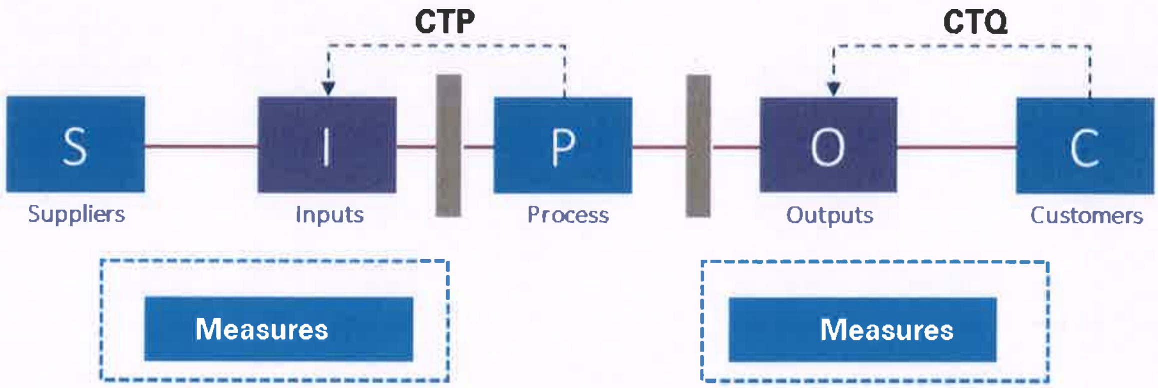
**Input:** Materials, resources or data required to execute your process

**Process:** A collection of activities that takes one or more kinds of input and creates output that is of value to the customer

**Output:** The products or services that result from the process

**Customer:** The recipient of the process output – may be internal or external

# SIPOC






# SIPOC Example

Let us look at an example of Purchase Order (P.O.) Requisition to final Approval

| SUPPLIER | INPUT | PROCESS | OUTPUT | CUSTOMER |
|---|---|---|---|---|
| S | I | P | O | C |
| User Department | Stock List | 1. **Generate Purchase Requisition** | Purchase Requisition | User Department HOD |
| User Department HOD | 1. Purchase Requisition<br>2. Budget | 2. **Approve Purchase Requisition** | Approved Purchase Requisition | Procurement |
| Procurement | 1. Approved Purchase Requisition<br>2. List of Approved Vendors | 3. **Raise Request for Quotation** | Request for Quotation | Approved Vendors |
| Approved Vendors | Quotations | 4. **Techno Commercial Evaluation of Received Quotations** | Shortlisted Quotations | Procurement |
| Procurement | Shortlisted Quotations | 5. **Select Preferred Vendor** | Quotation of Preferred Vendor | Procurement |
| Procurement | Quotation of Preferred Vendor | 6. **Prepare Purchase Order** | Purchase Order | Signing Authority |
| Signing Authority | Purchase Order | 7. **Approve Purchase Order** | Approved Purchase Order | Preferred Vendor |

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# Map the Process

## Sub Process Mapping

## Sub-process mapping

Here are some guidelines on building a sub process map. These are not absolute – but they should help you avoid some of the pitfalls of process mapping:

– Focus on 'As is' – To find out why problems are occurring in a process, you need to concentrate on how it's working now

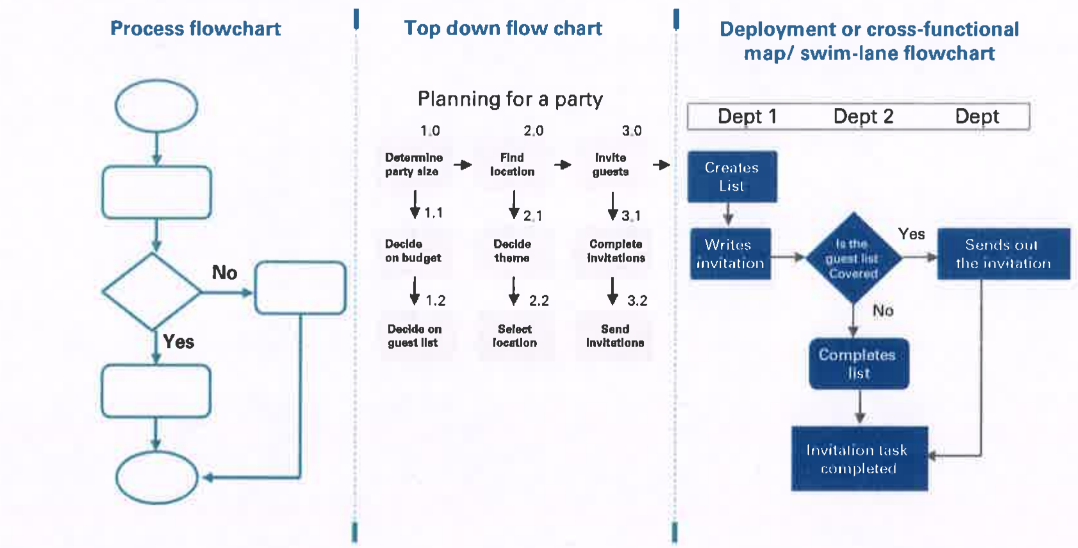
– Clarify boundaries – If you're working from a well-done high level map, this should be easy. If not, you will need to clarify start and stop points

– Brainstorm Steps – It is usually much easier to identify the steps before you try to build the map

– Starting each step description with a verb (e.g., 'collate orders'; 'review credit data') helps you focus on action in the process

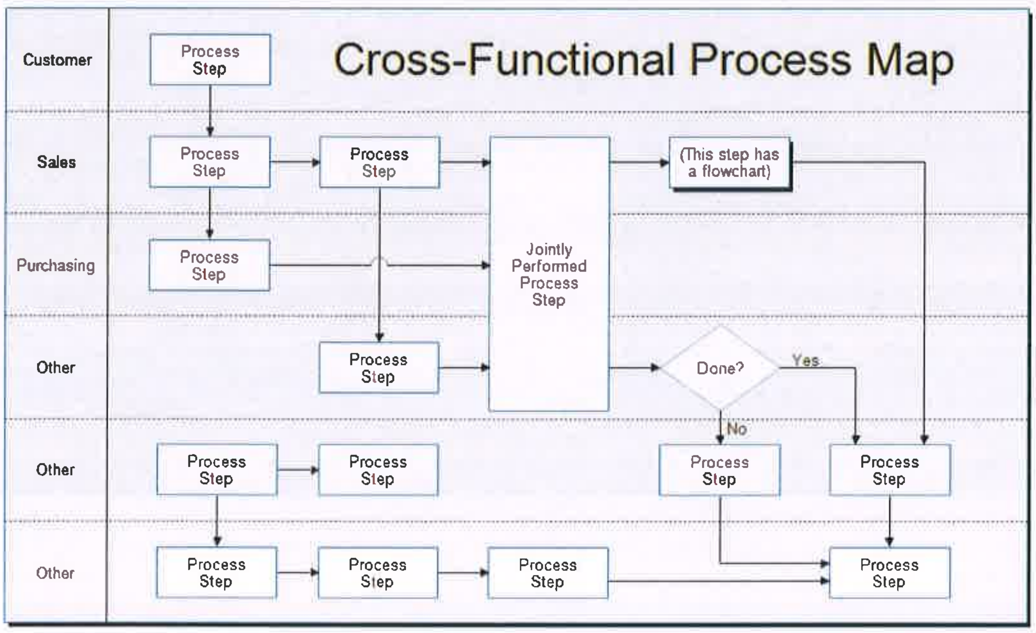
– Who does the step is best left in parentheses (or left out) – you want to avoid equating a person with the process step

# Examples: Sub-process mapping






# Examples: Cross Functional Process mapping



# Process mapping guidelines

- Define business process to be reviewed – name it – agree on beginning and end of process – bound it.
- Refer to CTQ work to identify primary outputs, the customers who receive them, and the customers' CTQs
  - Use nouns for outputs (e.g., sales call, proposal, etc.)
  - Use adjectives for CTQs (.e.g., timely, knowledgeable, accurate)
- Identify the process steps using brainstorming and affinity techniques
  - Write large one step per card
  - Do not try to establish order
  - All steps should begin with a verb
  - Do not discuss process steps in detail
- Use brainstorming and affinity techniques to identify critical inputs which affect the quality of the process
- For each critical input, identify the 'supplier' who provides it
- Validate to be sure the map represents the situation as it really is today (the 'as is' map) – not how you think it is, or how it should be



# Group Exercise

- Earlier in define, you developed a high-level or SIPOC process map. By looking at a process from a 'big picture' perspective
- You evaluated customer needs and supplier inputs, and determined initial measurement objectives
- Now, you will look in more detail at the sub processes defined in the SIPOC map
- Sub process maps provide specifics on the process flow that you can then analyze using several useful techniques.
- Choose what to sub process map by determining which of the major steps in the SIPOC have the biggest impact on the output (Ys).
- The block (or blocks) selected is the one on which you create a sub process map – using it to understand how and why it impacts the output
  - If the output is a time measure, which of the blocks consumes the largest portion of total time, or which one has the most variation or delays?
  - If the output is a cost measure, which of the blocks adds the most cost?
  - If the output is a function measure, which block has the most errors or problems?
- Like working with a puzzle, you begin to assemble the pieces of an area on which it makes sense to focus our efforts

# Points to Remember

**Points to Remember:**

- People who work on the process know it the best. Involve people who know (focus on) the 'as Is process'
- Decide, clarify and agree upon process boundaries
- Use group activities like brainstorming
  - Use verb - noun format (e.g., Prepare contract not contracting)
  - Do not aim at the person taking care of the activity
- Respect the boundaries
- Do not start 'problem solving'
- Validate and refine before analyzing



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# Map the Process

## Value Stream Mapping

# What is a value stream?

- A value stream is all the activities required to bring a service/product from a customer request to fulfillment/completion.
- All the activities involved in creating value for the customer
- The process starts with raw material or information and ends with the end customer.
- The process involves functions both internal and external to the firm.
- Activities can be described as value added (VA) or non-value added (NVA)



# Key Terms

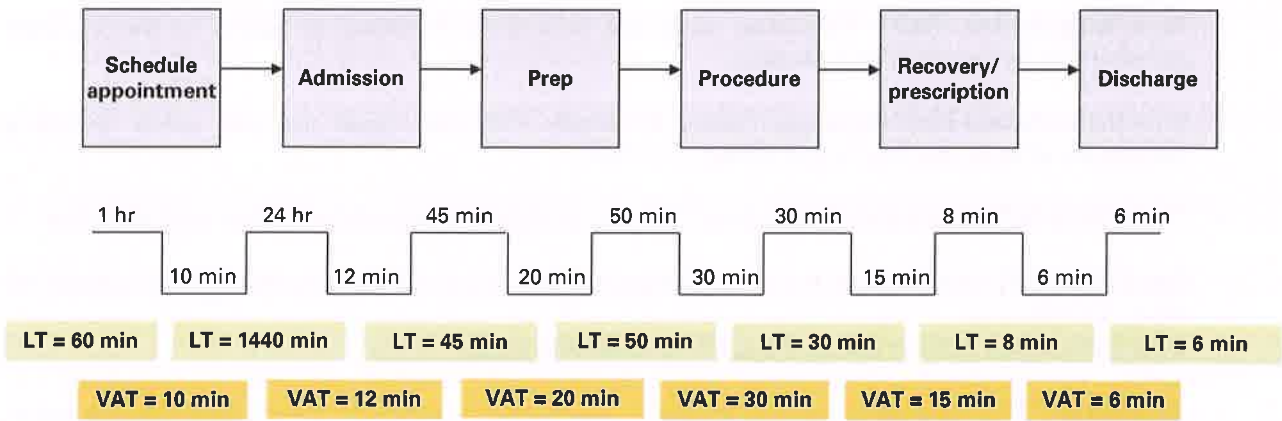
- **Value-added (VA):** This step in the process adds form, function, and value to the end product and for the customer
- **Non-Value-Added (NVA):** This step does not add form, function, or assist in the finished goods manufacturing of the product
- **Non-Value-Added-But-Necessary (Value Enabled):** This step does not add value, but is a necessary step in the final value-added product
- **Cycle Time (CT):** Cycle time is the time taken to complete a specific task from start to finish.
- **Lead Time (LT):** Lead time is the time it takes for one unit to make way through the operation from front to end.
  **LT = Time taken from order to dispatch (end-to-end time)**
- **Takt Time (TT):** Takt time is the rate at which one needs to complete the production process in order to meet customer demand.
  **TT = Net Operating Time / Customer Demand**
- **Process Cycle Efficiency (PCE):** Overall efficiency of a process, it is the value added time up on cycle time
  **PCE = Value Added Time / Lead Time**

# Why map the value stream?

- Enables to visualize the process / production flow
- Allows to see waste in the system
- Prevents focusing on large improvement opportunities with little impact
- Creates framework for designing complete system
- Demonstrates interaction between information and material flow
- Enables to know the Lead Time and Cycle Time for the process



# Value Stream Mapping - Example




**Value Added Time = 93 min**

**Total Lead Time = 1732 min**

**PCE = 5.36%**

# Points to Remember

- Start with the customer – information flow
- Identify the product or service that is being worked on
- Determine your process steps from cradle to grave
- Identify the time it takes to perform the task without delays (starting or within the process) or interruptions within the total cycle time
- Identify and quantify the time it takes to perform the task including delays and interruptions – lead time (LT = CT + delays)
- Investigate the causes of the waste between processes – what are the barriers to flow?
- Calculate total processing time (cycle time) versus total lead time (throughput/turnaround)



# Inference from Define Phase

At the end of the Define phase, we should be able to identify the problem from all the following perspectives:

- Define the problem statement
- Identify your customers
- Identify the CTQ
- Create high-level process map
- Identify team members and business functions required
- Develop a project charter

# Measure Phase

## Measure Phase - Roadmap

Types of Data → Introduction to Minitab → Data Distribution → Develop sampling strategy → Develop Data Collection Plan → MSA → Process Capability

# Types of Data

## Types of Data - Discrete and Continuous

**Discrete (Attribute) Data**

- Data that can be counted is termed as a Discrete or Attribute data

- Binary (Yes/No, Defect/No Defect)
- Ordered categories (1-5)
- Counts

**Examples**
- Number of incomplete applications
- Percent of responding with a "5" on survey
- Number of Green Belts trained

**Continuous (Variable) Data**

- Data that can be measured (with a unit value) is termed as a Continuous or Variable data.

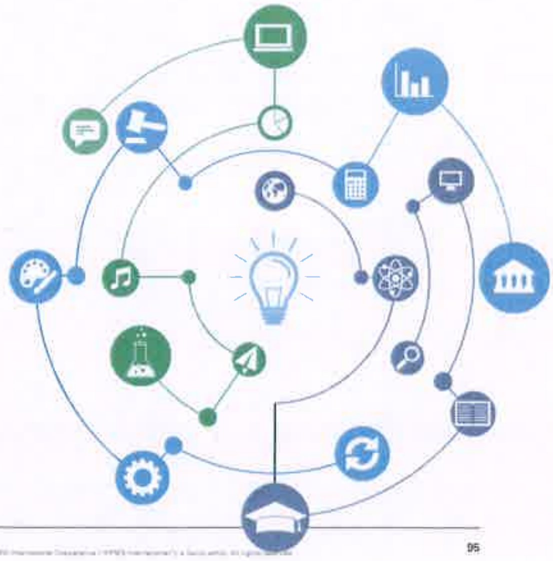
- Continuous data can be broken down into increments with infinite number of possible values

**Examples**
- Cycle time (measured in days, hours, minutes, etc.)
- Weight (measured in tons, pounds, etc.)

# Why do we need data?

**Why Data Type Important ?**

- Choice of data display and analysis tools
- Amount of data required: continuous data often requires a smaller sample size than discrete data
- Information about current and historical process performance





# Exercise - Type of data

1. Percent defective parts in hourly production
2. Percent cream content in milk bottles (comes in four bottle container sets)
3. Time taken to respond to a request
4. Number of blemishes per square yard of cloth, where pieces of cloth may be of variable size
5. Daily test of water acidity
6. Number of accidents per month
7. Number of defective parts in lot of size 100
8. Length of screws in samples of size ten from production lot
9. Number of employees who took leave in the last 5 years

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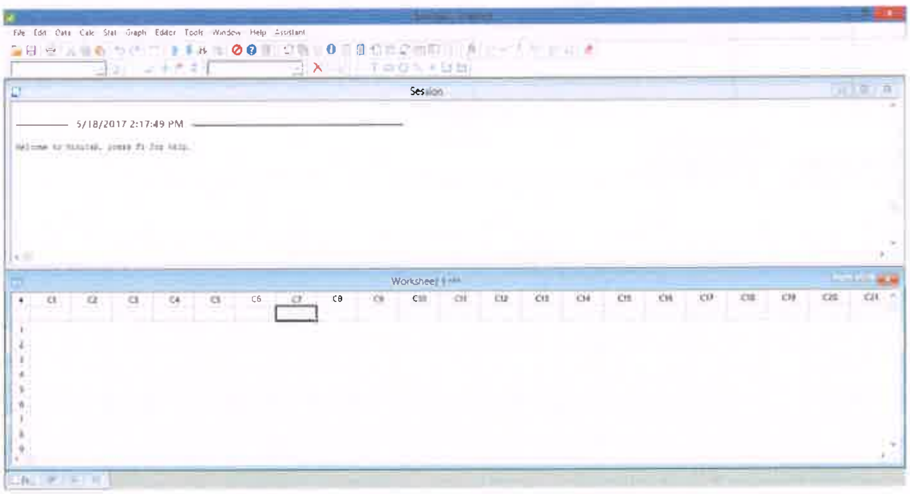
# Introduction to Minitab

## Introduction to Minitab

- Minitab is a statistical software that is widely used across businesses and industries to solve or analyze complex statistical problems

- Minitab provides convenient features that streamline your workflow, a comprehensive set of statistics for exploring your data, and graphs for communicating your success.

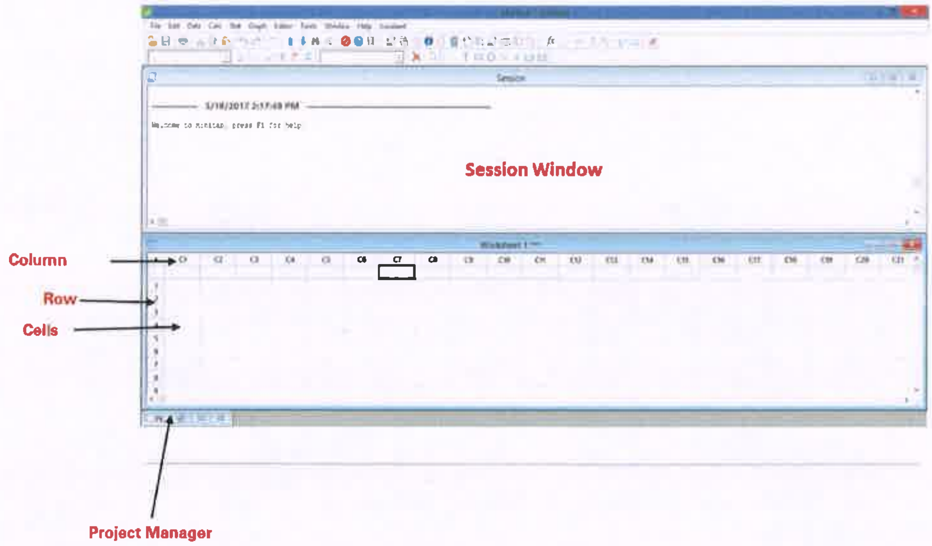


# Introduction to Minitab

1. **Session Window:** The Session window displays the results of your analyses in text format. Also, in this window, you can enter session commands instead of using Minitab's menus.

