LEAN SOLUTIONS ACADEMY

Lean Six Sigma Training

Black Belt

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Measure Phase

"You can't manage what you don't measure.

- W. Edward Deming

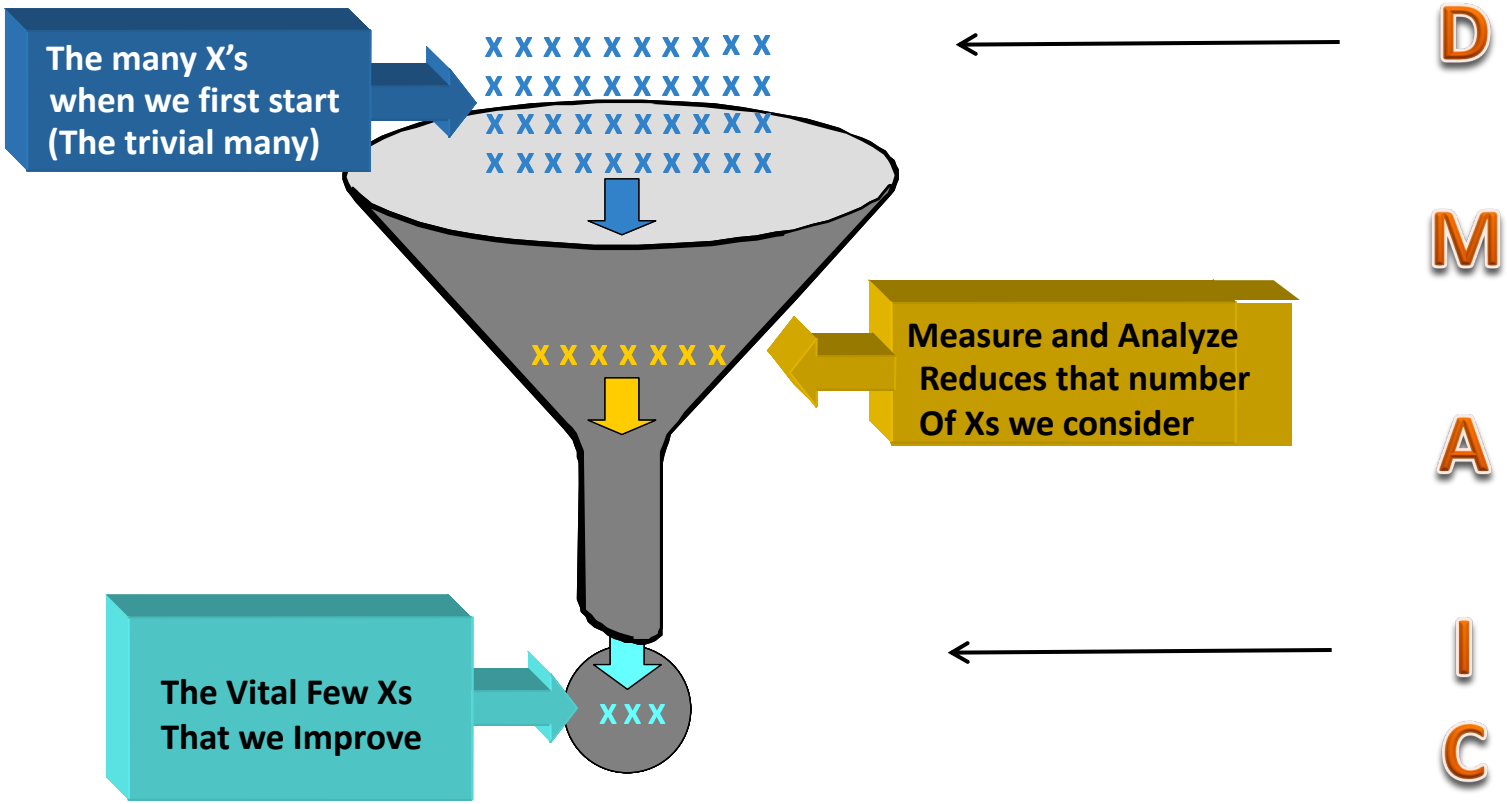
MEASURE PHASE

Measure

- Measurements of Inputs
- Measurement of Outputs
- Collection of Historical Data
- Process Mapping
- ‘As-Is’ Value Stream Mapping
- ‘As-Is’ process Capability

The X's

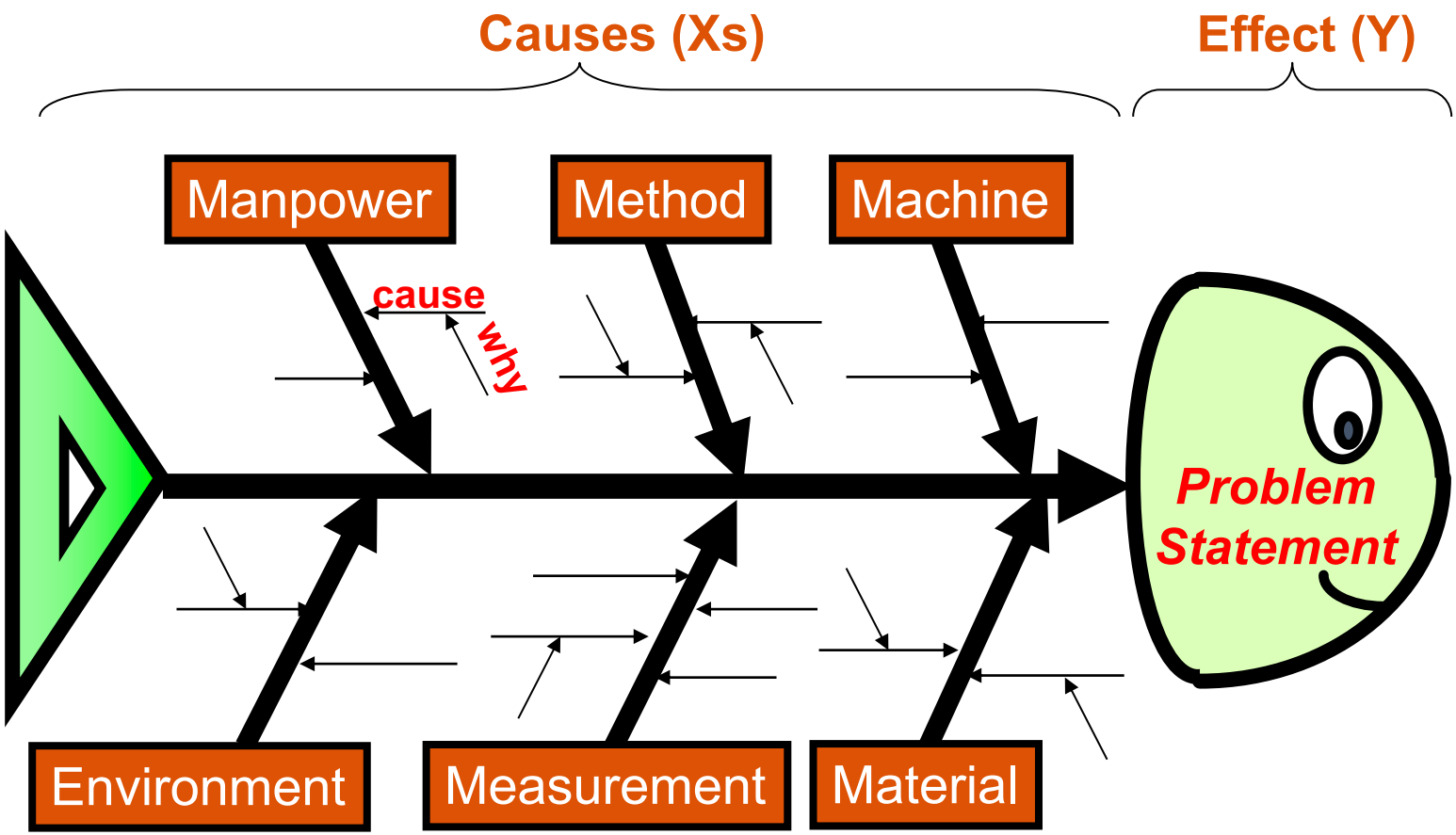
1. Understand the Process using Process Mapping and VSM
2. Identify all the ***possible X's*** using the Fishbone
3. Use X-Y Matrix, FMEA and Pareto Analysis to narrow our investigation to the ***probable X's***
4. Collect data on the ***probable X's.***