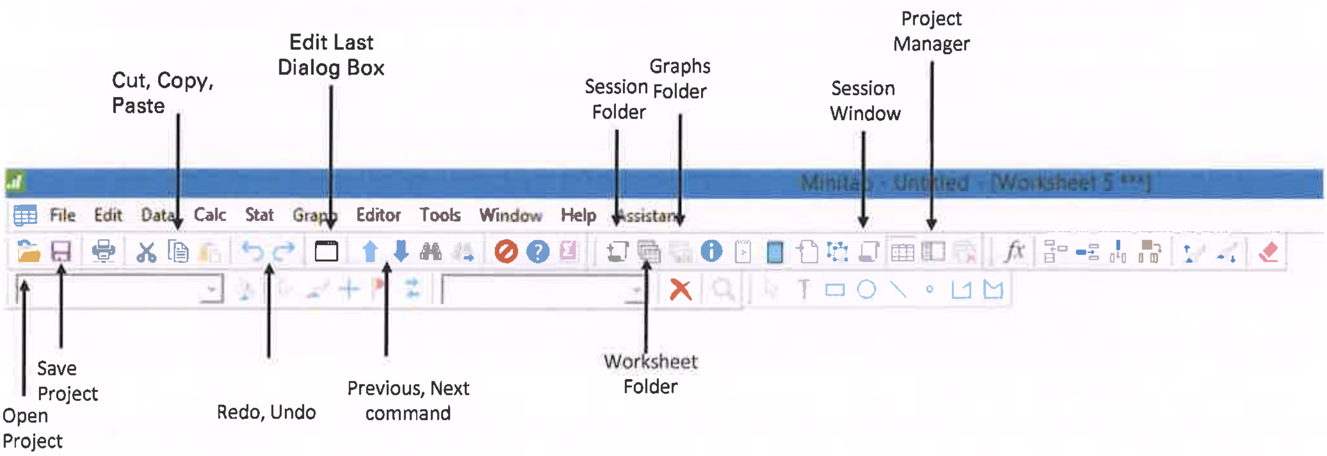
2. **Worksheet:** The worksheet, which is similar to a spreadsheet, is where you enter and arrange your data. You can open multiple worksheets.

3. **Project Manager:** The third window, the Project Manager, is minimized below the worksheet.

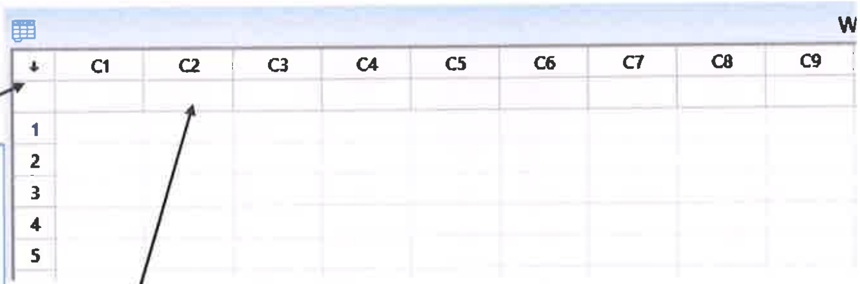





# Data Window Elements



# Worksheet Elements




**The Data Entry Arrow**

There is a data entry arrow above row 1, which indicates the direction the cursor will move after the "Enter" key is pressed

**Column Name Row**

The column name row is located just above row 1of the worksheet. Column names can be up to 31 characters and may contain space

**Remember**

When data is entered into Minitab, the program will read it as one of the three formats:

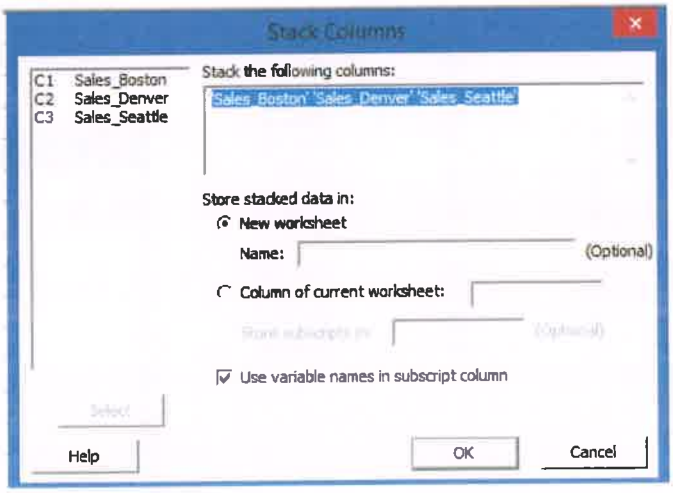
- Numeric
- Text
- Date / Time



# Combine data into single column

Stack Data

| C1 | C2 | C3 |
|---|---|---|
| Sales_Boston | Sales_Denver | Sales_Seattle |
| 36 | 52 | 63 |
| 32 | 46 | 71 |
| 35 | 51 | 68 |
| 29 | 50 | 66 |




- Stack Data
- Go to Minitab
- Select: Data>Stack Columns
- Double click C1, C2 and C3 and the data is put in the variables box
- Click OK

# Combine data into single column

Stack Data

| C1-T Subscripts | C2 |
|---|---|
| Sales_Boston | 36 |
| Sales_Boston | 32 |
| Sales_Boston | 35 |
| Sales_Boston | 29 |
| Sales_Denver | 52 |
| Sales_Denver | 46 |
| Sales_Denver | 51 |
| Sales_Denver | 50 |
| Sales_Seattle | 63 |
| Sales_Seattle | 71 |
| Sales_Seattle | 68 |
| Sales_Seattle | 66 |

- Minitab can stack data from to multiple columns to single column



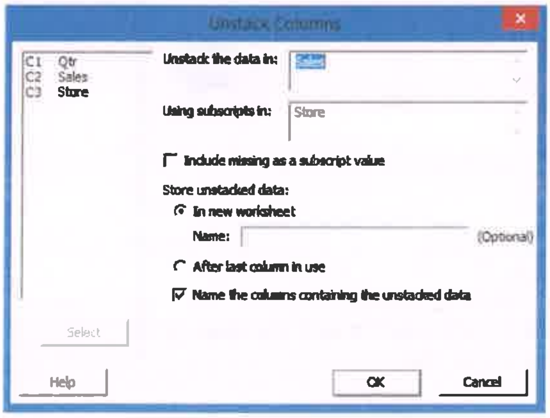
# Distribute data into different columns

Unstack Data

| Qtr | Sales | Store |
|---|---|---|
| 1 | 52 | Denver |
| 1 | 36 | Boston |
| 1 | 63 | Seattle |
| 2 | 46 | Denver |
| 2 | 32 | Boston |
| 2 | 71 | Seattle |
| 3 | 51 | Denver |
| 3 | 35 | Boston |
| 3 | 68 | Seattle |
| 4 | 50 | Denver |
| 4 | 29 | Boston |
| 4 | 66 | Seattle |

Unstack Data

- Go to Minitab
- Select: Data>Unstack Columns
- Double click C2 and C3 and the data is put in the variables box
- Click OK



# Distribute data into different columns

Unstack Data

| C1 | C2 | C3 |
|---|---|---|
| Sales_Boston | Sales_Denver | Sales_Seattle |
| 36 | 52 | 63 |
| 32 | 46 | 71 |
| 35 | 51 | 68 |
| 29 | 50 | 66 |
| | | |

- Minitab can unstack data from single column to multiple columns



# Data Format for import to Minitab

When a data is imported to Minitab, it expects the data to fulfil following conditions for a proper interpretation:

- Unlike MS Excel, Minitab does not have blank rows between the column name and row name
- There are no total rows in the worksheet
- Columns must not contain special characters or symbols

# Data Import

At time, you may have to enter or import data into a Minitab worksheet before you start an analysis.

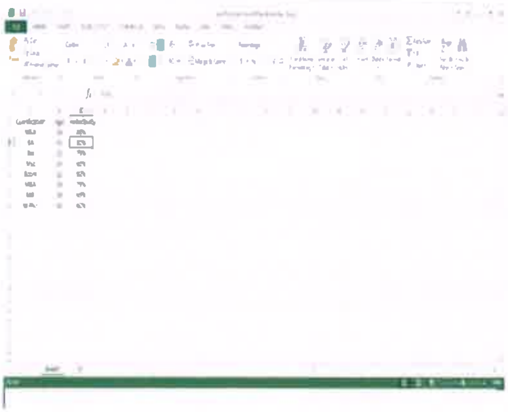
You can enter data in a Minitab worksheet in the following ways:

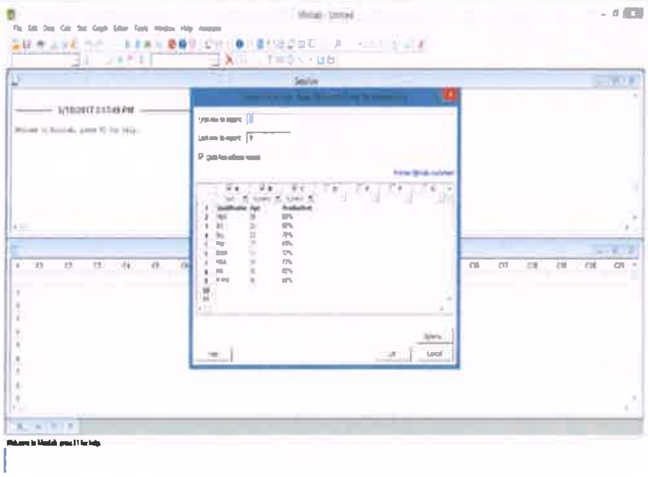
- Type the data directly into the worksheet.
- Copy and paste the data from other applications.
- Import the data from Microsoft Excel files or text files.

After your data are in Minitab, you might need to edit cells or reorganize columns and rows to prepare the data for analysis. Some common manipulations are stacking, specifying column names, and editing data values.



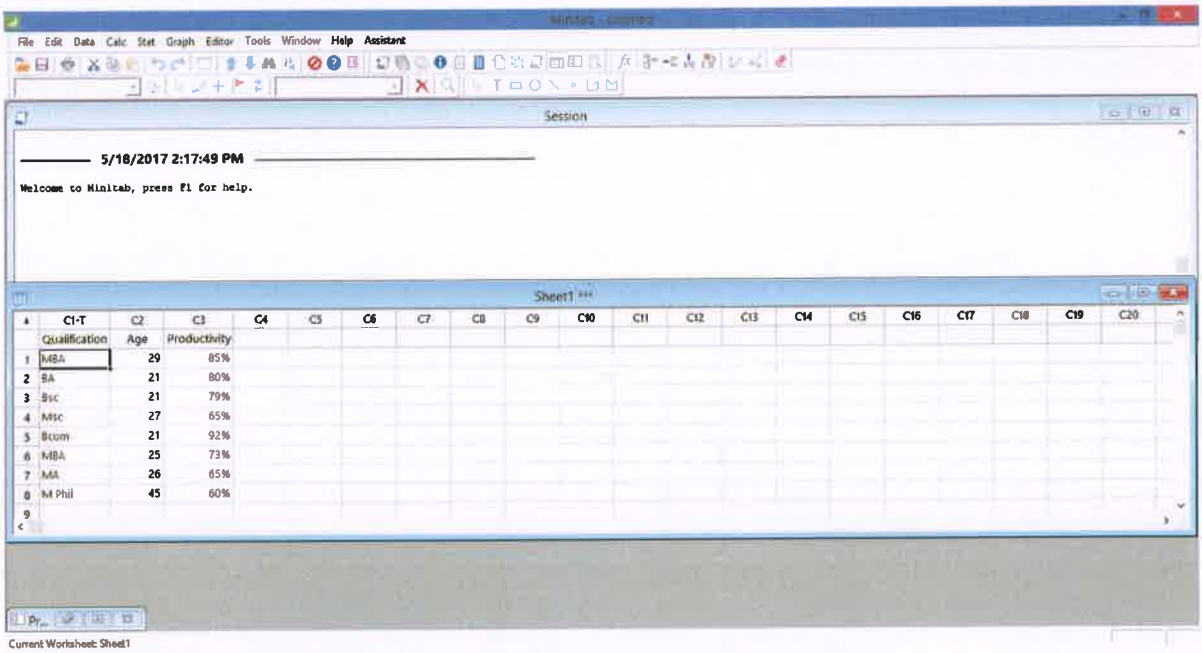
# Import Excel file to Minitab





- Export MS Excel file to Minitab.
- Open the excel file from Minitab and click ok

# Import Excel file to Minitab






# Projects and Worksheets

In a project, you can perform analyses, and generate graphs. Projects contain one or more worksheets.

Project (.MPJ) files store the following items:

- Worksheets
- Graphs
- Session window output
- Session command history
- Dialog box settings
- Window layout
- Options

Worksheet (.MTW) files store the following items:

- Columns of data
- Constants
- Matrices
- Design objects
- Column descriptions
- Worksheet descriptions

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# Data Distribution

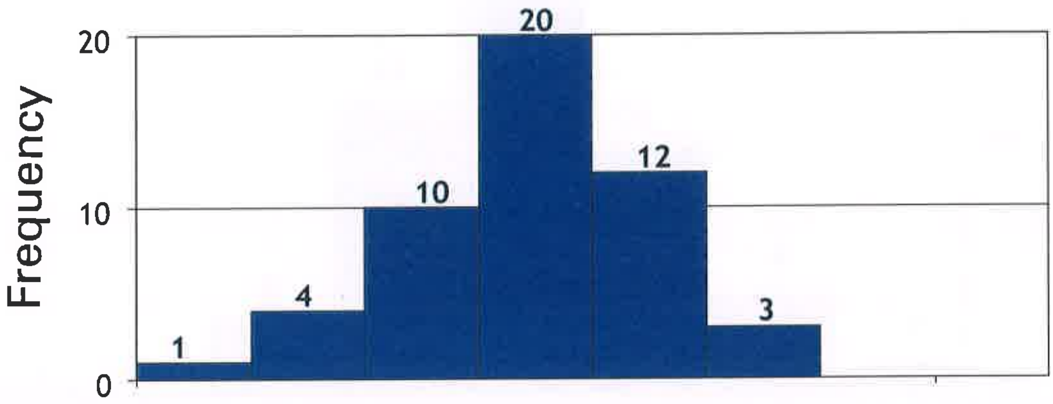
## Characteristics of variable data

The following characteristics of a data set can provide considerable insight:

- Shape (Histogram)
- Central Tendency (Mean, Median, Mode)
- Variation (Range, Standard Deviation, Variance)
- Distribution (Normal and Skewed Distributions)
- Graphical Analysis (Histogram, Box Plot)

# Histograms

- A histogram is a frequency polygon in which data are grouped into classes.
- The height of each bar shows the frequency in each class.





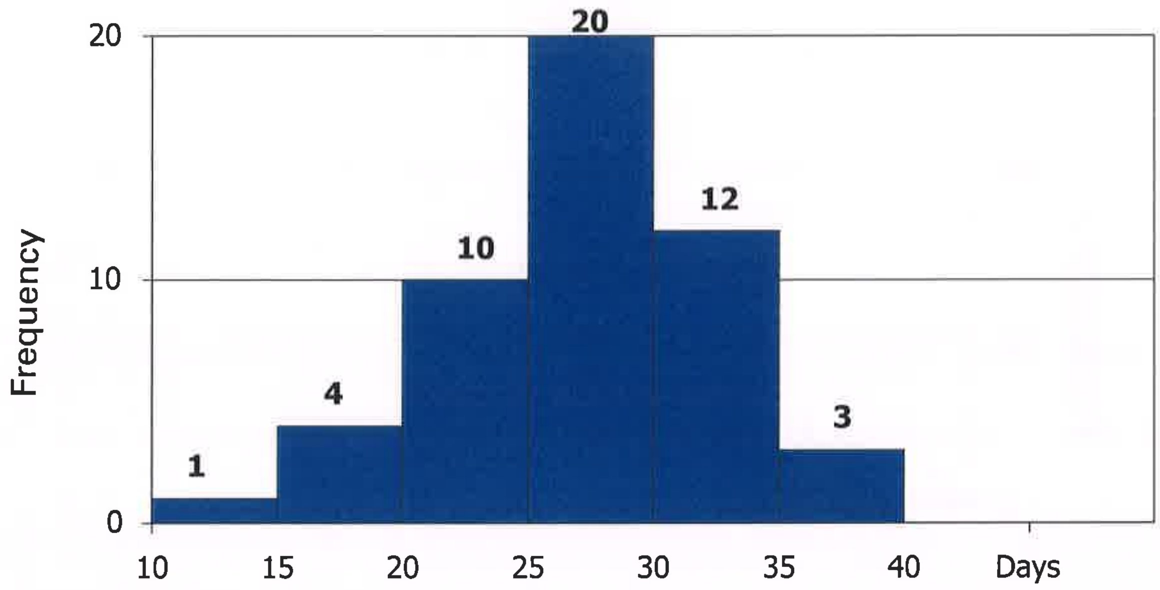

# Example: Histogram

For each of 50 placements, the time (in days) it took to place a person in the position was recorded.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 22 | 26 | 30 | 19 | 22 | 31 | 34 | 29 | 28 | 18 |
| 16 | 22 | 31 | 24 | 26 | 36 | 28 | 33 | 36 | 24 |
| 26 | 27 | 35 | 14 | 26 | 30 | 33 | 26 | 31 | 36 |
| 28 | 33 | 18 | 26 | 29 | 30 | 22 | 30 | 24 | 31 |
| 27 | 21 | 28 | 35 | 32 | 28 | 33 | 28 | 23 | 25 |

# Histograms

A histogram is a bar graph in which data are grouped into classes. The height of each bar shows how many data values fall in each class.






# Histograms

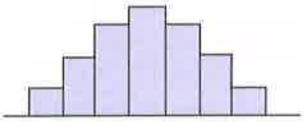
- When creating a histogram, the data must be properly grouped in order to understand the shape of the data distribution.
- For the given sample size, the right number of classes should be used.

| Number of Data Points | Number of Classes |
|---|---|
| Under 50 | 5-7 |
| 50 – 100 | 6-10 |
| 100 – 250 | 7-12 |
| Over 250 | 10-20 |

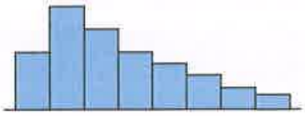
In Minitab, refer the file 'PotatoChip.MTW' to create a histogram.

What might you conclude from the histogram?

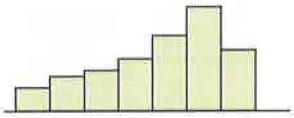
# Shapes of Data Sets



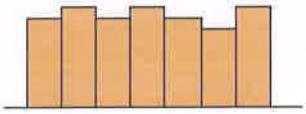
Bell Shape – The Normal Distribution



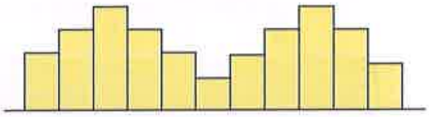
Right Skewed (Positively Skewed)



Left Skewed (Negatively Skewed)



Uniform Distribution



Bimodal Distribution





# Measures of Central tendency

| Placement Time for an Analyst's Positions (in days) |
| --- |
| 22, 26, 26, 31, 33, 37, 37, 42, 52, 52, 52, 57, 59 |

**Mean or Average**
The sum of the values in a data set divided by the number of values.

$\overline{X}$ = 40.5 days

**Mode**
The most frequently occurring data value.

Mode = 52 days

**Median**
The middle observation in the data set that has been arranged in ascending or descending order.

Median = 37 days

# Measures of Dispersion

Placement Time for an Analyst's Positions (in days)

22, 26, 26, 31, 33, 37, 37, 42, 52, 52, 52, 57, 59

<u>Range</u>
The largest data value minus the smallest data value:

Range = Max - Min

Range = 37

<u>Variance ($s^2$)</u>
The average deviation of all data values from the mean.

$$s^2 = \frac{\sum (x - \bar{x})^2}{n - 1}$$

$s^2 = 162.67$

<u>Standard Deviation ($\sigma$)</u>
The square root of variance is standard deviation.

$$\sigma = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

$\sigma = 12.74$



# Standard Deviation

Essentially, the standard deviation is representation of the deviation of individual data values from the sample mean.

**Why Standard Deviation?**

- Unlike the range, the standard deviation takes into account all the data values in the sample.
- Unlike the variance, the standard deviation has the same units of measurement as the original data.

# What is Normal Distribution?

- Normal or Gaussian distribution is a descriptive model that describes real world situations.
- It is defined as a continuous frequency distribution of infinite range (can take any values not just integers as in the case of Binomial and Poisson distribution).
- This is the most important probability distribution in statistics and important tool in data analysis.

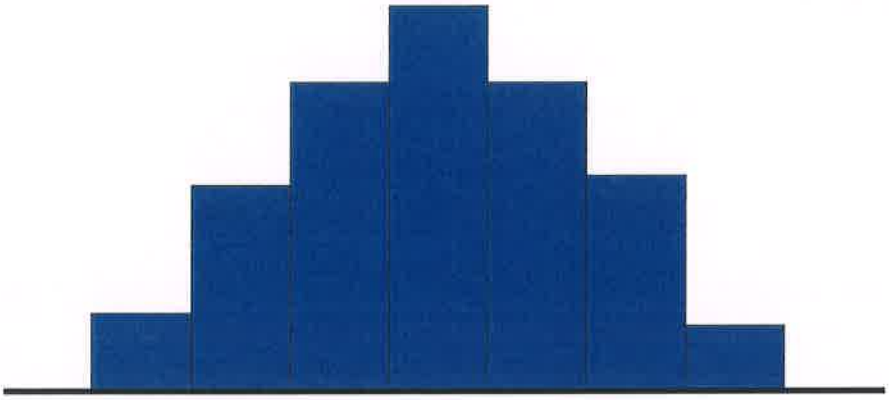


# Characteristics of Normal Distribution

- It links frequency distribution to probability distribution
- Has a bell shape curve and is symmetric
- It is symmetric around the mean: two halves of the curve are the same (mirror images),
- In a perfectly centered Normal Distribution; mean = median = mode
- The total area under the curve is 1 (or 100%)

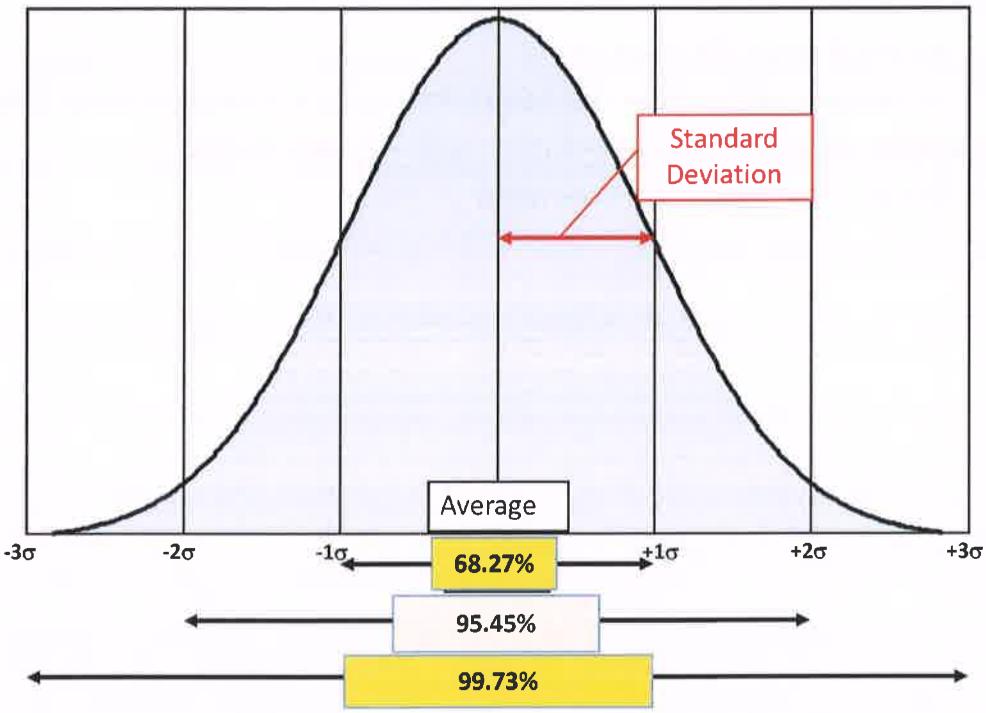
# Properties of Normal Distribution

Since many process outputs have this shape, the properties of the normal curve can be used to make predictions about the process population.





# Properties of Normal Distribution



# Test for Normality

A normal curve originates from a histogram. A histogram is a frequency distribution chart showing the number of times a given value of the parameter we are trying to measuring occurs.

Minitab uses the Anderson-Darling test to determine if a set of data can be treated as normal data.

**Interpreting the P-value:**

The P-value is the probability of getting the particular sample if the population is normal.

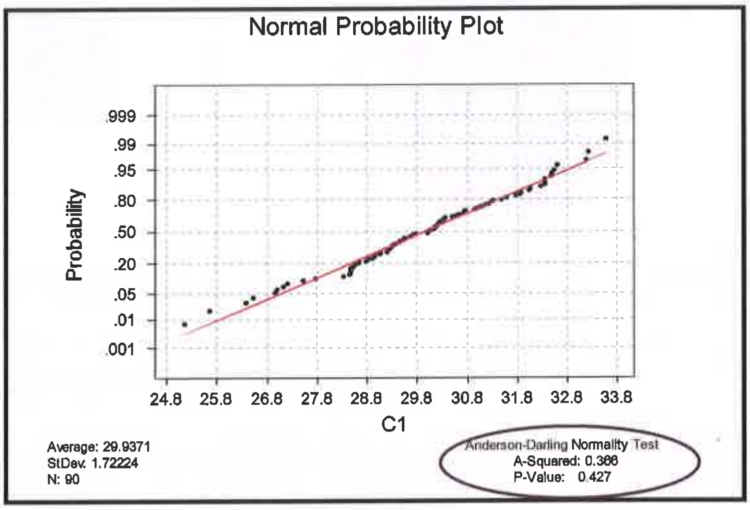
P-value < 0.05 means that the chance of getting this sample from a normal population is very small (less than 5%).

**Stat > Basic Statistics >Normality Test**

Null Hypothesis: Data is Normal

Alternate Hypothesis: Data is not Normal

Since the P-value > 0.05 we conclude that the data falls a normal distribution

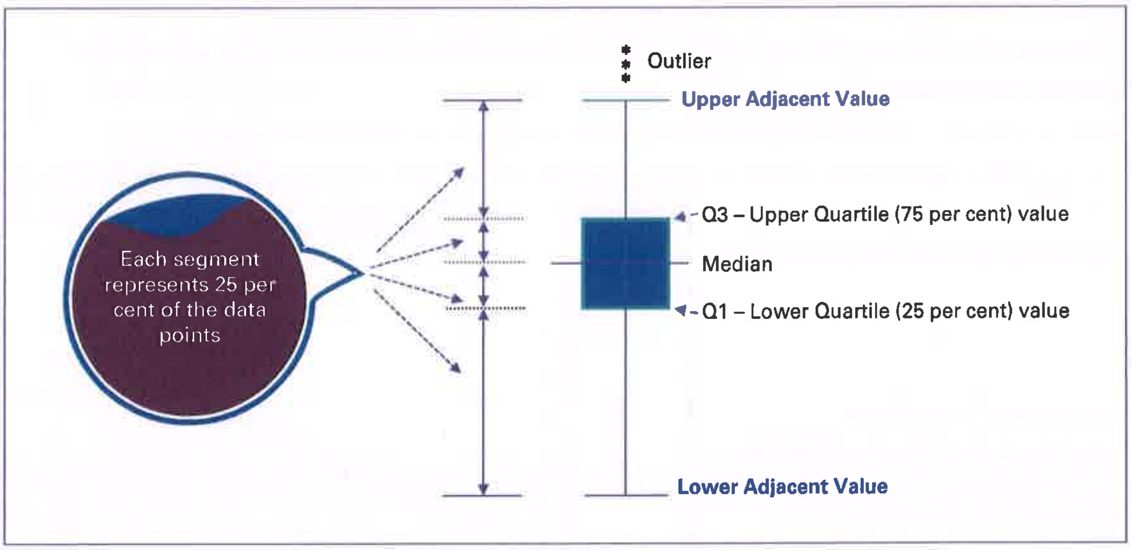





# Box plot

- Box Plot is a graphical tool to display central tendency (median) and dispersion (range)
- Box Plot enables to understand the distribution of data (quartiles)
- Box Plot gives the location of data
- Box Plot enables to get a quick comparison of two or more processes
- Box Plot is usually used at the initial stages of data analysis
- Box Plot indicates imminent instability in the process, through illustration of outliers

# Box plot




We can calculate the Inter Quartile Range (IQR): Q3 – Q1

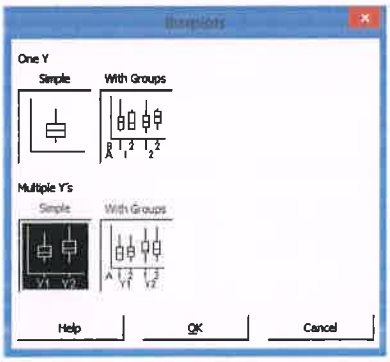


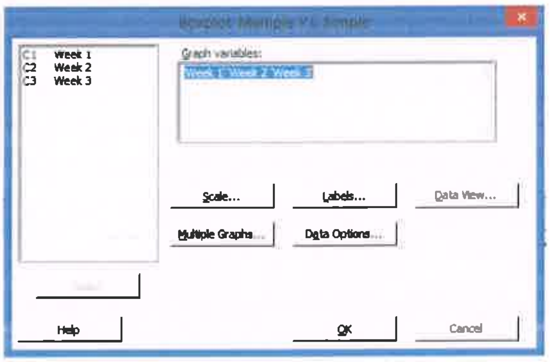
# Things to look for in a Box plot

- Are the boxes about equal or different sizes?
- Do the groups appear normal or skewed?
- Are there any outliers?

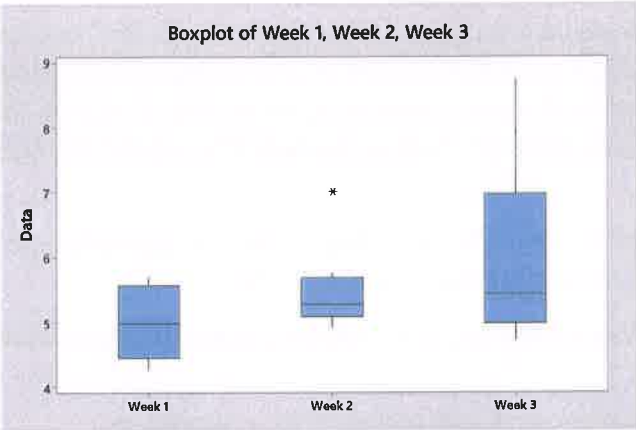
Refer the data sheet – Pipe.MTW in Minitab

**Choose Graph> Box Plot > Multiple Y's Simple**



# Box Plot using Minitab




Interpretation:

- Week 1 median is 4.985, and the interquartile range is 4.4525 to 5.5575.
- Week 2 median is 5.275, and the interquartile range is 5.08 to 5.6775. An outlier appears at 7.0.
- Week 3 median is 5.43, and the interquartile range is 4.99 to 6.975. The data are positively skewed.
- The medians for the three weeks are similar. However, during Week 2, an abnormally wide pipe was created, and during Week 3, several abnormally wide pipes were created.



# Develop Sampling Strategy

# Sampling: Overview

- The Six Sigma team would always face a question 'How much data do we need to have a valid sample?' Though an important part of data collection is to obtain a sample of reasonable size, it is one of many questions to be addressed during the planning and development of a data collection strategy. Sample size is just one aspect of a valid data collection activity
- The validity of the data is impacted by many things: For example, operational definitions, data collection procedures and recording
- In process improvement, there are a number of questions to keep in mind relative to sampling:
- Is the data representative of the situation or is bias possible?
- Why am I sampling? To improve or control a process or to describe some characteristic of a population?
- What are the key considerations for either a process or population situation?
- What is the approach to sampling (e.g., random, systematic, etc.) and approximately how many to sample



# Population and Sampling

An entire set of items is called the *Population*.

What is Sampling?

- The small number of items taken from the population to make a judgment of the population is called a *Sample*.
- The numbers of samples taken to make this judgment is called *Sample size*.

# Sampling Strategy

1. **Random Sampling**

Samples drawn at random.

That is, at any point in time, each unit in a "lot" has an equal chance of being the next unit selected for the sample.

*Example: Cycle tyres produced in the assembly line have a random check of 10 per cent (QC) on daily production*

2. **Stratified Sampling**

An attempt to draw the sample proportionately over the full operating range of the process.

For example: various batches of material; small and large contracts; all three shifts

*Example: Every third tyre used with an aircraft is cut open and checked for quality*



# Sampling Methods

**Simple Radom Sampling:** Every unit has the same chance of being selected.

*Example: Survey across organization to know –"What percentage of employees have visited the intranet in last seven days. Select employees from Population at random And collect data.*

**Stratified Random Sampling:** Random sampling from proportional subgroups of the population

*Example: Average cycle time for LC issuance process of different countries. Each country is a strata (segment). Collect random data from each strata*

**Systematic Sampling:** Includes every nth unit. The formula is

k = N/n (where N is population size and n is the sample size)

*Example: Suppose you want to sample 10 houses from a street of 150 houses. 150/10=15, so every 15th house is chosen*

**Sampling subgroups:** Subgrouping is the process of putting measurements into meaningful groups to better understand the important sources of variation.

*Example: While studying the arrival rate of documents as dispatched by the customer. The entire day is split up into quadrants, rational being the arrival rate of documents is similar within each quadrant and different between quadrants*

# When to Sample?

**When to sample?**

- Collecting all the data is impractical
- High cost implications due to population study
- Time availability
- Data collection can be a destructive process (crash testing of cars)
- When measuring a high-volume process



# Sampling bias

- Sampling must be representative to enable solid conclusions.
- The data have to represent the population or process.
- There should be no systematic (non-random) difference between the data you collect or do not collect.

# Determining the Sample Size

## Three metrics that determine the sample size

- **Level of confidence (Zc):**
  - "How confident I am that the result represents the true population"
  - The team needs to be sure of the adequate representation of the population with the sample chosen
  - For higher levels of confidence the sample size increases
- **Precision (Δ)**
  - "How accurate is the result or what are the errors or uncertainty in my result?"
  - Precision improves as sample size increases
  - Higher the precision, larger is the sample size required
- **Standard deviation of the population (σ)**
  - How much variation is in the total data population?
  - As standard deviation increases, a larger sample size is needed to obtain reliable results

**Sample size is not dependent on the 'population size'**



# Determining the Sample Size - Continuous Data

The formula for calculating the sample size for continuous data is

$$n = \left[ \frac{Z_c \, \sigma}{\Delta} \right]^2 \qquad n = \left[ \frac{1.96 \, \sigma}{\Delta} \right]^2$$

Where:
n = minimum sample size
σ = estimate of standard deviation of the population
Δ = level of precision desired from the sample in units of proportion
1.96 = value of Zc at 95% confidence

# Determining the Sample Size - Example

Suppose you want to estimate the average length of incoming phone calls within 1 minute. Historical data for the population shows a typical standard deviation of 3 minutes. How many samples do you need?

$$n = \left[ \frac{1.96\,\sigma}{\Delta} \right]^2$$

$$n = \left[ \frac{1.96 * 3}{1} \right]^2 \qquad n = \left[ \frac{(\ 5.88\ )}{1} \right]^2$$

**Thus Sample Size = n = 35 samples**



# Determining the Sample Size - Attribute Data

For Discrete Proportion data

$$n = \left[ \frac{1.96}{\Delta} \right]^2 P(1-P)$$

Where:
n = minimum sample size
P = estimation of the proportion of the population or process which is defective
$\Delta$ = level of precision desired from the sample in units of proportion
1.96 = value of $Z_{\alpha/2}$ at 95% confidence

# Determining the Sample Size - Example

Suppose you want to estimate within 2% the proportion of customers who will buy a new product. Your guess says that 50% of them will buy. How many samples do you need?

$$n = \left[\frac{1.96}{\Delta}\right]^2 P(1-P)$$

$$n = \left[\frac{1.96}{0.02}\right]^2 0.5\,(1-0.5)$$

**Thus Sample Size = n = 2400 samples**



# Determining the Sample Size - Example

How many customers do you need to sample for your estimate to be within 4%

$$n = \left[\frac{1.96}{\Delta}\right]^2 P(1-P)$$

$$n = \left[\frac{1.96}{0.04}\right]^2 0.5\,(1-0.5)$$

$$n = 625$$

**625 customers needed**

# Develop a Data Collection Plan

## What is Segmentation and Stratification?

### Segmentation

A process used to divide a large group of data into smaller, logical categories for analysis. Segmentation is commonly used by us in our day to day business to understand and interpret information

- Example: Segmentation of customers based on the cities

### Stratification

A process which uses summary metrics (central tendency, dispersion) to make the decision about when to separate different processes for continued analysis

Unlike segmentation, stratification involves the uses data rather than just 'information'. Values of the central tendency and dispersion are used to stratify the given data set.