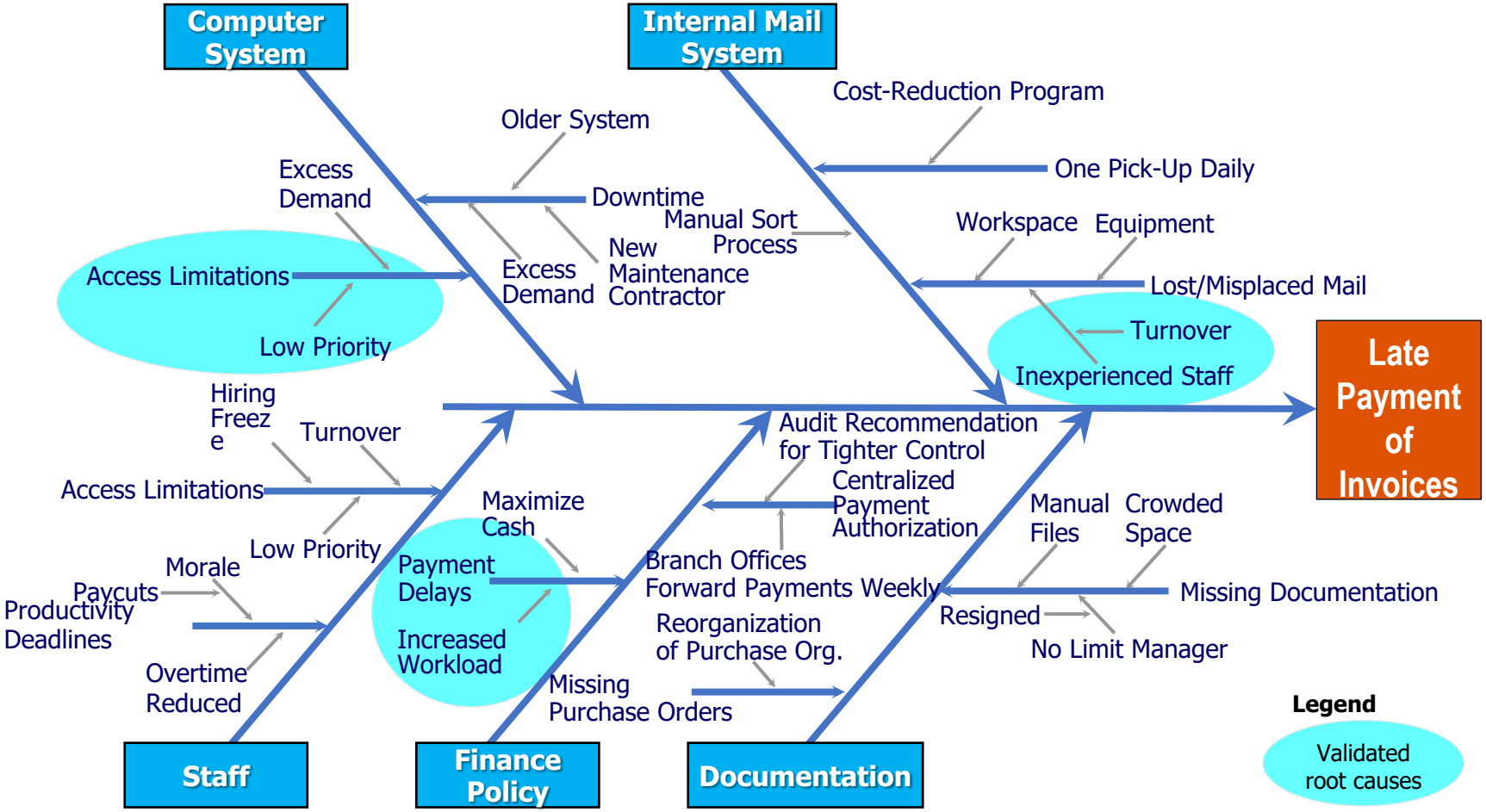
Fish-bone Diagram (a.k.a. Ishikawa Diagram, Cause and Effect Diagram)

- Purpose
  - To identify and structure the **causes** of a given **effect**
- When to use
  - When investigating a problem, to identify and select key problem causes to address
  - When effect of a problem is known, but possible causes are unclear
  - To find other causal relationships, such as potential risks or causes of desired effects

Cause & Effect Diagram



Example: Cause and effect diagram used in solving the problem of "Late Payment of Invoices"



How to Construct a Fishbone Diagram

1. Develop and agree on a problem statement (effect)
2. Brainstorm a list of possible causes; remove symptoms and solutions related to the stated effect
3. Identify major categories of causes (e.g. Man, Machines, Material, Method, Measurement, Environment)
4. Place each cause in a category (same cause can occur in several category)
5. Ask “Why does this happen?” for each cause
6. Design data collection strategy to verify and prioritize main causes

5 Whys

Example of 5-Whys being used :

1. **"Why did the robot stop?"**
   The circuit has overloaded, causing a fuse to blow.
2. **"Why is the circuit overloaded?"**
   There was insufficient lubrication on the bearings, so they locked up.
3. **"Why was there insufficient lubrication on the bearings?"**
   The oil pump on the robot is not circulating sufficient oil.
4. **"Why is the pump not circulating sufficient oil?"**
   The pump intake is clogged with metal shavings.
5. **"Why is the intake clogged with metal shavings?"**
   Because there is no filter on the pump.

Group exercise : Fish Bone Diagram

A Laptop Failure

You are an trouble-shooter and need to
Get to the Root Cause of a recent laptop failure.
It appears to be overheating !

What are the possible causes ?

Draw a Fishbone Diagram.