- Example : Stratification of the customers based on the business volumes they provide us

# Data collection plan

| Why collect data? | What to collect ? | How to collect? | Collect data | Ensure consistency & stability |
|---|---|---|---|---|
| • The purpose of the data collection exercise | • Identify measures<br>• Define operational definitions<br>• What data to be collected | • Formulate data collection plan<br>• Sampling strategy<br>• Pilot data collection plan | • Pilot collection and validation plan<br>• Train data collectors | • Develop measurement system analysis<br>• Test and validate<br>• Monitor and improvise |

**Word of caution:** Ineffective data leads to ineffective conclusions



# Data collection plan

- Data collection occurs multiple times throughout DMAIC. The data collection plan described here can be used as the guide for data collection. This help us ensure that we collect useful, accurate data that is needed to answer our process questions
- Data collection plan needs to be prepared / referred for data collection on Y in Measure phase and X's in Analyze phase
- It is important to be clear about the data collection goals to ensure the right data is collected. If your data is in the wrong form or format, you may not be able to use it in your analysis
- Operational definitions help to guide thinking on what properties will be measured and how they will be measured. There is no single right way to write an operational definition. There is only what people agree to for a specific purpose. The critical factor is that any two people using the operational definition will be measuring the same thing in the same manner.

# Operational Definition

**What is an Operational Definition?**

An operational definition is a clear, concise description of a measurement and the process by which it is to be collected.

**Purpose of Operational Definition:**

- To remove ambiguity: Everyone has a consistent understanding
- To provide a clear way to measure the characteristic
  - Identifies what to measure
  - Identifies how to measure it
  - Makes sure that no matter who does the measuring, the results are consistent



# Data collection plan - Example

A format of an excel spread sheet that can be used for creating data collection plans for our projects. The sample data collection plan below is for the project CTQ, in this example, number of rejections.

However one should remember that based on C-E diagram and the SIPOC all those Xs which the team feels to have a influence over the Y should also be included in the data collection plan.

**Example of a data collection plan**

| | | | | | Sampling | | | Reporting Plan | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | Operational Definition | Target | Method/ Source | Unit of Measur | Sample | Collection Frequency | Sample Size | Reported On | Reported Frequency | Reporting to | Responsi-bility | Time Frame |
| No. of Rejections | Any Transaction getting rejected in the Misc Step Processing & appearing in the GAMX Rejection Report & GMC Transmission Rejection Message | 0.10% | GAMX Rejection Report & GMC Transmission Rejection Message | Nos. | No Sampling. Entire Population data collected | Daily | 6803 | Every Monday | Daily | Manager | Processor of Misc Step | 1 Month |

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# Validate Measurement System

## Validate Measurement System

**Why do we need to validate Measurement System?**

- To verify the adequacy of measurement system for Y when establishing process baseline
- To verify the adequacy of measurement system when verifying causes
- To verify the adequacy of measurement system when verifying solutions.
- To verify the adequacy of measurement system when controlling the X's

# Validate Measurement System - Objective

To determine what percentage the Total Observed Variation is due to Measurement Device and Measurement Method in addition to the true Part to Part variation.

To statistically verify that the current measurement system provides:

- Unbiased results
- Minimal variability within the measurement system
- True representative values of the factors being measured

**Key Points**

- There is no perfect measurement system.
- All measurement systems contain variation.
- Gage system error within a measurement system is the sum of:
  - *Bias (Accuracy)*
  - *Stability*
  - *Sensitivity*
  - *Repeatability*
  - *Reproducibility*



# Types of Measurement Errors - Key Definitions

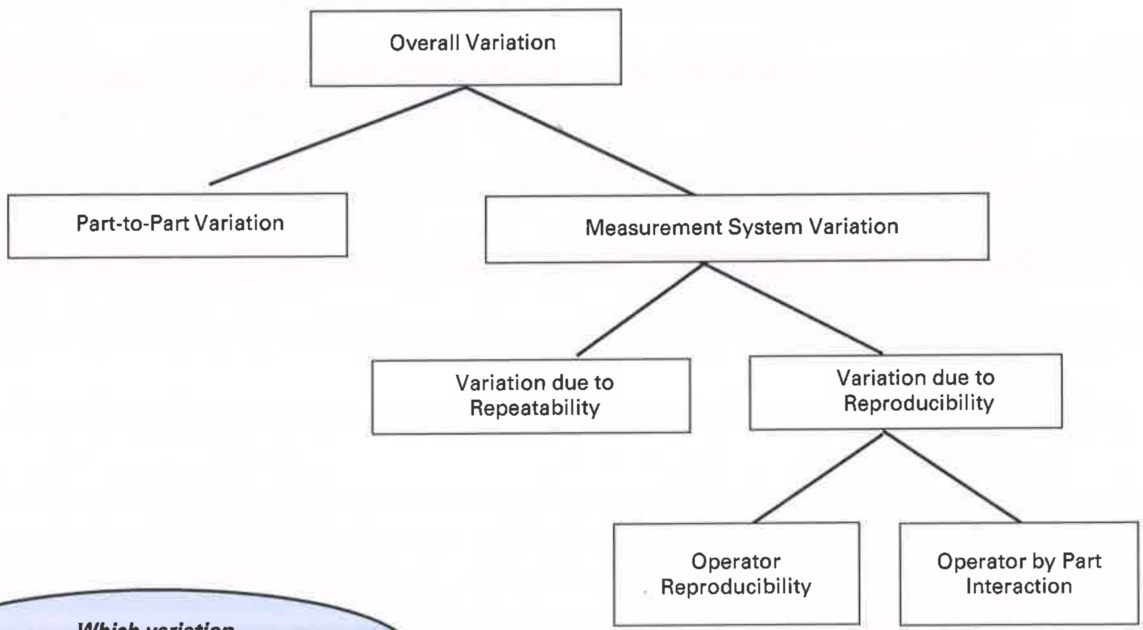
- ***Accuracy:*** *The difference between the observed average of measurements and the true average of the items measured.*
- ***Repeatability:*** *The variation in measurements obtained with a gage when used several times by one operator while measuring the identical characteristic on the same sample piece*
- ***Reproducibility:*** *The variation in the average of measurements taken by different operators using the same gage while measuring the identical characteristic on the same pieces.*
- ***Stability:*** *The variation in the average of at least two sets of measurements obtained with a gage as a result of time on the same pieces.*
- ***Sensitivity:*** *The ability of the measuring instrument to detect the smallest unit of change in measured value.*

# Key Points

- Gage R&R Studies are a method to quantify the repeatability and reproducibility of a measuring system.
- Gage R&R studies are conducted to evaluate a Gage's suitability for a defined purpose.
- Accuracy and Stability are addressed by calibration.
- Sensitivity is addressed through ensuring correct Least Count of measuring instrument.



# Breaking down overall variation




***Which variation component do we want to be large?***

# Validate Measurement System - Methods

Two methods for Validating Measurement System:

- Variable Gage R&R
- Attribute Agreement Analysis



# Variable Gage R&R

- At least two operators (persons doing the measuring) should participate. Two or three operators are typical.
- At least 10 parts should be measured. The same characteristic is measured on each part. These are 10 units of the same type product that represent the full range of manufacturing variation.
- Each operator needs to measure each part two or three times. Parts should be measured in random order.
- Parts should be masked so that operator does not realize that he / she is measuring the same part number of times.


*It is very important that an operator not be aware of his or her earlier measurement when doing a repeat measurement on the same part.*

# Variable Gage R&R - Acceptability Criteria

| Study Variation (SV%) | % Contribution | Acceptable Criteria |
|---|---|---|
| 0% to 10% | Less than 1% | Good Measurement System |
| 10% to 30% | 1% to 9% | Conditionally Accepted (Depending on the Criticality of the Application) |
| Greater than 30% | Greater than 9% | Not Acceptable |

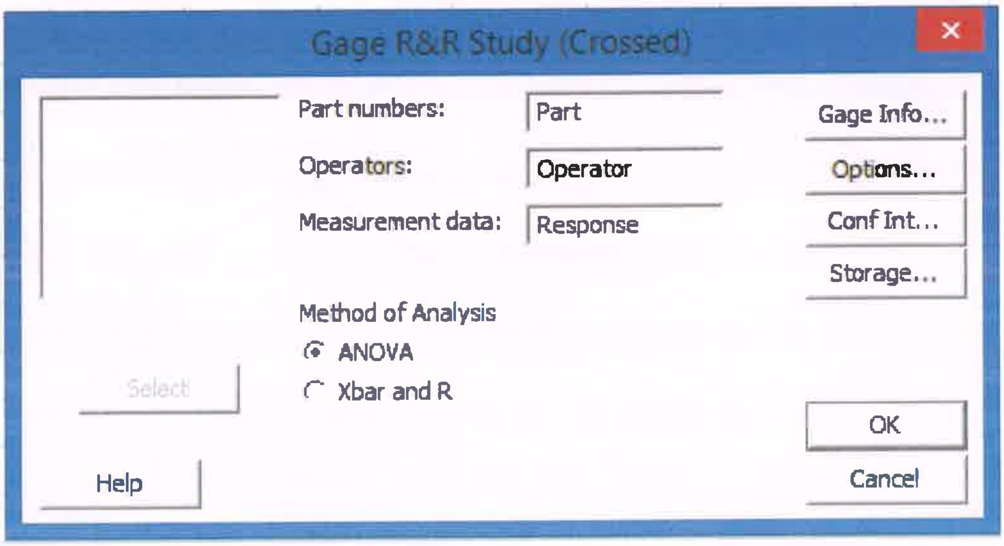
| Number of Distinct Categories | Less than 5 | Not Acceptable |
|---|---|---|



# Variable Gage R&R using Minitab

Refer the data sheet – Thickness. MTW in Minitab

**Choose Stat > Quality Tools > Gage Study > Gage R&R Study (Crossed).**



# Variable Gage R&R using Minitab

**Results for: Thickness.MTW**

**Gage R&R Study - ANOVA Method**
**Two-Way ANOVA Table With Interaction**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Part | 9 | 2.05871 | 0.228745 | 39.7178 | 0.000 |
| Operator | 2 | 0.04800 | 0.024000 | 4.1672 | 0.033 |
| Part * Operator | 18 | 0.10367 | 0.005759 | 4.4588 | 0.000 |
| Repeatability | 30 | 0.03875 | 0.001292 | | |
| Total | 59 | 2.24913 | | | |

α to remove interaction term = 0.05

**Gage R&R**

| Source | VarComp | %Contribution (of VarComp) |
|---|---|---|
| Total Gage R&R | 0.0044375 | 10.67 |
| Repeatability | 0.0012917 | 3.10 |
| Reproducibility | 0.0031458 | 7.56 |
| Operator | 0.0009120 | 2.19 |
| Operator*Part | 0.0022338 | 5.37 |
| Part-To-Part | 0.0371644 | 89.33 |
| Total Variation | 0.0416019 | 100.00 |

Measurement System does not meet the criteria as the SV% and Contribution % exceed the criteria

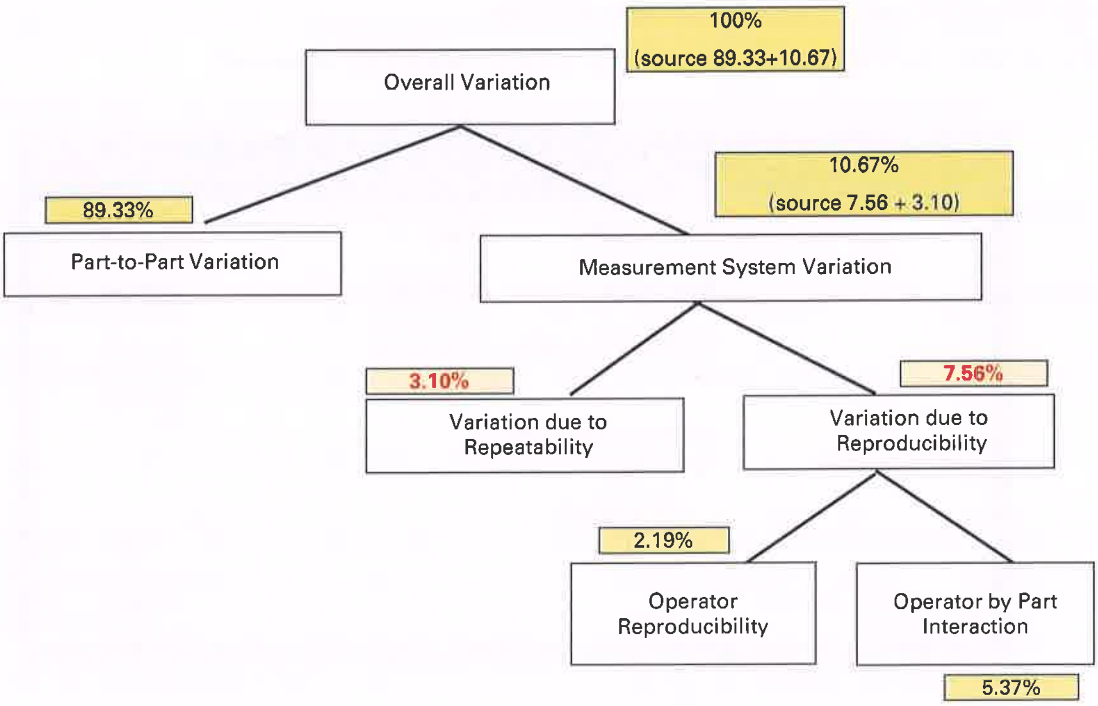
| Source | StdDev (SD) | Study Var (6 × SD) | %Study Var (%SV) |
|---|---|---|---|
| Total Gage R&R | 0.066615 | 0.39969 | 32.66 |
| Repeatability | 0.035940 | 0.21564 | 17.62 |
| Reproducibility | 0.056088 | 0.33653 | 27.50 |
| Operator | 0.030200 | 0.18120 | 14.81 |
| Operator*Part | 0.047263 | 0.28358 | 23.17 |
| Part-To-Part | 0.192781 | 1.15668 | 94.52 |
| Total Variation | 0.203965 | 1.22379 | 100.00 |

**Number of Distinct Categories = 4**

The number of distinct categories is less than 5, therefore it is not acceptable.

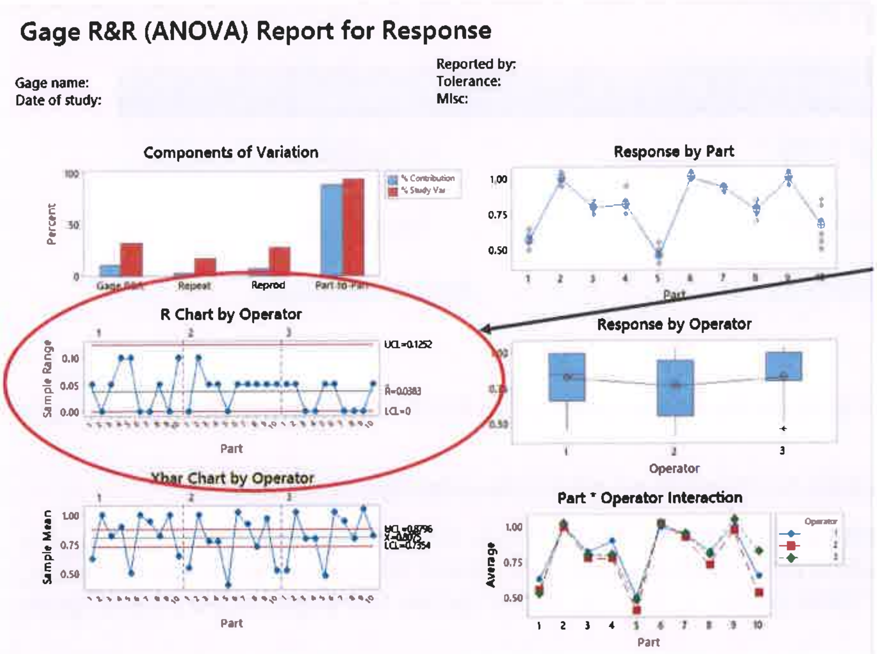


# Breaking down overall variation



# Variable Gage R&R using Minitab

2




Range Chart must be in statistical control over all operators.

If special cause is present, implement counteraction then redo the test.

In this case, the range chart is acceptable



# Attribute Agreement Analysis

- It is also important to have good repeatability and reproducibility when obtaining attribute data.
- If one operator, for example, decides a unit has an "appearance" defect and another operator concludes the same unit has no defect, then there is a problem with the measurement system.
- Similarly, the measurement system is inadequate when the same person draws different conclusions on repeat evaluations of the same unit of product.
- An attribute measurement system compares each part to a standard and accepts the part if the standard is met.
- The screen effectiveness is the ability of the attribute measurement system to properly discriminate good from bad.

## Attribute Agreement Analysis - Acceptability Criteria

While 100% is the most desirable result in Attribute Agreement Analysis , the following guidelines are frequently used:

| Kappa | Guideline |
|---|---|
| 0.90 to 1.00 | Acceptable |
| 0.80 to 0.90 | Marginal |
| Less than 0.80 | Not Acceptable |

**Key Points:**

- Before collecting new data, evaluate the gage using MSA for either variable or attribute data
- Before using existing data, try to estimate the trustworthiness of the data.
- Don't delay a Six Sigma project due to a poor MSA. Keep the project moving with non numerical analysis wherever possible, such as Process Analysis, Waste Identification, identification of Non Value Added Activities, and improve the gage as the project goes forward.



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# Determine Process Capability

# What is Process Capability?

- Process capability is a simple tool which helps us determine if a process, given its natural variation, is capable of meeting the customer requirements or specifications
- Helps to determine if there has been a change in the process
- Also enables the six sigma team to determine the percent of the product/service not meeting the customer requirement



# Measuring the Capability

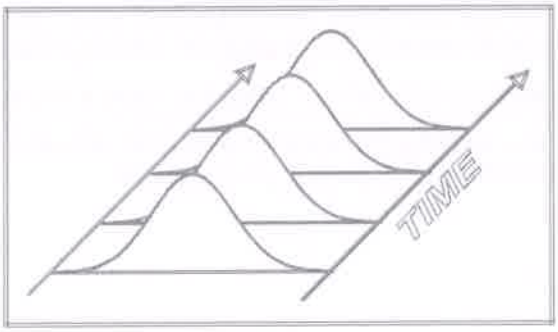
- Sigma is a statistical unit of measure, used to denote the value of standard deviation in a set of variable data
- For a given process, Sigma Level is a metric that indicates how well a process is performing
- In Six Sigma, the capability of a process to meet customer specification is captured by the Process Sigma Level.
- Hence as value of Standard Deviation ($\sigma$) decreases the Process Sigma Level increases.

Let us look at different scenarios in a process

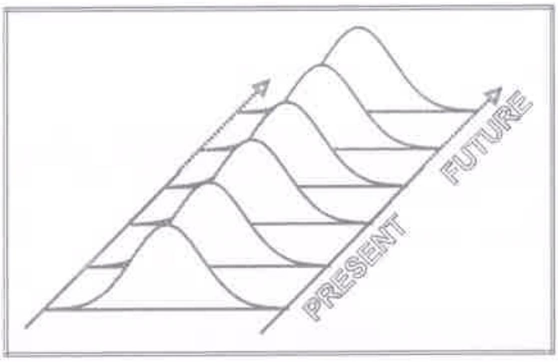
# What is Process Control?