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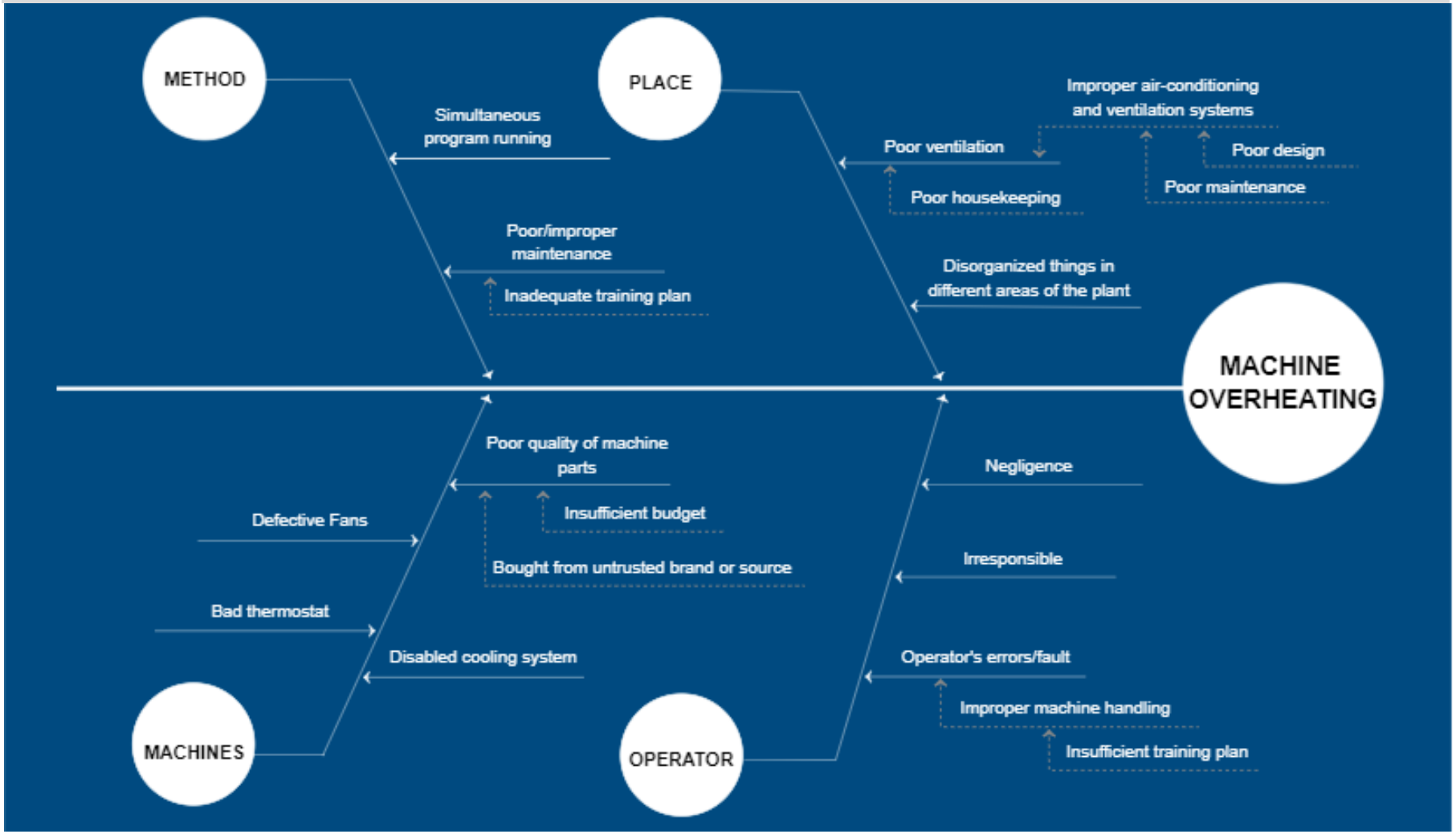
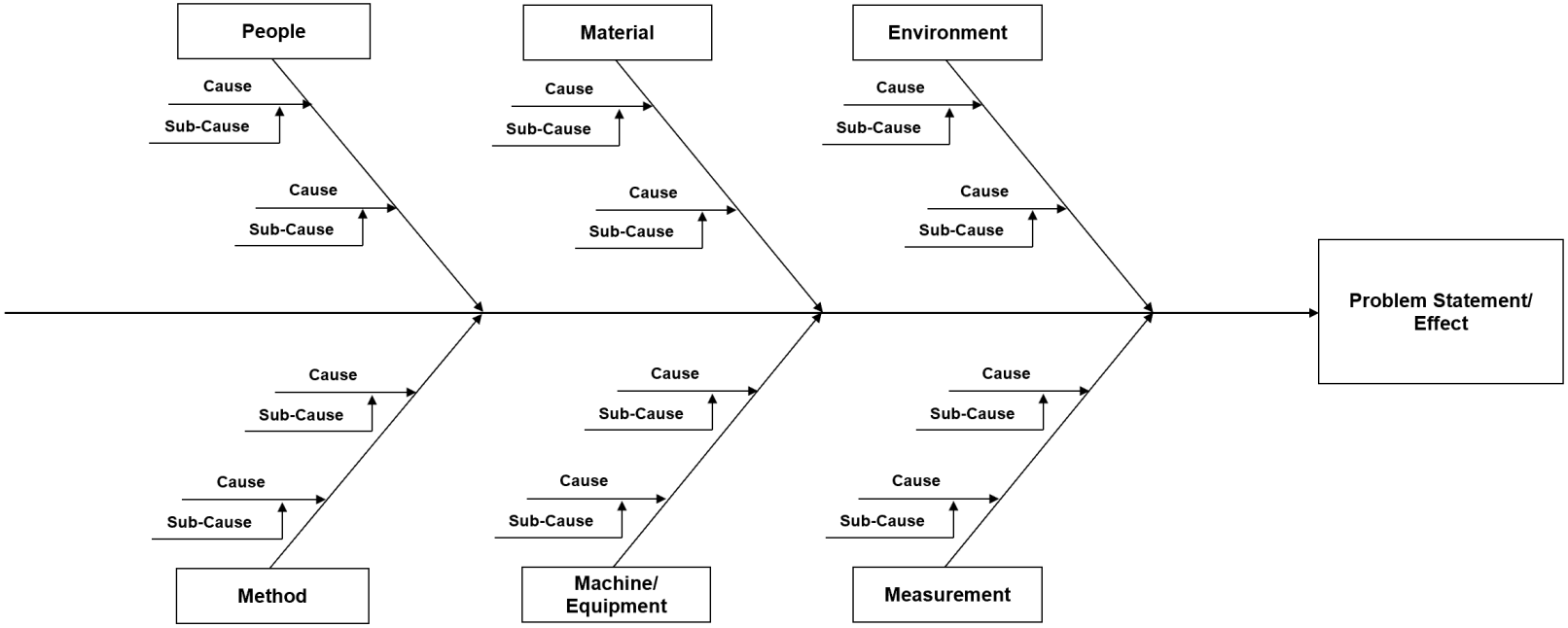

METHOD
PLACE
Simultaneous program running
Poor/improper maintenance
Inadequate training plan
Improper air-conditioning and ventilation systems
Poor ventilation
Poor design
Poor housekeeping
Poor maintenance
Disorganized things in different areas of the plant
MACHINE OVERHEATING
Poor quality of machine parts
Insufficient budget
Bought from untrusted brand or source
Defective Fans
Bad thermostat
Disabled cooling system
MACHINES
Negligence
Irresponsible
Operator's errors/fault
Improper machine handling
Insufficient training plan
OPERATOR

Identifying all the possible X's

CAUSE & EFFECT (FISHBONE) DIAGRAM

Process/Project Name:	
Date:	
Prepared By:	
Notes:	

A tool used to document ALL possible causes for our issue of concern. Depends on Brainstorming from Functional Experts.