A Process is in statistical control when it is stable...

100% of the individual data values are within the spread of natural variation (+-3σ) of the process

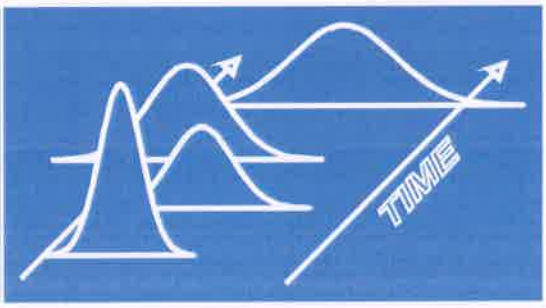



And, therefore, predictable...





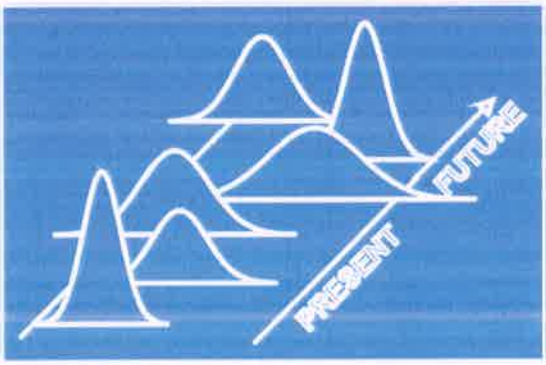

# What is "Out of Control" process?




An unstable process...

100% of the individual data values are NOT within the spread of natural variation ($\pm 3\sigma$) of the process

Few data values fall beyond the $\pm 3\sigma$ limits and are referred to as "OUTLIERS"




...is unpredictable

# Common Cause vs. Special Cause

| Type of variation | Characteristics |
|---|---|
| **COMMON CAUSE** | **Inherent to the process**<br>• Expected<br>• Predictable<br>• Normal<br>• Random |
| **SPECIAL CAUSE** | **Not always present**<br>• Unexpected<br>• Unpredictable<br>• Not normal<br>• Not random |



# Common Cause vs. Special Cause

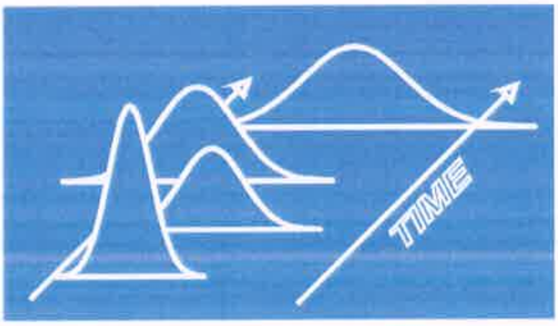

Only "COMMON" causes of variation are present in a Stable Process.

This variation is Random and Routine.

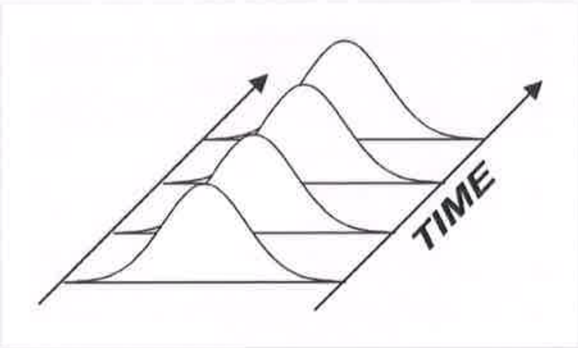
"SPECIAL" causes of variation are present in an Unstable Process.

This variation is Non-Random and Sporadic

Some points in time are exceptional when compared to the rest.

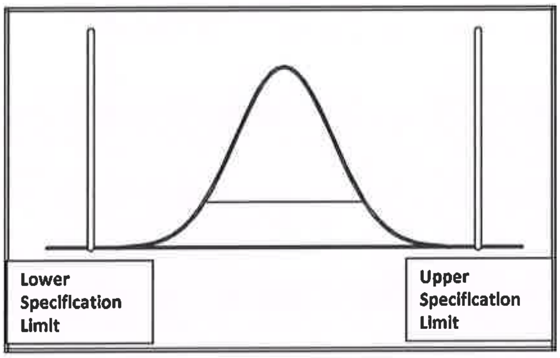


# Process Control vs. Process Capability



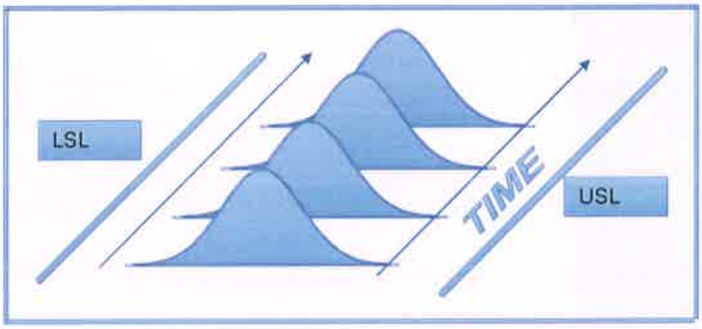

Process Control = Stability over time.

Process Capability = Ability of a stable process to meet specifications.



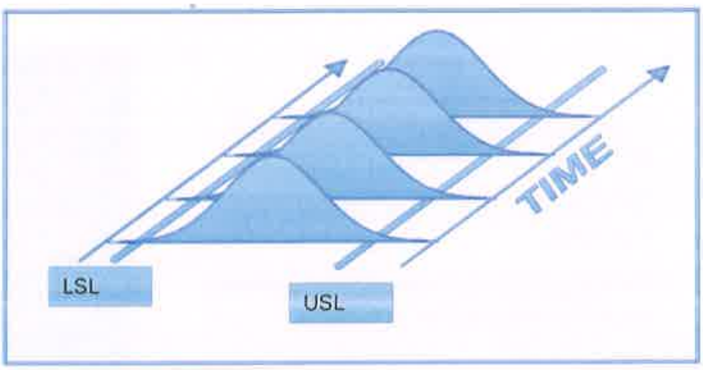



# Examples of Stable and Capable processes

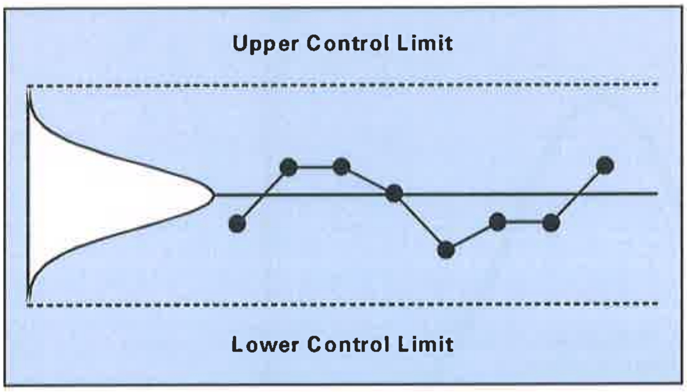



Process is Stable and Capable

Process is Stable but not Capable



# Control Limits vs. Specification Limits



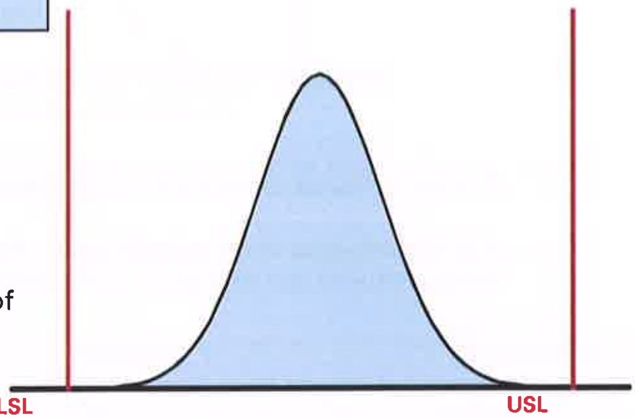

Control Limits are statistical bounds (the natural bounds of the data) used to determine process stability.

Statistically Control Limits are equivalent to $\pm 3\sigma$

Control limits are determined by the data (voice of the process).

Specification Limits are applied to individual measurements.

Specification limits are decided by people (voice of the process)



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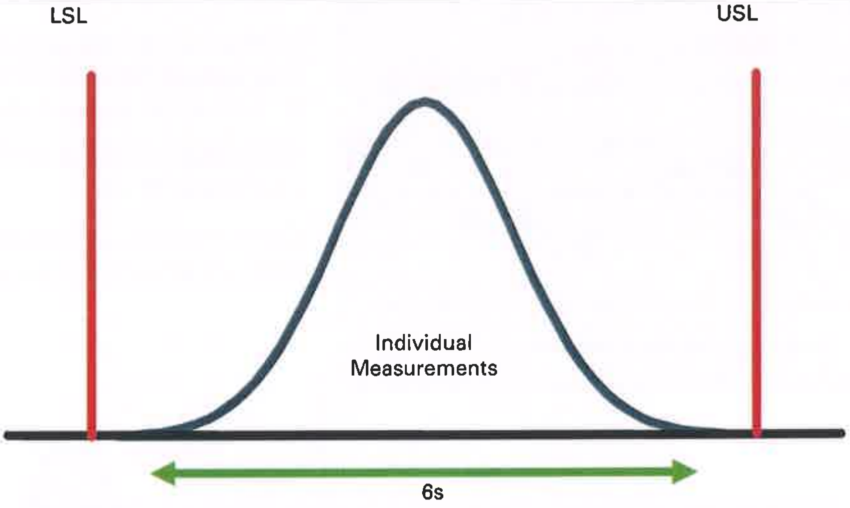
# Determine Process Capability

## Variable Data

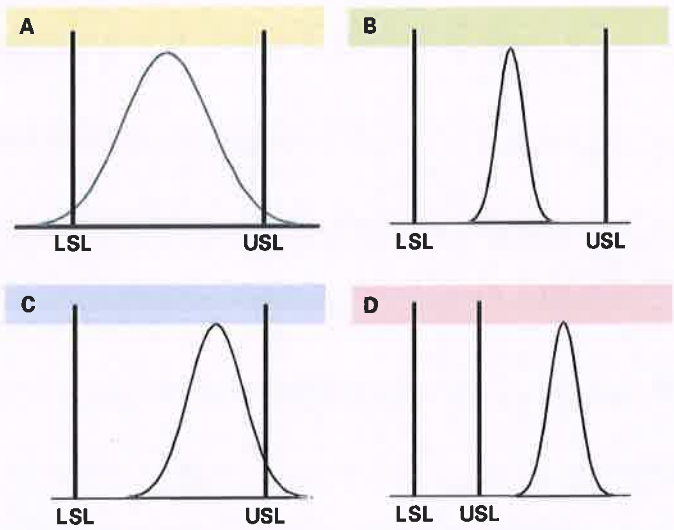
## Stable and Capable Process




- A stable process provides the most reliable estimates of process capability
- A process is said to be capable when the ± 3σ points of the distribution of individual measurements are contained well within the specification limits.

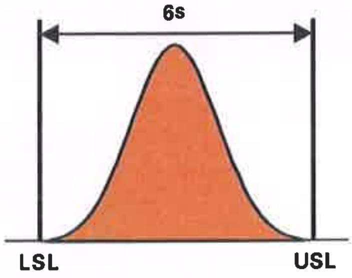


## Stable and Capable Process

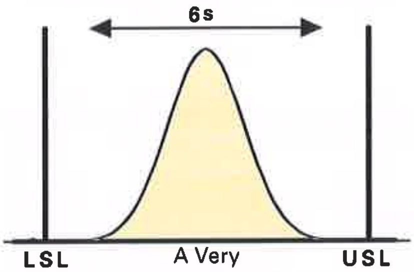



What can be said about the capability of these four processes?

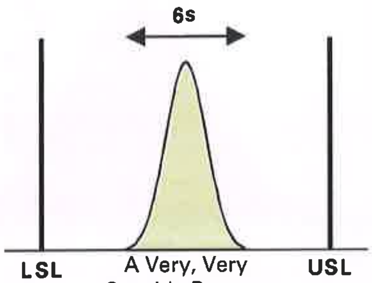
# How capable is the process?




Capable Process




A Very
Capable Process




A Very, Very
Capable Process

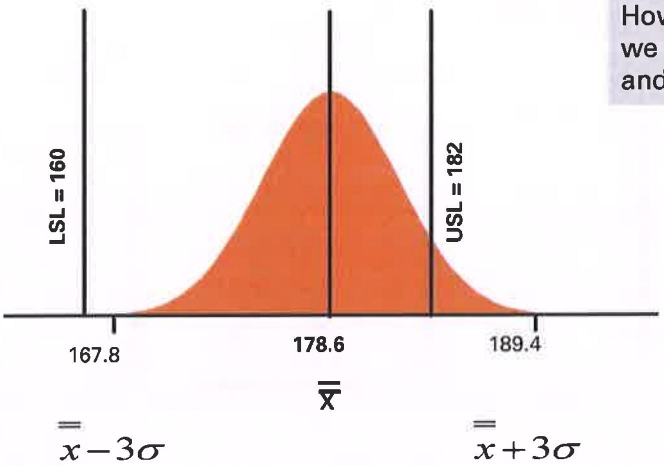


# Steps for evaluating process capability for variable data

- Assure the data is normally distributed
- Estimate the average and standard deviation of the process
- Determine the process' potential capability
- Quantify process performance

# Process variation vs Specification

Let us assume that for a normally distributed stable process, the average is 178.6 and the standard deviation is 3.6. The process target is 171, USL = 182, LSL = 160



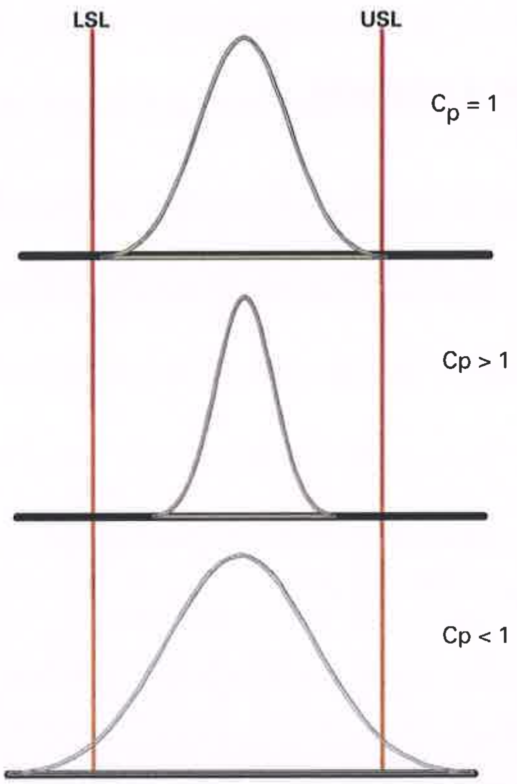

Process Variation:
At ± 3σ that is 99.73% of the time, the process is producing products that falls between 167.8 and 189.4.

However, as per customer specification, we want all product to fall between 160 and 182

KPMG



# Determine the potential process capability




Process is just about meeting the specification but centering needs attention

Process variation well under control. Larger the Cp, better the process

Process variation exceeds specification in this case. Process is producing defects

KPMG

# Determine the potential process capability

The Cp index reflects the potential of the process if the average were perfectly centered between the specification limits.

$$C_p = \frac{USL - LSL}{6\sigma}$$

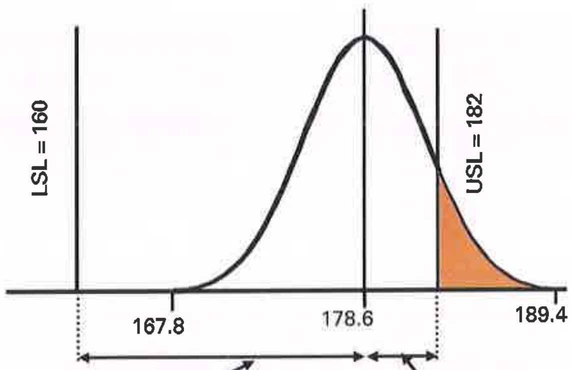
$$C_p = \frac{182 - 160}{6\sigma}$$

For the given example, the potential process capability Cp is 1.01



# Quantify actual process performance (Cpk)

To estimate the percentage of product / process that falls outside the specification limits, we compute Cp (upper) and Cp (lower)




$z_{lower}$ is the number of standard deviations between the Process Average and the Lower Specification Limit.

$z_{upper}$ is the number of standard deviations between the Process Average and the Upper Specification Limit.

## Quantify actual process performance (Cpk)

**The Cp index reflects the potential of the process if the average were perfectly centered between the specification limits.**

$$Z_{(upper)} = \frac{USL - \bar{X}}{\sigma}$$

$$Z_{(lower)} = \frac{\bar{X} - LSL}{\sigma}$$

$$C_{PK} = \frac{\text{Minimum of } Z\,(\text{upper})\ \&\ Z\,(\text{lower})}{3}$$





## Quantify actual process performance (Cpk)

**The Cp index reflects the potential of the process if the average were perfectly centered between the specification limits.**

$$Z_{(upper)} = \frac{182.0 - 178.6}{3.6}$$

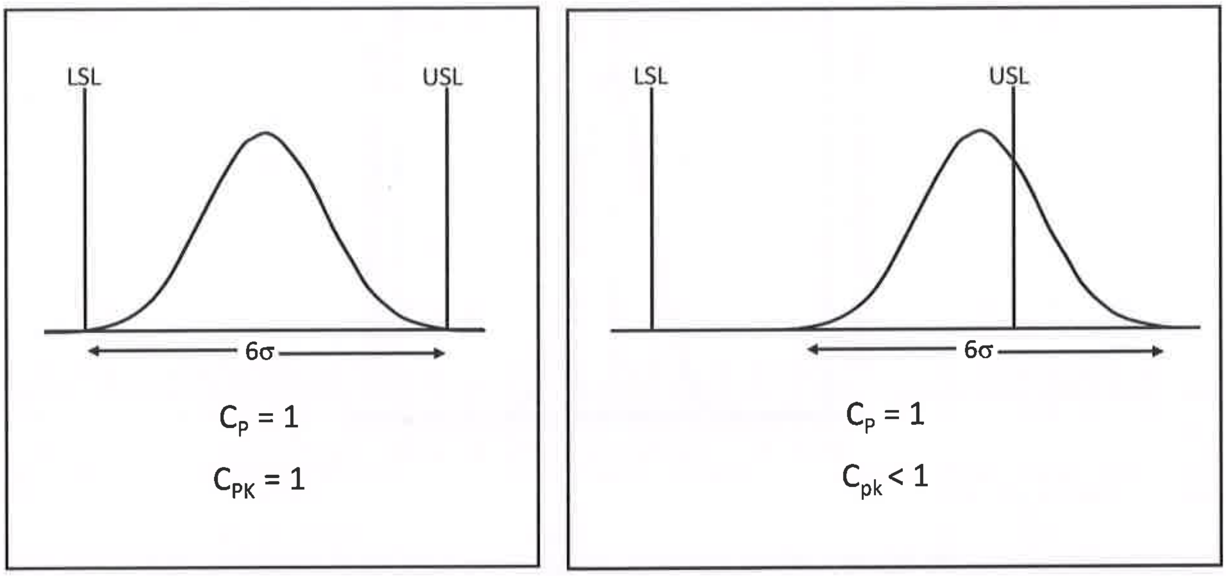
$$Z_{(lower)} = \frac{178.6 - 160}{3.6}$$

$Z_{(upper)} = 0.94$ $\quad$ $Z_{(lower)} = 5.17$

**Cpk = 0.94 / 3 = 0.31**

# Quantify actual process performance (Cpk)

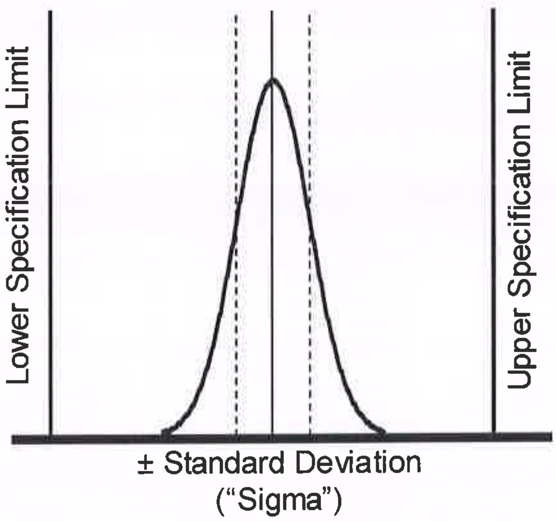
Unlike the Cp, the Cpk index takes into account off-centering of the process. The larger the Cpk index, the better.