Notes:
1. Overwrite the text in the Cause, Sub-Cause and Problem Statement/Effect as appropriate.
2. Use copy and paste to create additional causes or sub-causes.
3. The arrows with text are grouped. To ungroup use Excel's Draw > Ungroup tool.

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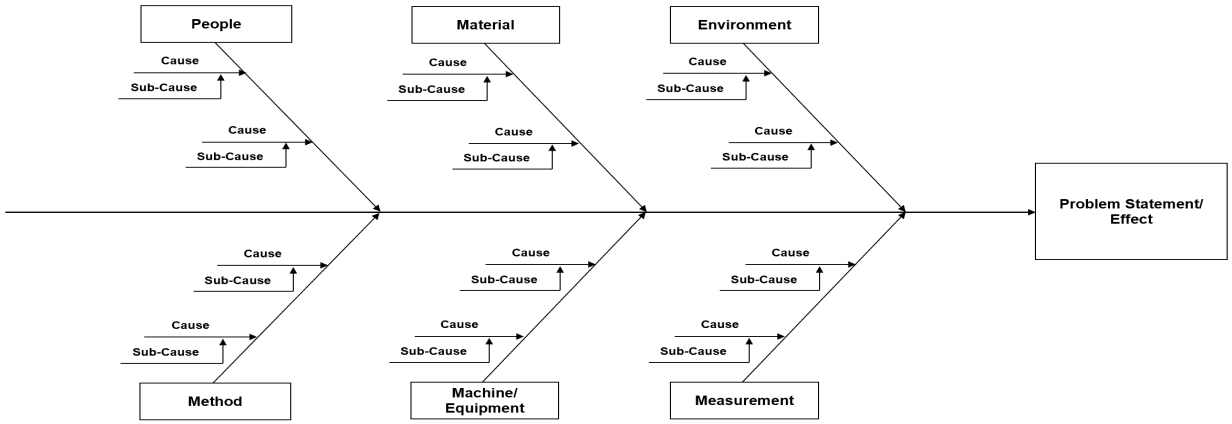
Cause and Effect Diagram / Fishbone Diagram / Ishikawa Diagram

CAUSE & EFFECT (FISHBONE) DIAGRAM

Process/Project Name:	
Date:	
Prepared By:	
Notes:	



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Products (6Ms)
- Measurement
- Manpower
- Method
- Materials
- Machines
- Mother Nature

Categories for the legs of the diagram can use templates for products or transactional symptoms. Or you can select the categories by process step or what you deem appropriate for the situation.

Transactional (5Ps)
- People
- Policy
- Procedure
- Place
- Plant (tech)

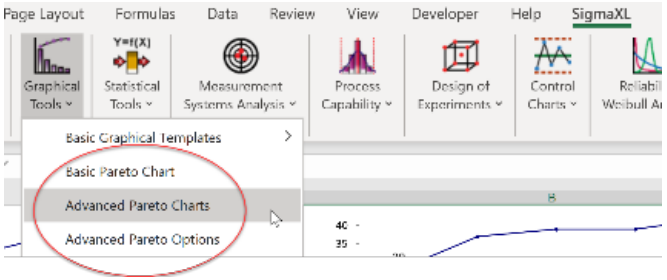
Pareto Analysis

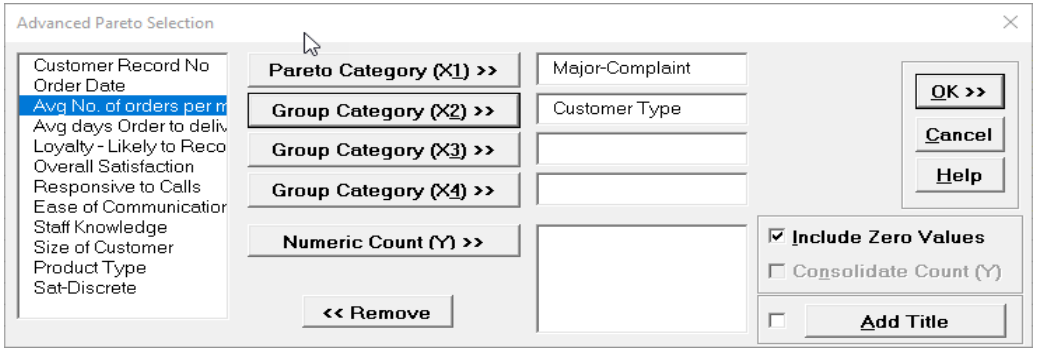
- ✓ **The Pareto Rule**
- ✓ **Pareto Analysis**
- ✓ **The Pareto Chart (Graph)**

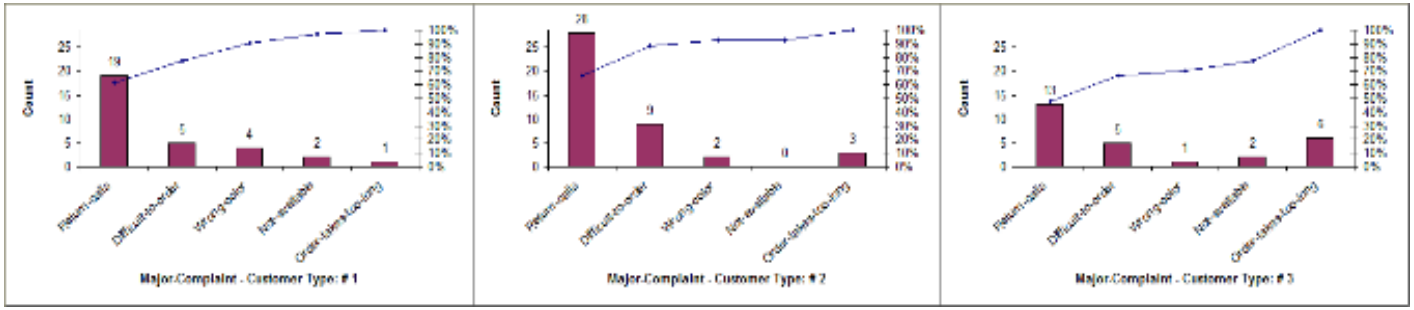
The Pareto Principle

- ✓ The Pareto Principle was first developed in 1906 by Italian economist, Vilfredo Pareto, who observed that 20% of the population owned 80% of the wealth.
- ✓ Also called the 80 : 20 rule.
- ✓ Joseph M. Juran adapted Pareto's economic observations to business applications.
- ✓ Juran stated that “80% of Defects in Process Outputs are as a result of 20% of the total Defective Process Inputs