# What is Sigma?

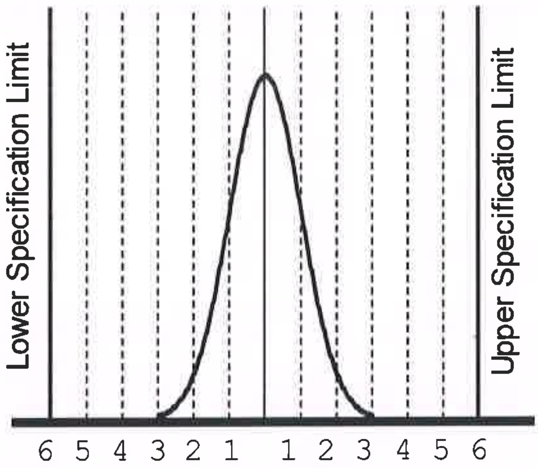
"Sigma" (Standard deviation) is a measure of variation




Plus or minus one standard deviation around the mean is about 68% of the total process output.

# What is a Six Sigma process?

If we can squeeze six standard deviations in between our process average and the customer's requirements...

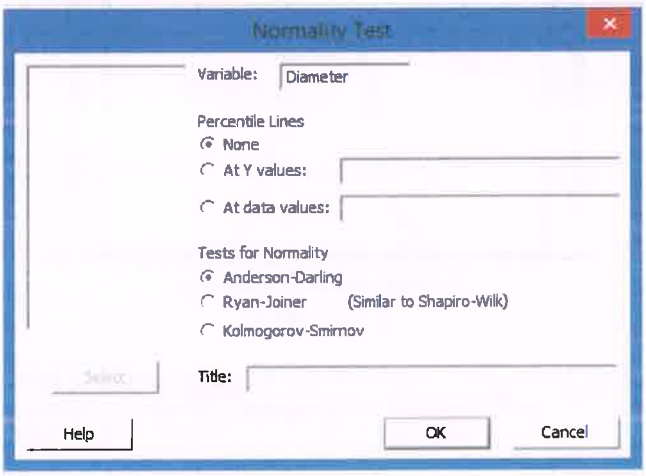



then
99.99966% of our "opportunities" meet customer requirements!

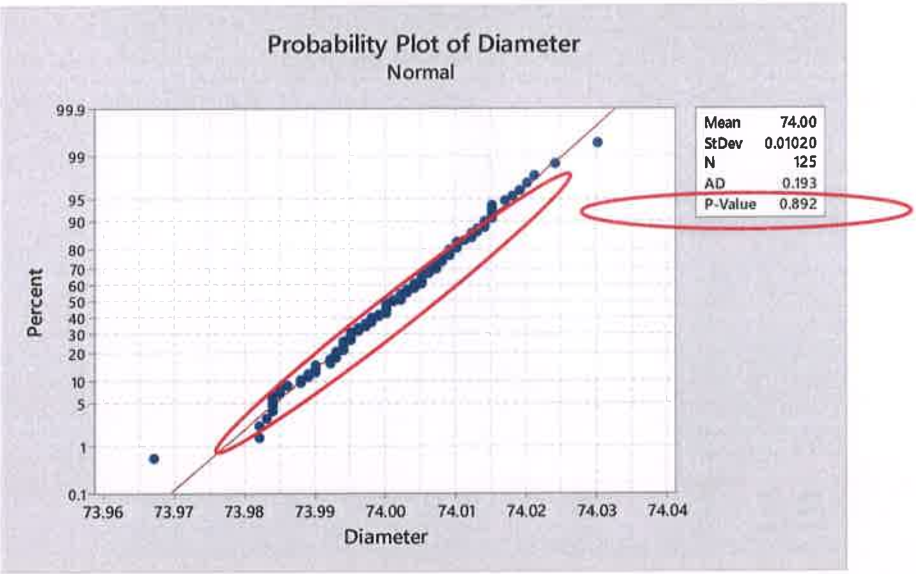


# Checking stability for variable data in Minitab

- To identify the average and standard deviation of a process, we first need to check the distribution i.e. if it is normal distribution?
- Let us refer the data sheet – Piston.MTW in Minitab for the same
- We check the normality of the data
- **Choose Stat> Basic Statistics> Normality Test**



# Checking stability for variable data in Minitab

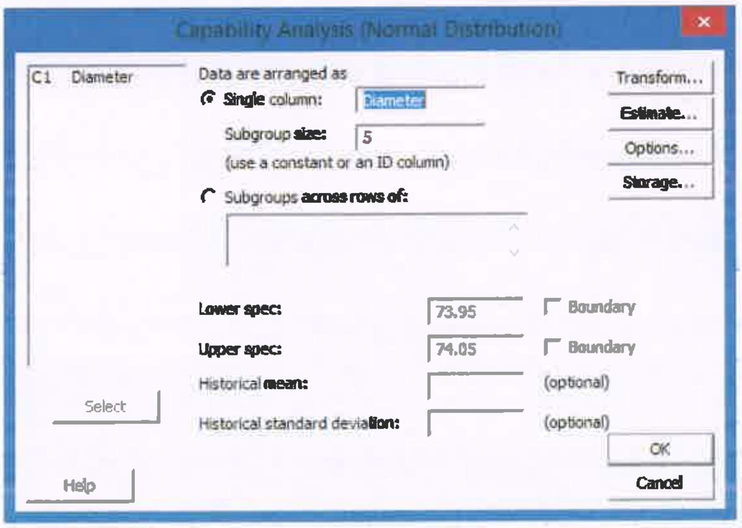



The Anderson-Darling test's p-value at 0.892 indicates that the data follows a normal distribution.

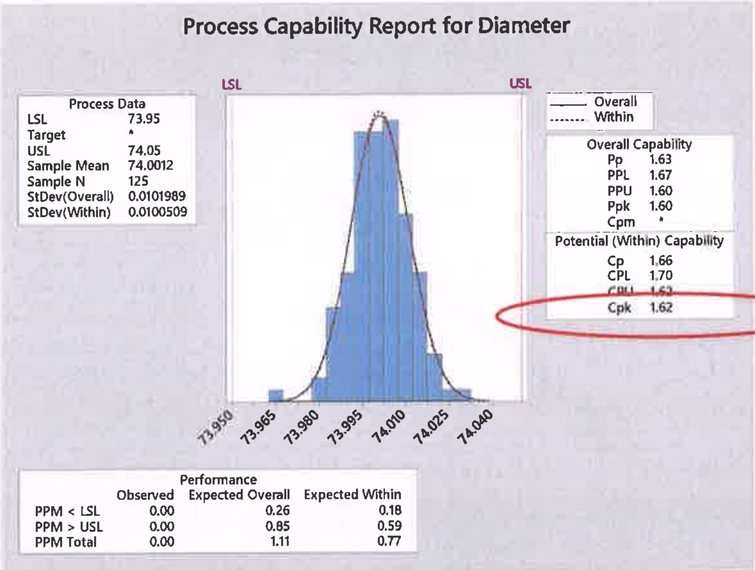


# Cp and Cpk in Minitab

- Since the data follows a normal distribution, we can now check the capability of the data.
- Let us refer the same data sheet – Piston.MTW in Minitab
- Choose Stat> Quality Tools> Capability Analysis> Normal



# Cp and Cpk in Minitab






# Determine Process Capability

## Attribute Data - DPMO

# Attribute Data - DPMO

| Item | Definition | Example |
|---|---|---|
| **Unit** | The Item produced or Processed. It is the specific Product or Service used to evaluate whether or not Customer Requirements are met | Transaction processed/ Query addressed. |
| **Defect** | Any Event that does not meet the specifications of a CTQ | Incorrect information provided/ Incorrect address etc. |
| **Defective** | Any Unit that contains one or more Defects. Such a unit is called a "Defective Unit". | A Bill with two Defects.(Name & Amount) |
| **Defect Opportunity** | Any Event which can be Measured that provides a CHANCE of not meeting a Customer Requirement. | Name, Address & Amount on a Bill Each represent an opportunity for Defect |



# Attribute Data - PPM and DPMO

DPU = Total Number of defects / Total number of units inspected

Department: Purchase
Defect: Incorrect entry
Total Defects: 56
Unit: Each MIS report (monthly)
No of units inspected: 5,000

**DPU = 56 / 5000 = 0.0112**
**PPM = DPU * 10^6 = 11,200 = 3.8 Sigma**

---

DPO per unit = $\frac{\text{Total Number of Defects}}{\text{Total number of units inspected * Opportunities}}$

Department: Purchase
Defect: Incorrect entry
Total Defects: 56
Unit: Each MIS report (monthly)
No of units inspected: 5,000
No of Opportunities per report: 6
**DPO = 56 / 5,000 *6 = 0.001866**
**DPMO = DPO*10^6 = 1,866 = 4.4 Sigma**

# Sigma and DPMO table

| Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.01 | 931888 | 0.26 | 892512 | 0.51 | 838913 | 0.76 | 770350 | 1.01 | 687933 | 1.26 | 594835 | 1.51 | 496011 | 1.76 | 397432 |
| 0.02 | 930563 | 0.27 | 890651 | 0.52 | 836457 | 0.77 | 767305 | 1.02 | 684386 | 1.27 | 590954 | 1.52 | 492022 | 1.77 | 393580 |
| 0.03 | 929219 | 0.28 | 888767 | 0.53 | 833977 | 0.78 | 764238 | 1.03 | 680822 | 1.28 | 587064 | 1.53 | 488033 | 1.78 | 389739 |
| 0.04 | 927855 | 0.29 | 886860 | 0.54 | 831472 | 0.79 | 761148 | 1.04 | 677242 | 1.29 | 583166 | 1.54 | 484047 | 1.79 | 385908 |
| 0.05 | 926471 | 0.30 | 884930 | 0.55 | 828944 | 0.80 | 758036 | 1.05 | 673645 | 1.30 | 579260 | 1.55 | 480061 | 1.80 | 382089 |
| 0.06 | 925066 | 0.31 | 882977 | 0.56 | 826391 | 0.81 | 754903 | 1.06 | 670031 | 1.31 | 575345 | 1.56 | 476078 | 1.81 | 378281 |
| 0.07 | 923641 | 0.32 | 881000 | 0.57 | 823814 | 0.82 | 751748 | 1.07 | 666402 | 1.32 | 571424 | 1.57 | 472097 | 1.82 | 374484 |
| 0.08 | 922196 | 0.33 | 878999 | 0.58 | 821214 | 0.83 | 748571 | 1.08 | 662757 | 1.33 | 567495 | 1.58 | 468119 | 1.83 | 370700 |
| 0.09 | 920730 | 0.34 | 876976 | 0.59 | 818589 | 0.84 | 745373 | 1.09 | 659097 | 1.34 | 563559 | 1.59 | 464144 | 1.84 | 366928 |
| 0.10 | 919243 | 0.35 | 874928 | 0.60 | 815940 | 0.85 | 742154 | 1.10 | 655422 | 1.35 | 559618 | 1.60 | 460172 | 1.85 | 363169 |
| 0.11 | 917736 | 0.36 | 872857 | 0.61 | 813267 | 0.86 | 738914 | 1.11 | 651732 | 1.36 | 555670 | 1.61 | 456205 | 1.86 | 359424 |
| 0.12 | 916207 | 0.37 | 870762 | 0.62 | 810570 | 0.87 | 735653 | 1.12 | 648027 | 1.37 | 551717 | 1.62 | 452242 | 1.87 | 355691 |
| 0.13 | 914656 | 0.38 | 868643 | 0.63 | 807850 | 0.88 | 732371 | 1.13 | 644309 | 1.38 | 547758 | 1.63 | 448283 | 1.88 | 351973 |
| 0.14 | 913085 | 0.39 | 866500 | 0.64 | 805106 | 0.89 | 729069 | 1.14 | 640576 | 1.39 | 543795 | 1.64 | 444330 | 1.89 | 348268 |
| 0.15 | 911492 | 0.40 | 864334 | 0.65 | 802338 | 0.90 | 725747 | 1.15 | 636831 | 1.40 | 539828 | 1.65 | 440382 | 1.90 | 344578 |
| 0.16 | 909877 | 0.41 | 862143 | 0.66 | 799546 | 0.91 | 722405 | 1.16 | 633072 | 1.41 | 535856 | 1.66 | 436441 | 1.91 | 340903 |
| 0.17 | 908241 | 0.42 | 859929 | 0.67 | 796731 | 0.92 | 719043 | 1.17 | 629300 | 1.42 | 531881 | 1.67 | 432505 | 1.92 | 337243 |
| 0.18 | 906582 | 0.43 | 857690 | 0.68 | 793892 | 0.93 | 715661 | 1.18 | 625516 | 1.43 | 527903 | 1.68 | 428576 | 1.93 | 333598 |
| 0.19 | 904902 | 0.44 | 855428 | 0.69 | 791030 | 0.94 | 712260 | 1.19 | 621719 | 1.44 | 523922 | 1.69 | 424655 | 1.94 | 329969 |
| 0.20 | 903199 | 0.45 | 853141 | 0.70 | 788145 | 0.95 | 708840 | 1.20 | 617911 | 1.45 | 519939 | 1.70 | 420740 | 1.95 | 326355 |
| 0.21 | 901475 | 0.46 | 850830 | 0.71 | 785236 | 0.96 | 705402 | 1.21 | 614092 | 1.46 | 515953 | 1.71 | 416834 | 1.96 | 322758 |
| 0.22 | 899727 | 0.47 | 848495 | 0.72 | 782305 | 0.97 | 701944 | 1.22 | 610261 | 1.47 | 511967 | 1.72 | 412936 | 1.97 | 319178 |
| 0.23 | 897958 | 0.48 | 846136 | 0.73 | 779350 | 0.98 | 698468 | 1.23 | 606420 | 1.48 | 507978 | 1.73 | 409046 | 1.98 | 315614 |
| 0.24 | 896165 | 0.49 | 843752 | 0.74 | 776373 | 0.99 | 694974 | 1.24 | 602568 | 1.49 | 503989 | 1.74 | 405165 | 1.99 | 312067 |
| 0.25 | 894350 | 0.50 | 841345 | 0.75 | 773373 | 1.00 | 691462 | 1.25 | 598706 | 1.50 | 500000 | 1.75 | 401294 | 2.00 | 308538 |



# Sigma and DPMO table

| Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.01 | 305026 | 2.26 | 223627 | 2.51 | 156248 | 2.76 | 103835 | 3.01 | 65522 | 3.26 | 39204 | 3.51 | 22216 | 3.76 | 11911 |
| 2.02 | 301532 | 2.27 | 220650 | 2.52 | 153864 | 2.77 | 102042 | 3.02 | 64255 | 3.27 | 38364 | 3.52 | 21692 | 3.77 | 11604 |
| 2.03 | 298056 | 2.28 | 217695 | 2.53 | 151505 | 2.78 | 100273 | 3.03 | 63008 | 3.28 | 37538 | 3.53 | 21178 | 3.78 | 11304 |
| 2.04 | 294599 | 2.29 | 214764 | 2.54 | 149170 | 2.79 | 98525 | 3.04 | 61780 | 3.29 | 36727 | 3.54 | 20675 | 3.79 | 11011 |
| 2.05 | 291160 | 2.30 | 211855 | 2.55 | 146859 | 2.80 | 96800 | 3.05 | 60571 | 3.30 | 35930 | 3.55 | 20182 | 3.80 | 10724 |
| 2.06 | 287740 | 2.31 | 208970 | 2.56 | 144572 | 2.81 | 95098 | 3.06 | 59380 | 3.31 | 35148 | 3.56 | 19699 | 3.81 | 10444 |
| 2.07 | 284339 | 2.32 | 206108 | 2.57 | 142310 | 2.82 | 93418 | 3.07 | 58208 | 3.32 | 34380 | 3.57 | 19226 | 3.82 | 10170 |
| 2.08 | 280957 | 2.33 | 203269 | 2.58 | 140071 | 2.83 | 91759 | 3.08 | 57053 | 3.33 | 33625 | 3.58 | 18763 | 3.83 | 9903 |
| 2.09 | 277595 | 2.34 | 200454 | 2.59 | 137857 | 2.84 | 90123 | 3.09 | 55917 | 3.34 | 32884 | 3.59 | 18309 | 3.84 | 9642 |
| 2.10 | 274253 | 2.35 | 197663 | 2.60 | 135666 | 2.85 | 88508 | 3.10 | 54799 | 3.35 | 32157 | 3.60 | 17864 | 3.85 | 9387 |
| 2.11 | 270931 | 2.36 | 194895 | 2.61 | 133500 | 2.86 | 86915 | 3.11 | 53699 | 3.36 | 31443 | 3.61 | 17429 | 3.86 | 9137 |
| 2.12 | 267629 | 2.37 | 192150 | 2.62 | 131357 | 2.87 | 85343 | 3.12 | 52616 | 3.37 | 30742 | 3.62 | 17003 | 3.87 | 8894 |
| 2.13 | 264347 | 2.38 | 189430 | 2.63 | 129238 | 2.88 | 83793 | 3.13 | 51551 | 3.38 | 30054 | 3.63 | 16586 | 3.88 | 8656 |
| 2.14 | 261086 | 2.39 | 186733 | 2.64 | 127143 | 2.89 | 82264 | 3.14 | 50503 | 3.39 | 29379 | 3.64 | 16177 | 3.89 | 8424 |
| 2.15 | 257846 | 2.40 | 184060 | 2.65 | 125072 | 2.90 | 80757 | 3.15 | 49471 | 3.40 | 28717 | 3.65 | 15778 | 3.90 | 8198 |
| 2.16 | 254627 | 2.41 | 181411 | 2.66 | 123024 | 2.91 | 79270 | 3.16 | 48457 | 3.41 | 28067 | 3.66 | 15386 | 3.91 | 7976 |
| 2.17 | 251429 | 2.42 | 178786 | 2.67 | 121000 | 2.92 | 77804 | 3.17 | 47460 | 3.42 | 27429 | 3.67 | 15003 | 3.92 | 7760 |
| 2.18 | 248252 | 2.43 | 176186 | 2.68 | 119000 | 2.93 | 76359 | 3.18 | 46479 | 3.43 | 26803 | 3.68 | 14629 | 3.93 | 7549 |
| 2.19 | 245097 | 2.44 | 173609 | 2.69 | 117023 | 2.94 | 74934 | 3.19 | 45514 | 3.44 | 26190 | 3.69 | 14262 | 3.94 | 7344 |
| 2.20 | 241964 | 2.45 | 171056 | 2.70 | 115070 | 2.95 | 73529 | 3.20 | 44565 | 3.45 | 25588 | 3.70 | 13903 | 3.95 | 7143 |
| 2.21 | 238852 | 2.46 | 168528 | 2.71 | 113139 | 2.96 | 72145 | 3.21 | 43633 | 3.46 | 24998 | 3.71 | 13553 | 3.96 | 6947 |
| 2.22 | 235762 | 2.47 | 166023 | 2.72 | 111232 | 2.97 | 70781 | 3.22 | 42716 | 3.47 | 24419 | 3.72 | 13209 | 3.97 | 6756 |
| 2.23 | 232695 | 2.48 | 163543 | 2.73 | 109349 | 2.98 | 69437 | 3.23 | 41815 | 3.48 | 23852 | 3.73 | 12874 | 3.98 | 6569 |
| 2.24 | 229650 | 2.49 | 161087 | 2.74 | 107488 | 2.99 | 68112 | 3.24 | 40930 | 3.49 | 23295 | 3.74 | 12545 | 3.99 | 6387 |
| 2.25 | 226627 | 2.50 | 158655 | 2.75 | 105650 | 3.00 | 66807 | 3.25 | 40059 | 3.50 | 22750 | 3.75 | 12224 | 4.00 | 6210 |