SigmaXL Advanced Pareto Chart Example



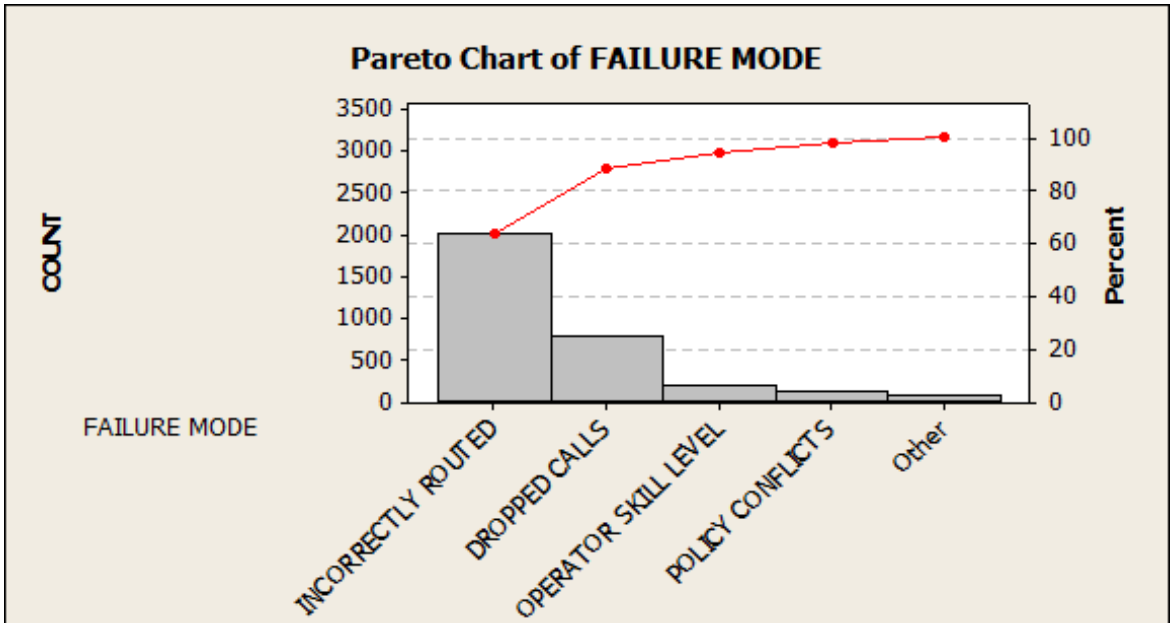




Pareto Analysis

Pareto Analysis using a Pareto Chart (Pareto Graph)

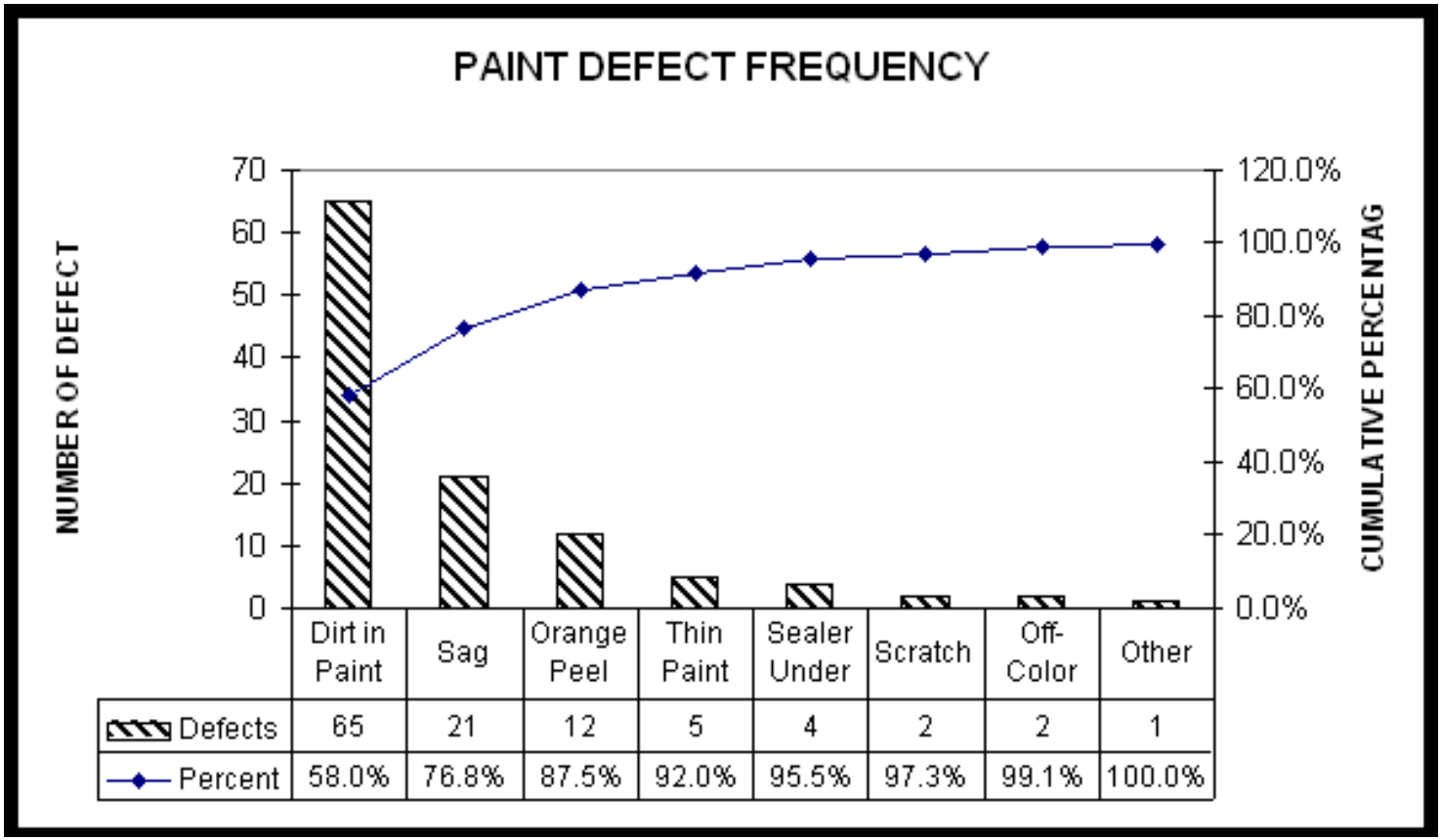
- Pareto Analysis is done using a bar graph used to arrange data in such a manner that priorities for process improvement can be established.