# Sigma and DPMO table

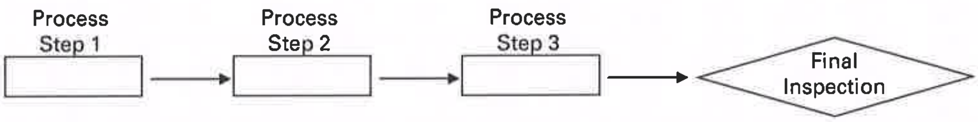
| Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO | Sigma | DPMO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.01 | 6037 | 4.26 | 2890 | 4.51 | 1306 | 4.76 | 557 | 5.01 | 224 | 5.26 | 85 | 5.51 | 30.4 | 5.76 | 10.2 |
| 4.02 | 5868 | 4.27 | 2803 | 4.52 | 1264 | 4.77 | 538 | 5.02 | 216 | 5.27 | 82 | 5.52 | 29.1 | 5.77 | 9.8 |
| 4.03 | 5703 | 4.28 | 2718 | 4.53 | 1223 | 4.78 | 519 | 5.03 | 208 | 5.28 | 78 | 5.53 | 27.9 | 5.78 | 9.4 |
| 4.04 | 5543 | 4.29 | 2635 | 4.54 | 1183 | 4.79 | 501 | 5.04 | 200 | 5.29 | 75 | 5.54 | 26.7 | 5.79 | 8.9 |
| 4.05 | 5386 | 4.30 | 2555 | 4.55 | 1144 | 4.80 | 483 | 5.05 | 193 | 5.30 | 72 | 5.55 | 25.6 | 5.80 | 8.5 |
| 4.06 | 5234 | 4.31 | 2477 | 4.56 | 1107 | 4.81 | 467 | 5.06 | 185 | 5.31 | 70 | 5.56 | 24.5 | 5.81 | 8.2 |
| 4.07 | 5085 | 4.32 | 2401 | 4.57 | 1070 | 4.82 | 450 | 5.07 | 179 | 5.32 | 67 | 5.57 | 23.5 | 5.82 | 7.8 |
| 4.08 | 4940 | 4.33 | 2327 | 4.58 | 1035 | 4.83 | 434 | 5.08 | 172 | 5.33 | 64 | 5.58 | 22.5 | 5.83 | 7.5 |
| 4.09 | 4799 | 4.34 | 2256 | 4.59 | 1001 | 4.84 | 419 | 5.09 | 165 | 5.34 | 62 | 5.59 | 21.6 | 5.84 | 7.1 |
| 4.10 | 4661 | 4.35 | 2186 | 4.60 | 968 | 4.85 | 404 | 5.10 | 159 | 5.35 | 59 | 5.60 | 20.7 | 5.85 | 6.8 |
| 4.11 | 4527 | 4.36 | 2118 | 4.61 | 936 | 4.86 | 390 | 5.11 | 153 | 5.36 | 57 | 5.61 | 19.8 | 5.86 | 6.5 |
| 4.12 | 4397 | 4.37 | 2052 | 4.62 | 904 | 4.87 | 376 | 5.12 | 147 | 5.37 | 54 | 5.62 | 19.0 | 5.87 | 6.2 |
| 4.13 | 4269 | 4.38 | 1988 | 4.63 | 874 | 4.88 | 362 | 5.13 | 142 | 5.38 | 52 | 5.63 | 18.1 | 5.88 | 5.9 |
| 4.14 | 4145 | 4.39 | 1926 | 4.64 | 845 | 4.89 | 350 | 5.14 | 136 | 5.39 | 50 | 5.64 | 17.4 | 5.89 | 5.7 |
| 4.15 | 4025 | 4.40 | 1866 | 4.65 | 816 | 4.90 | 337 | 5.15 | 131 | 5.40 | 48 | 5.65 | 16.6 | 5.90 | 5.4 |
| 4.16 | 3907 | 4.41 | 1807 | 4.66 | 789 | 4.91 | 325 | 5.16 | 126 | 5.41 | 46 | 5.66 | 15.9 | 5.91 | 5.2 |
| 4.17 | 3793 | 4.42 | 1750 | 4.67 | 762 | 4.92 | 313 | 5.17 | 121 | 5.42 | 44 | 5.67 | 15.2 | 5.92 | 4.9 |
| 4.18 | 3681 | 4.43 | 1695 | 4.68 | 736 | 4.93 | 302 | 5.18 | 117 | 5.43 | 42 | 5.68 | 14.6 | 5.93 | 4.7 |
| 4.19 | 3573 | 4.44 | 1641 | 4.69 | 711 | 4.94 | 291 | 5.19 | 112 | 5.44 | 41 | 5.69 | 14.0 | 5.94 | 4.5 |
| 4.20 | 3467 | 4.45 | 1589 | 4.70 | 687 | 4.95 | 280 | 5.20 | 108 | 5.45 | 39 | 5.70 | 13.4 | 5.95 | 4.3 |
| 4.21 | 3364 | 4.46 | 1538 | 4.71 | 664 | 4.96 | 270 | 5.21 | 104 | 5.46 | 37 | 5.71 | 12.8 | 5.96 | 4.1 |
| 4.22 | 3264 | 4.47 | 1489 | 4.72 | 641 | 4.97 | 260 | 5.22 | 100 | 5.47 | 36 | 5.72 | 12.2 | 5.97 | 3.9 |
| 4.23 | 3167 | 4.48 | 1441 | 4.73 | 619 | 4.98 | 251 | 5.23 | 96 | 5.48 | 34 | 5.73 | 11.7 | 5.98 | 3.7 |
| 4.24 | 3072 | 4.49 | 1395 | 4.74 | 598 | 4.99 | 242 | 5.24 | 92 | 5.49 | 33 | 5.74 | 11.2 | 5.99 | 3.6 |
| 4.25 | 2980 | 4.50 | 1350 | 4.75 | 577 | 5.00 | 233 | 5.25 | 88 | 5.50 | 32 | 5.75 | 10.7 | 6.00 | 3.4 |



# Rolled Throughput Yield

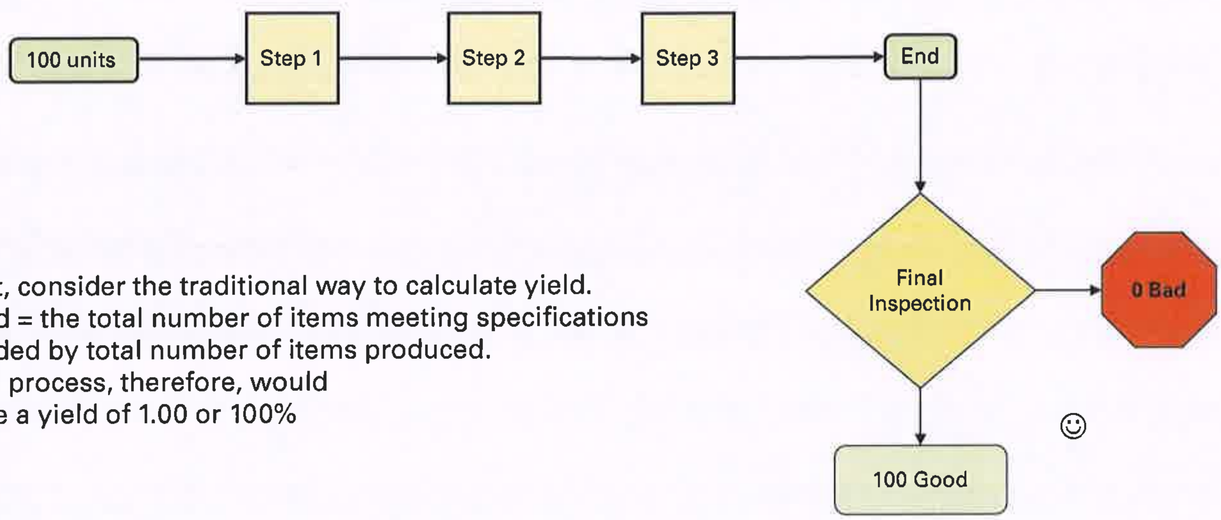
# Attribute Data - Rolled Throughput Yield

- Another useful metric in Six Sigma is the Rolled Throughput Yield (RTY)
- RTY is the probability of obtaining a unit with zero defects.
- Let us consider a process as below



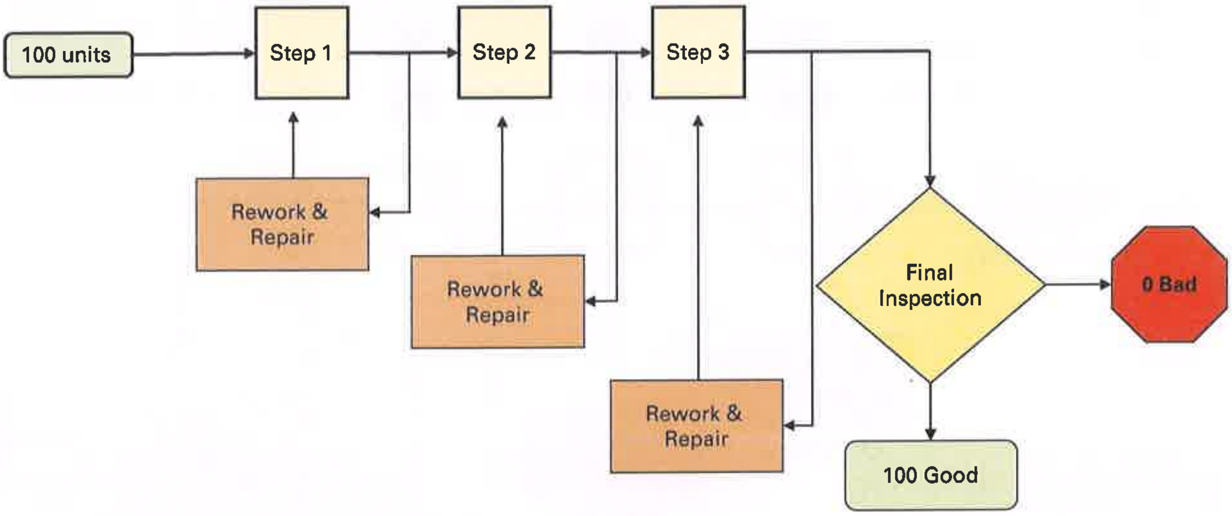



# Attribute Data - Rolled Throughput Yield




First, consider the traditional way to calculate yield.
Yield = the total number of items meeting specifications divided by total number of items produced.
This process, therefore, would have a yield of 1.00 or 100%

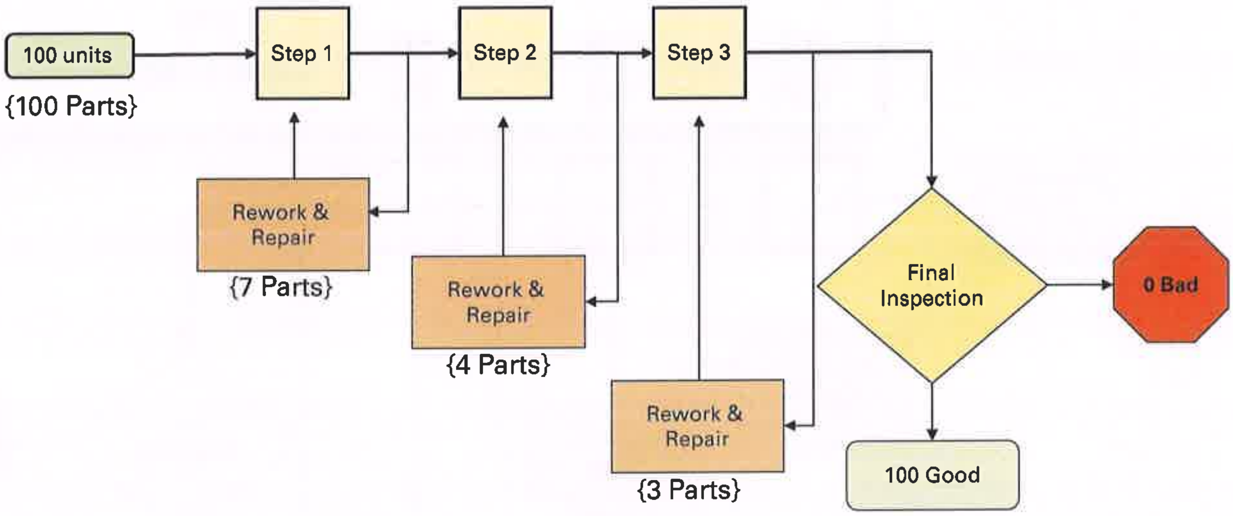
# Attribute Data - Rolled Throughput Yield




Upon closer inspection of the process, however, we begin to discover rework & repair at every station.

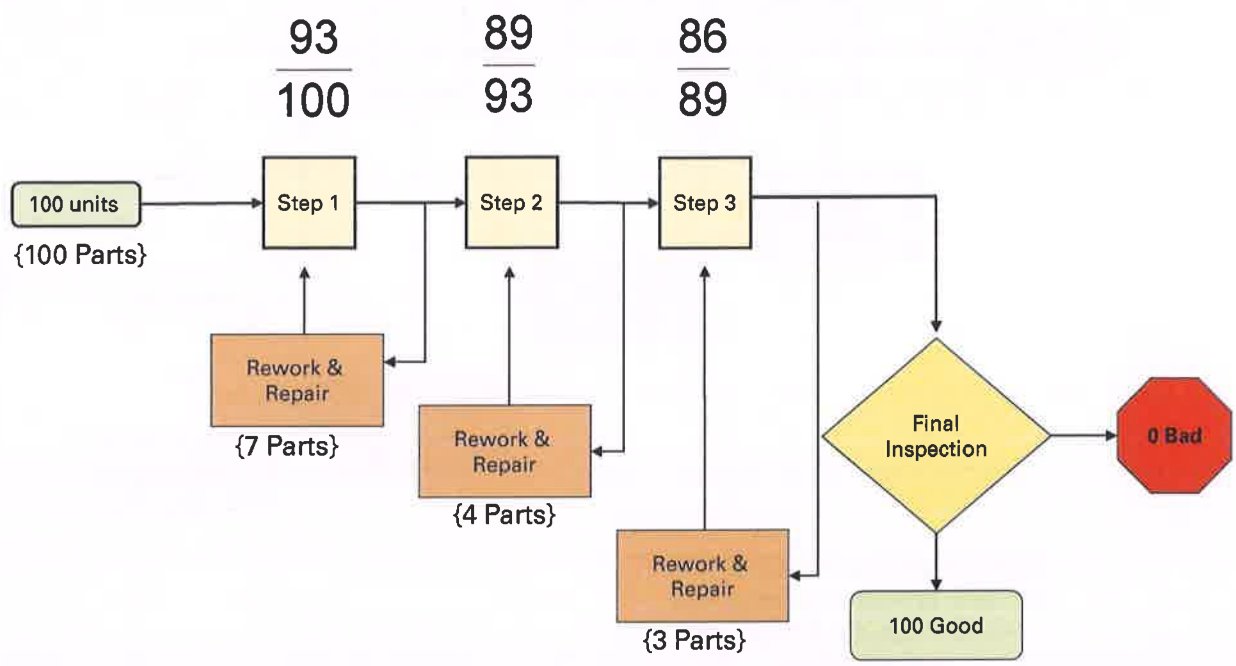


# Attribute Data - Rolled Throughput Yield




If we start 100 parts through the process, how many are reworked or repaired before final inspection?