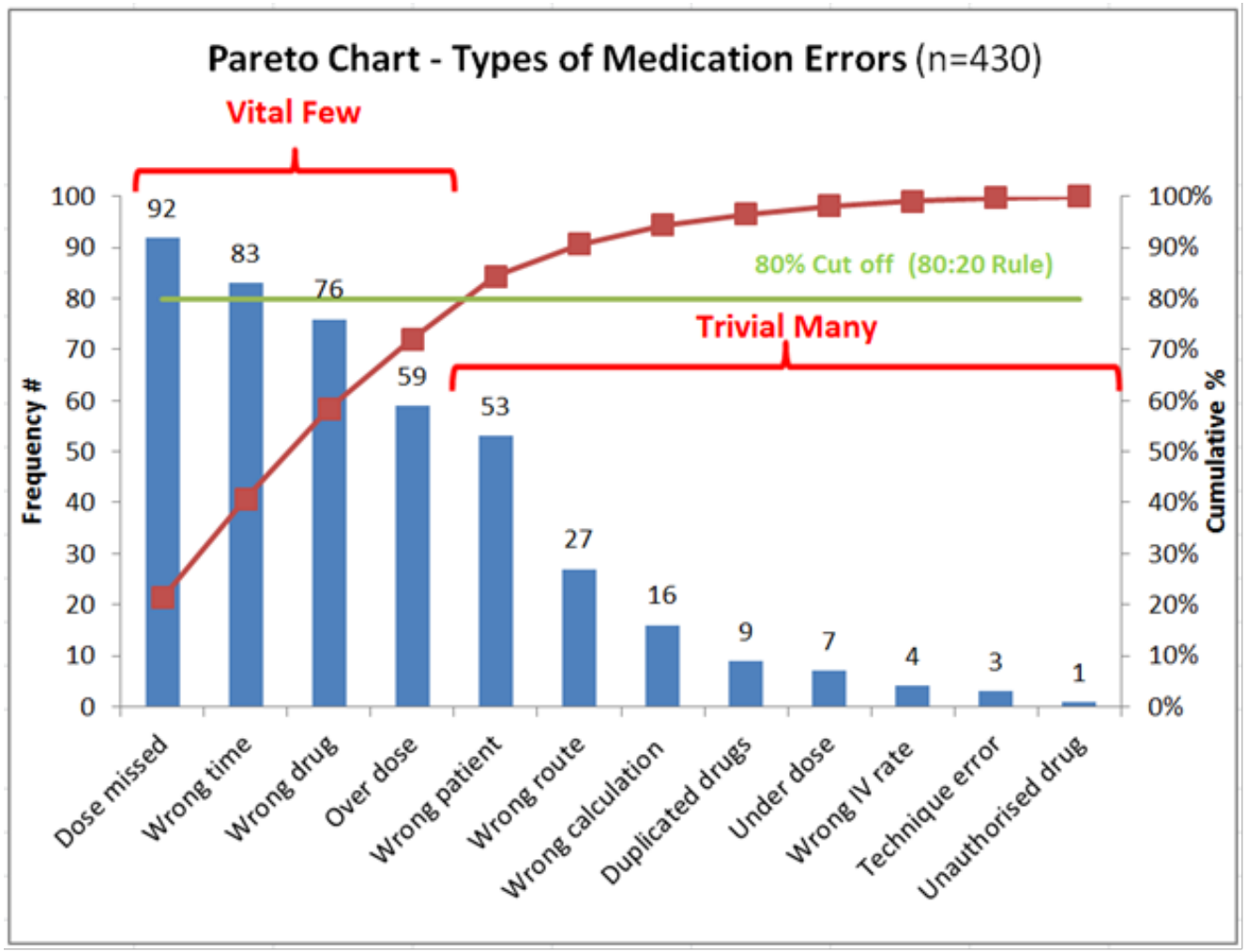
COUNT	2015	768	200	107	63
Percent	63.9	24.4	6.3	3.4	2.0
Cum %	63.9	88.3	94.6	98.0	100.0

Pareto Chart –Example

What does this Pareto Chart tell us ?



	Dirt in Paint	Sag	Orange Peel	Thin Paint	Sealer Under	Scratch	Off-Color	Other
Defects	65	21	12	5	4	2	2	1
Percent	58.0%	76.8%	87.5%	92.0%	95.5%	97.3%	99.1%	100.0%


Pareto Chart - Types of Medication Errors (n=430)
Vital Few
Trivial Many
80% Cut off (80:20 Rule)
Frequency #
Cumulative %
100
90
80
70
60
50
40
30
20
10
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
92
83
76
59
53
27
16
9
7
4
3
1
Dose missed
Wrong time
Wrong drug
Over dose
Wrong patient
Wrong route
Wrong calculation
Duplicated drugs
Under dose
Wrong IV rate
Technique error
Unauthorised drug

FMEA (Risk Analysis)

Why Create an FMEA?

Failure Modes and Effects Analysis (FMEA) is a methodology to manage…

RISK!!!

History of FMEA

History of FMEA:

- First used in the 1960's in the Aerospace industry to manage risk during the Apollo missions to the moon.

- In the late 1970's automotive industry incorporated FMEA into the management of risk in their processes

- Now used across industries and in design as well as production
  - **Design FMEA** used before a product / service goes to production
  - **Process FMEA** used on process used for production processes

Reasons for FMEA

Failure Modes and Effects Analysis (FMEA) is used to:

- **Predict failures** in manufacturing and service industries before they occur.
- **Estimate** the Severity, Probability of Occurrence and Detection **(SOD)** of failures.
- **Evaluate the current Control Plan** for preventing these failures from occurring.
- **Prioritize the risks using a Risk Priority Number (RPN)** in order to indicate which risks require the most attention and controls for prevention.
- **Decide on actions** to be taken to **mitigate the risks** and the responsible person or team for implementing the action.

Who Creates FMEAs and When?

Who

- The Project Team.
- This includes:
  - Functional Experts
  - Technical Experts
  - Supervisors
  - Managers
  - Etc.

When

- **Design FMEAs** should be created when new products or services are first being designed.
- **Process FMEAs** should be started:
  - Before the start of production processes.
- **Process FMEAs** should be updated:
  - When an existing process is being changed..
  - When a problem solving study is completed and needs to be documented.

The FMEA matrix

For a Process FMEA:

#	Process Function (Step)	Potential Failure Modes (process defects)	Potential Failure Effects (Y's)	SEV	Potential Causes of Failure (X's)	OCC	Current Process Controls	DET	RPN	Recommend Actions	Responsible Person & Target Date	Taken Actions	SEV	OCC	DET	RPN
1																
2																
3																
4																
5																
6																
7																
8																
9																

RPN = SEV x OCC x DET

RPN = Risk Prioritization Number
SEV = Severity of the Failure
OCC = Probability of Occurrence of the Failure
DET = Difficulty to detect the Failure

AIAG

www.aiag.org/quality/automotive-core-tools/fmea

In 1993 the Automotive Industry Action Group (AIAG) first published an FMEA standard for the automotive industry.

This is now used as the the 'Best in Class' standard for FMES in many industries. (outside of Automotive)

The **Ford Pinto** (1970 s) caught on Fire when
Involved in rear collisions and
Caused many companies to
Reconsider its RISK MANAGEMENT
Processes.

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FMEA VIDEO

https://www.youtube.com/watch?v=rIGRd4VICw4

FMEA Principles

- Use them to make more Money!!

By Paul Allen

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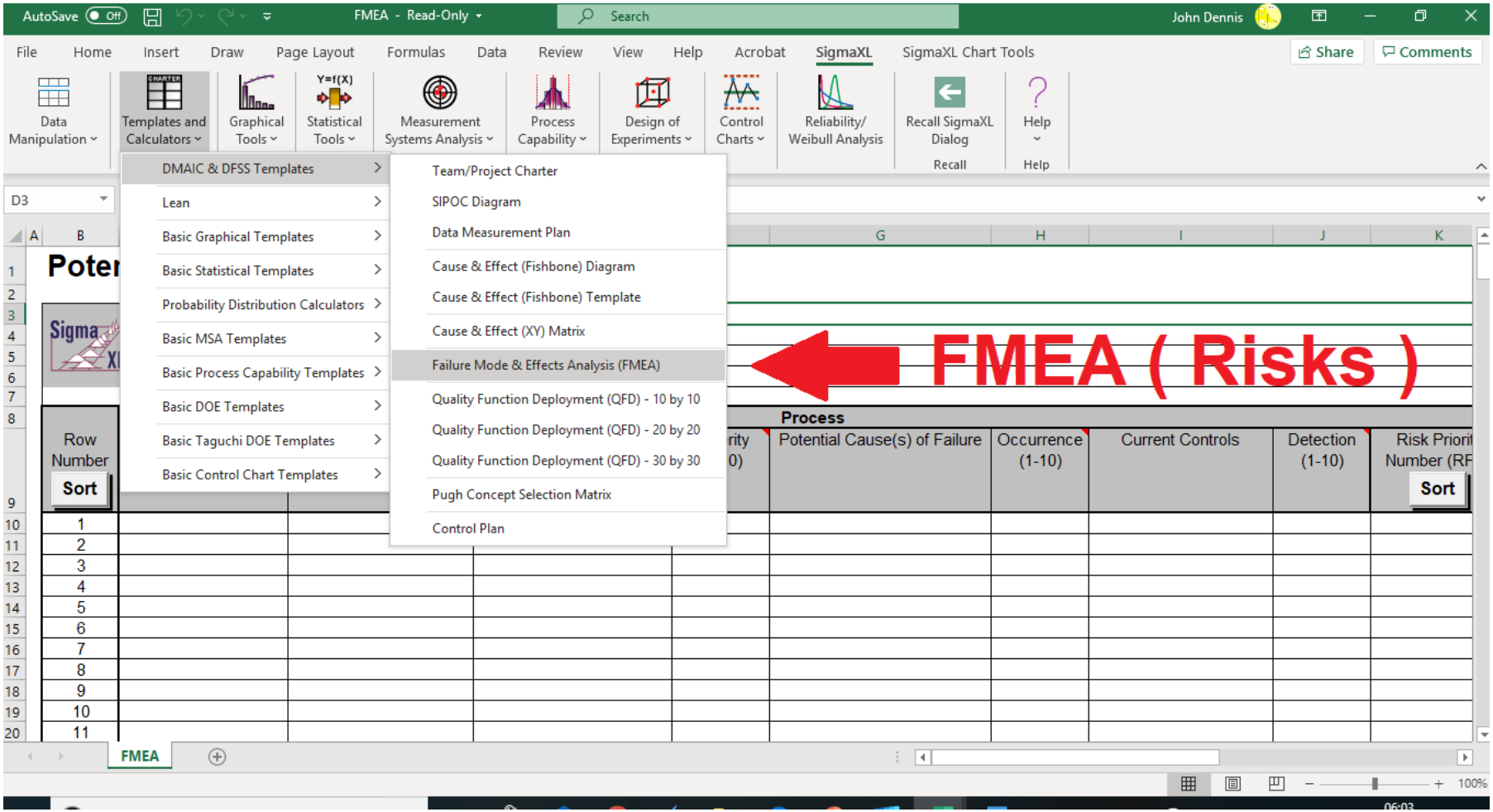
Calculate RPN for your Business Risk if there was a new Lockdown in next 3 months for Covid19 that lasts more than 3 months ! Compare to RPN risk of a Financial Crash in Stock Market of more than 40% in next 3 months.



Quiz 9:

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- What is the purpose of the MEASURE Phase in DMAIC?

To understand the Current State (As-Is) of the process that contains the Problem.

- Detailed Process Understanding is required in the Measure Phase ? Who are the People to involve to gain a better understanding of the process and problems ?
- **The people who work on the process. The workers at the GEMBA**

- Another name for an Ishikawa diagram is the _____ diagram.
- **FISH BONE**

- To ask your team '***Why does this happen ?'*** more than once in order
- to understand the Root Cause is called the _____ method.
- **5 WHYS**

- What is another name for the 80/20 Principe ?
- **PARETO PRINCIPLE**

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Measure Phase

Six Sigma Statistics

Purpose of Basic Statistics

The purpose of Basic Statistics is to:

- Provide a numerical summary of the data being analyzed.
  - **Data**

    Factual information organized for analysis
    - Numerical or other information represented in a form suitable for processing by computer
    - Values from scientific experiments
- Provide the basis for making inferences about the future.
- Provide the foundation for assessing process capability.
- Provide a common language to be used throughout an organization to describe processes.

Homework : Revise the “Presenting Data” section at

http://www.stats.gla.ac.uk/steps/glossary/

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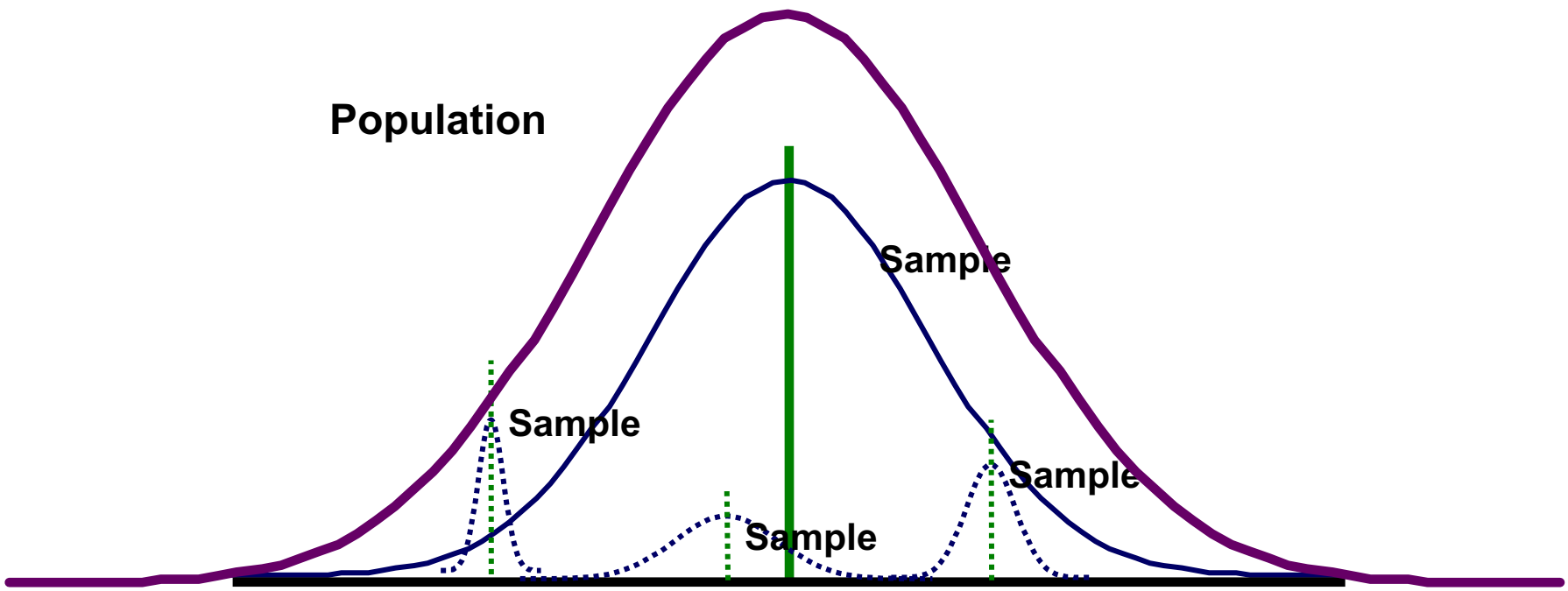
Statistical Notation – Cheat Sheet

$\sum$	Summation
s	The Standard Deviation of sample data
σ	The Standard Deviation of population data
s^2	The variance of sample data
σ^2	The variance of population data
R	The range of data
$\overline{R}$	The average range of data
k	Multi-purpose notation, i.e. # of subgroups, # of classes
$\lvert y \rvert$	The absolute value of some term
$>, <$	Greater than, less than
$\geq, \leq$	Greater than or equal to, less than or equal to
X	An individual value, an observation
X_1	A particular (1st) individual value
X_i	For each, all, individual values
$\overline{X}$	The Mean, average of sample data
$\overline{\overline{X}}$	The grand Mean, grand average
μ	The Mean of population data
p	A proportion of sample data
P	A proportion of population data
n	Sample size
N	Population size

Parameters versus Statistics

Population: All the items that have the "property of interest" under study.