# Attribute Data - Rolled Throughput Yield



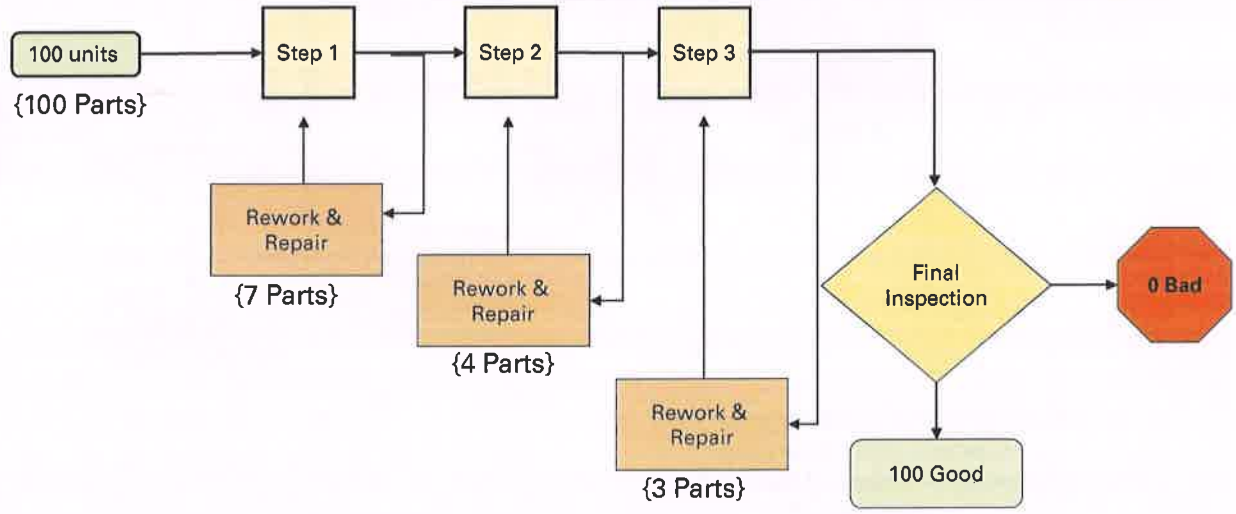



# Attribute Data - Rolled Throughput Yield

$$\frac{93}{100} \times \frac{89}{93} \times \frac{86}{89}$$

**RTY**

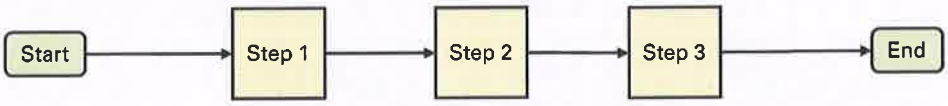
= 0.86 or 86%



# Attribute Data - Rolled Throughput Yield

**RTY**

$$\frac{93}{100} \times \frac{89}{93} \times \frac{86}{89} = 0.86 \text{ or } 86\%$$




This means that 14% of the effort expended in this process is due to defects which result in rework and repair. If there is a labor content of $430,000 per year, approximately 14% of that ($60,200) is waste.

That's the "hidden factory."

RTY can be used ...

- To identify opportunities for improvement.
- To characterize the process steps, unveiling the hidden factory.



# Inference from Measure Phase

- The Defect (Y) and Possible Opportunities for the Defect to Occur
- Data Type – Attribute or Continuous
- Types of Sampling
- Data Collection Check Sheets
- Operational Definitions and Measurement Method Statements
- Measurement System Analysis
- Current Process Capability (DPMO; RTY; Cp and Cpk)

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# Analyze Phase

## Analyze Phase - Roadmap

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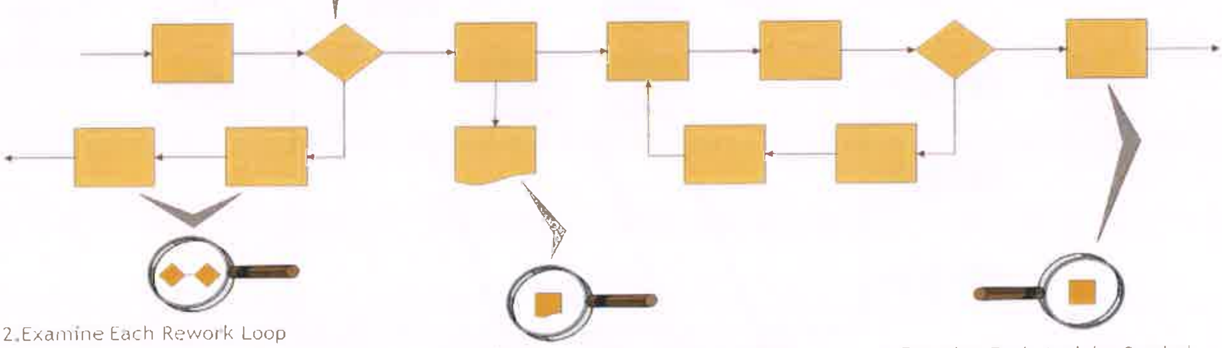
# Identify Possible Causes

## Root Cause Analysis

1. Examine Each Decision Symbol
   - Is this a checking activity?
   - Is this a complete check, or do some types of errors go undetected
   - Is this a redundant check?



2. Examine Each Rework Loop
   - Would we need to perform these activities if we had no failure?
   - How 'long' is this rework loop (steps, time lost, resources consumed, etc?)
   - Does this rework loop prevent the problem from reoccurring?

4. Examine Each Document or Database Symbol
   - Is this necessary?
   - How is this kept up to date?
   - Is there a single source for this information?
   - How can we use this information to monitor and improve the process?

3. Examine Each Activity Symbol
   - Is this a redundant activity?
   - What is the value of this activity relative to its cost?
   - How have we prevented errors in this activity?

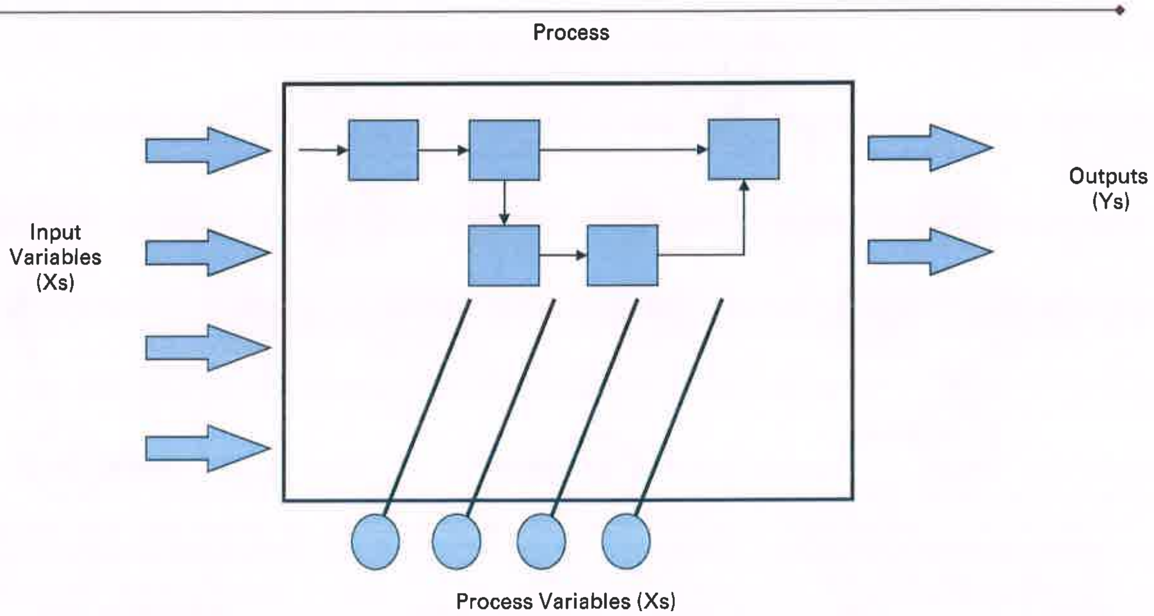
# Root Cause Analysis

Why do a root cause analysis?

- Use the process data to understand the problem and identify the vital few root causes in order to reduce variation that the customer experiences
- Eliminate actions based on intuition and preconceived ideas
- Recalibrate project scope
- Establish performance goals for the process
- Allows teams to develop sustainable process improvements that will lead to long-term benefits
- Determine potential benefit of project



# Root Cause Analysis




**What Are The Vital Few Process Inputs And Variables (X's) That Affect CTQ Performance Or Output Measures (Y's) ?**

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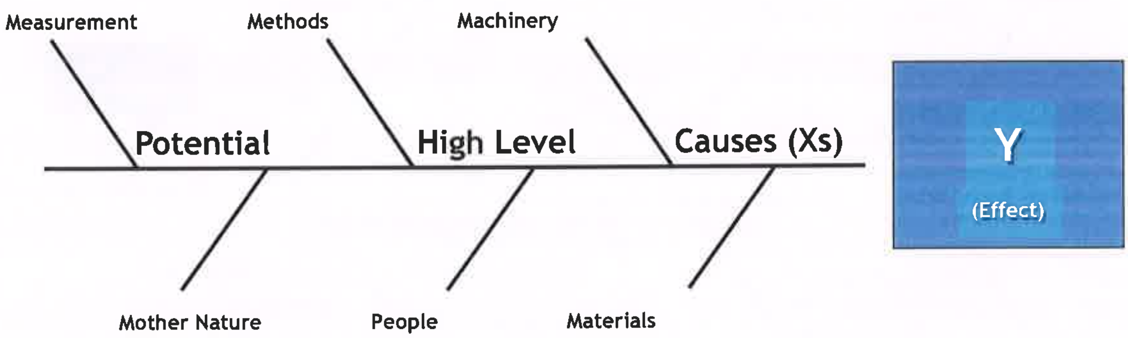
# Identify Possible Causes

## Cause and Effect Diagram

## Cause and Effect diagram

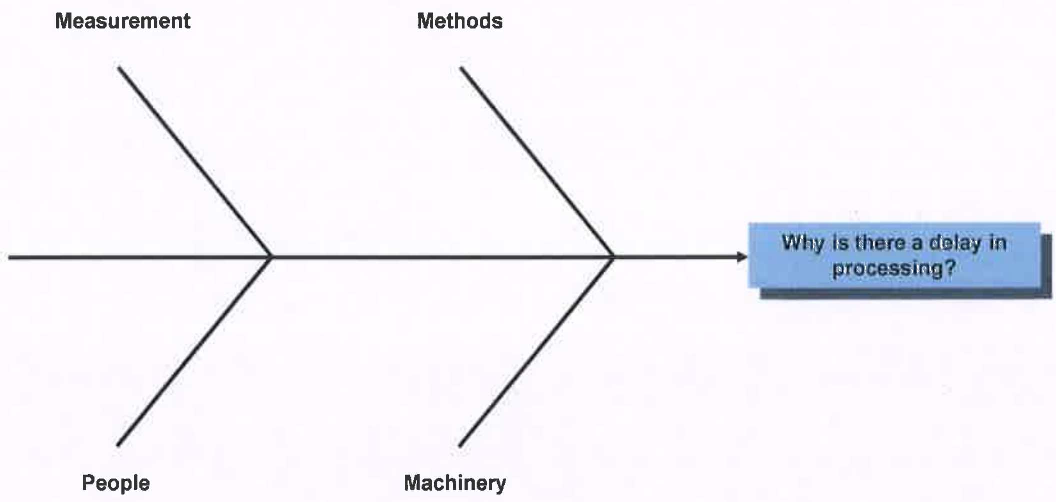
A visual tool used by an improvement team to **brainstorm** and **logically organize** possible causes for a specific problem or effect




- Summarize potential high-level causes
- Provide visual display of potential causes
- Stimulate the identification of deeper potential causes

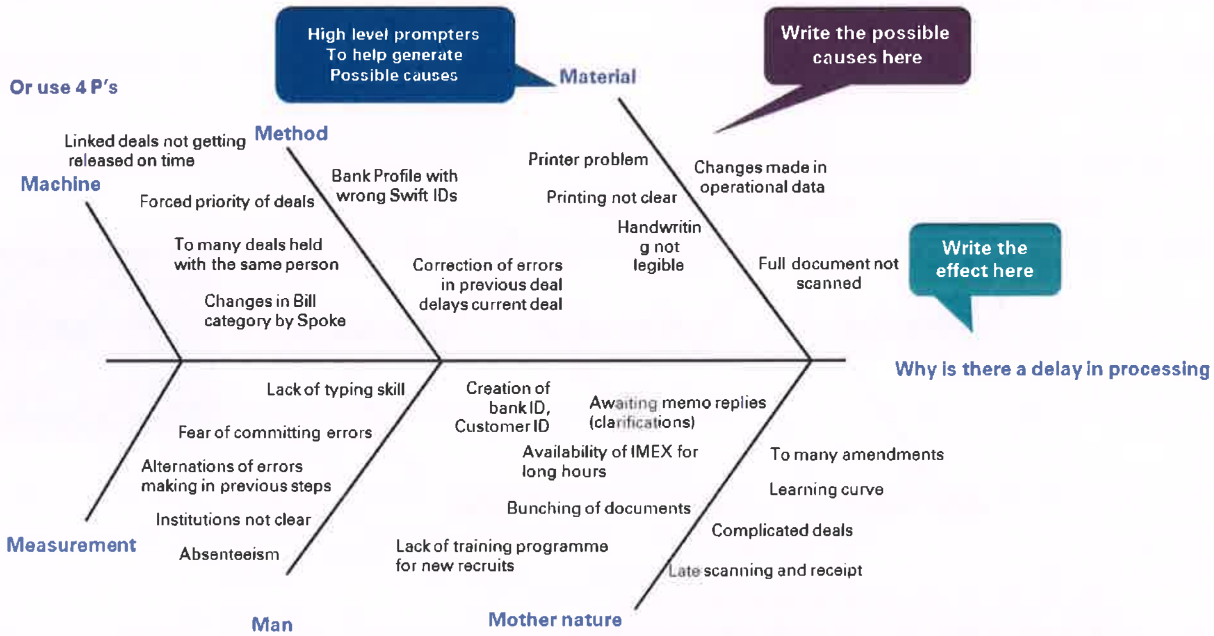
# Why Cause and effect diagram

**Brainstorm the "major" cause categories and connect to the centerline of the Cause & Effect diagram**






# Cause and effect diagram - An Example



## Sorting the Possible Causes

**Non-Controllable Causes:** These are causes that the team unanimously conclude are beyond the control of the present process boundaries or outside the physical location of the process execution.

**Lack of Solution OR Direct Improvements:** These are causes that are actually solutions that can be implemented directly and need no further analysis. They are usually stated as lack of resources, equipment, tools or training.

**Likely and Controllable Causes:** These causes are the causes that have passed the above two filters and need further analysis.



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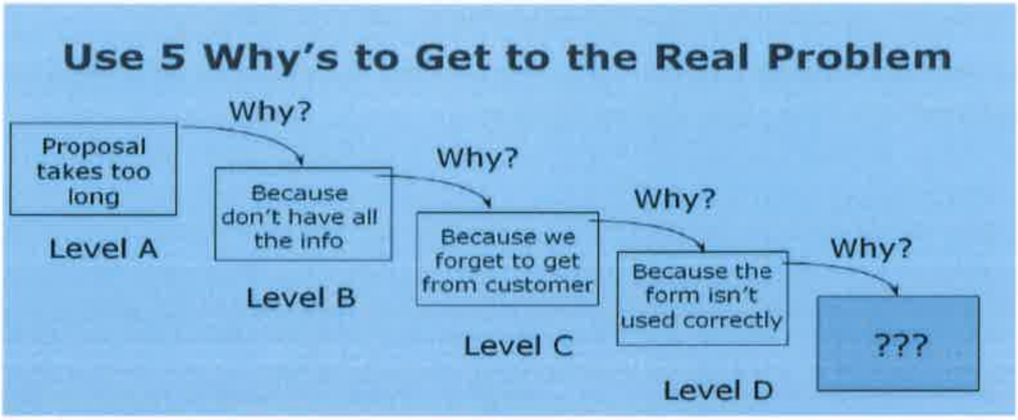
# Identify Possible Causes

## 5 Why's?

# Asking 5 Why's?

- The immediate next step after the segregation is to attack the likely and controllable causes and ask at least 3 – 5 why's?..... for each cause. This is called root cause drill down.
- Only after we have asked why 3 - 5 times to each of the likely causes, we will be able to arrive at the **possible root cause, also known as KPIV.**




Our project then becomes: Improving the percentage of RFQ's that the form is filled out correctly on.



# 5 Why's? - An Example

**WHY do we have poor and declining participation in improvement programs?**
1. Because people resist change .

**Why** do people resist change?
2. Because they fear making mistakes.

**Why** do people fear making mistakes?
3. Because they are criticized for mistakes.

**Why** are people criticized for mistakes?
No ideas, let's move on.

**Okay, then Why** else do people fear making mistakes
4. Because they are penalized for mistakes.

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# Identify Possible Causes

## Pareto Diagram

# Pareto Analysis

### What is a Pareto Diagram?

- A Pareto chart is a bar chart that graphically ranks defects from largest to smallest, which can help prioritize quality problems and focus improvement efforts on areas where the largest gains can be made.
- Pareto analysis was conceptualized by an Italian economist – Vilfredo Pareto
- In his endeavor, Pareto tried to prove that distribution of wealth and income in societies is not random, but there is a consistent pattern.
- In his study – Principle of Unequal Distribution, he proved that 80% of wealth in Italy is controlled by 20% of elite
- The concept was formulated in six sigma by Dr Joseph Juran.
- Juran extended this principle of 80-20 to quality control stating that most defects in a production are a result of small percentage of the cause of the defects – which he described as "vital few from trivial many"
- Therefore, Pareto analysis is based on the principle that 80% of problems find their roots in 20% causes.
- In other words, it is a diagram that shows 20% of the inputs (X's) cause 80% of the problems with dependent process outputs (Ys)

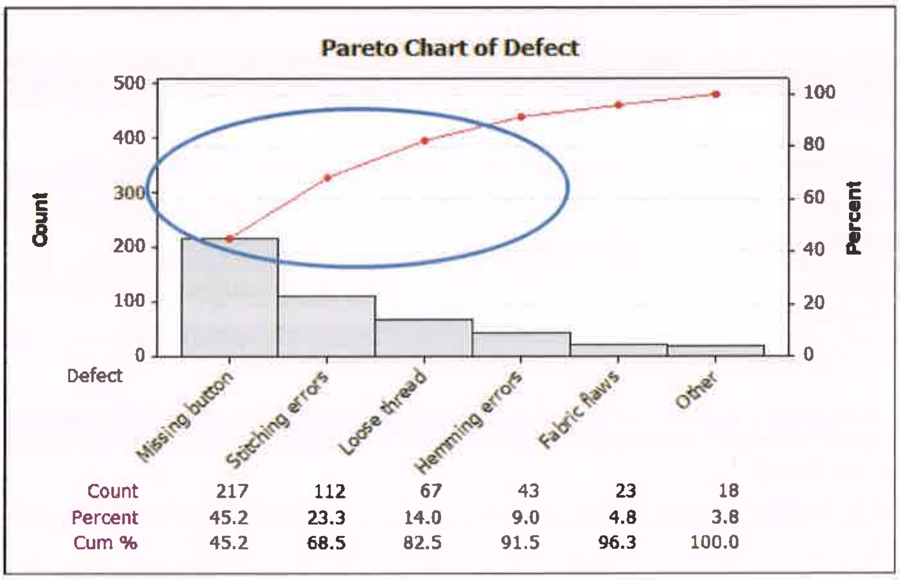
# Pareto Analysis

**Minitab path:**
Refer the data: "Clothing Defect"

- Click on Stat → Quality Tools → Pareto Chart
- In Defects or attribute data in, enter *Defect*.
- In Frequencies in, enter *Count*.
- Select Combine remaining defects into one category after this percent, and enter 95.
- Click OK.



# Pareto Analysis




In the above graph, 45.2% of the defects are missing buttons and 23.3% are stitching errors. The cumulative percentage for missing buttons and stitching errors is 68.5%. Thus, the largest improvement to the entire clothing process might be achieved by solving the missing button and stitching problems

## Tackling the other causes

- The non-controllable causes need to be factored into the improved process so that they do not affect the Process Capability.
- The team should launch initiatives to implement actions for the lack of solutions or direct improvements. This can happen in parallel as the project progresses.



# Process Door Approach

## Lean Principles