Sample: A smaller subset of the population used to make an inference.



Population Parameters:

- Arithmetic descriptions of a population
- μ, σ , P, σ^2, N

Sample Statistics:

- Arithmetic descriptions of a sample
- X-bar , s, p, s^2, n

Types of Data

Attribute Data (Qualitative or Categorical)

Can be displayed on Nominal Scale or Ordinal Scale

- Colors, Countries, Types of Defects, Types of Animal
- Binary Data (2 states)
  - Yes, No
  - Go, No Go
  - Pass/Fail

Variable Data (Quantitative) Can be displayed on Interval Scale or Ratio Scale

- Discrete (Count) Data
  - Can be categorized in a classification and is based on counts.
    - Number of defects
    - Number of defective units
    - Number of customer returns
- Continuous Data
  - Can be measured on a continuum, it has decimal subdivisions that are meaningful
    - Time, Pressure, Conveyor Speed, Material feed rate
    - Money
    - Pressure
    - Conveyor Speed
    - Material feed rate

Attribute Data

Attribute Variable	Possible Values for the Variable
Country of Origin	China, Korea, USA, Germany
Quality	Pass / Fail
Colour of Fruit	Crimson, Red, Orange, Yellow, Green
Finish of Paint	Matt, Satin, Gloss
Service rating	Excellent, Good, Bad

Discrete Variables

Discrete Variable	Possible Values for the Variable
The number of defective needles in boxes of 100 diabetic syringes	0,1,2, …, 100
The number of individuals in groups of 30 with a Type A personality	0,1,2, …, 30
The number of surveys returned out of 300 mailed in a customer satisfaction study	0,1,2, … 300
The number of employees in 100 having finished university	0,1,2, … 100
The number of times you need to flip a coin before a head appears for the first time	1,2,3, …

Continuous Variables

Continuous Variable	Possible Values for the Variable
The length of prison time served for individuals convicted of first degree murder	All the real numbers between ***a*** and ***b***, where ***a*** is the smallest amount of time served and ***b*** is the largest.
The household income for households with incomes less than or equal to $30,000	All the real numbers between ***a*** and $30,000, where ***a*** is the smallest household income in the population
The blood glucose reading for those people having glucose readings equal to or greater than 200	All real numbers between 200 and ***b***, where ***b*** is the largest glucose reading in all such people

Scales of Measurement

- **N**ominal scale: A nominal scale is really a list of categories to which objects can be classified.

- **O**rdinal scale: is a measurement scale that assigns values to objects based on their ranking with respect to one another.

- **I**nterval scale: one unit on the scale represents the same magnitude on the trait or characteristic being measured across the whole range of the scale. For example, if anxiety were measured on an interval scale, then a difference between a score of 10 and a score of 11 would represent the same difference in anxiety as would a difference between a score of 50 and a score of 51.

- **R**atio scale: Ratio scales are like interval scales except they have true zero points.

Scales

Nominal Data

- Sex – Nationality - Grade

Ordinal Data

- ordered but differences between values are not important
- e.g., political parties on left to right spectrum given labels 0, 1, 2
- e.g., Likert scales, rank on a scale of 1..5 your degree of satisfaction
- e.g., restaurant ratings

Interval Data

- ordered, constant scale, but no natural zero
- Achievement scale
- differences make sense, but ratios do not (e.g., 30°-20°=20°-10°, but 20°/10° is not twice as hot!
- e.g., temperature (C,F), dates

Ratio Data

- ordered, constant scale, natural zero
- e.g., height, weight, age, length

Descriptive Statistics

1. Measures of Location / Position (central tendency)

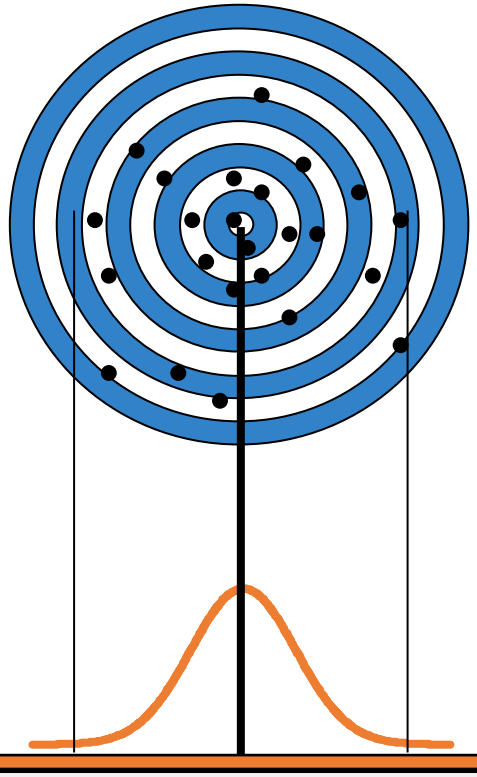
- Mean
- Median
- Mode

2. Measures of Variation (dispersion)

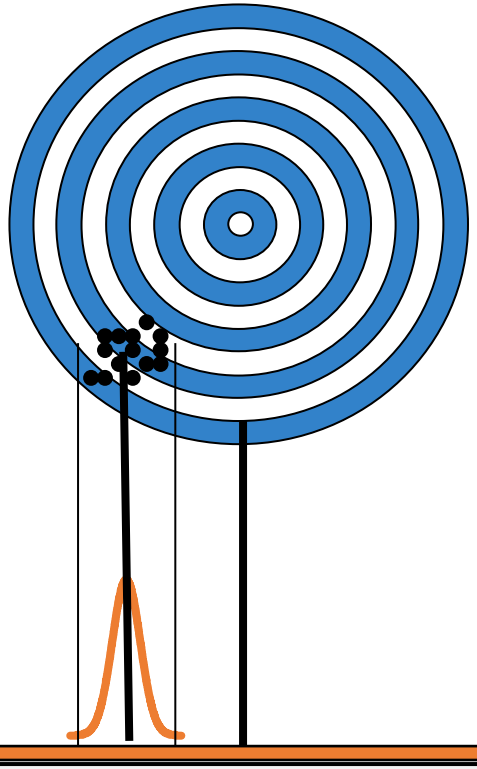
- Range
- Interquartile Range
- Standard deviation
- Variance

Position and Variation

- On average these shots are in the right position relative to the target but there is a lot of variation



- The position is not on the target but the variation is small



Measures of Location

Mean is:

- **Commonly referred to as the average.**
- **The arithmetic balance point of a distribution of data.**
- **The best measure of central tendency for 'Normal' or 'balanced' data distributions.**

Sample

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

Population

$$\mu = \frac{\sum_{i=1}^{N} X_i}{N}$$

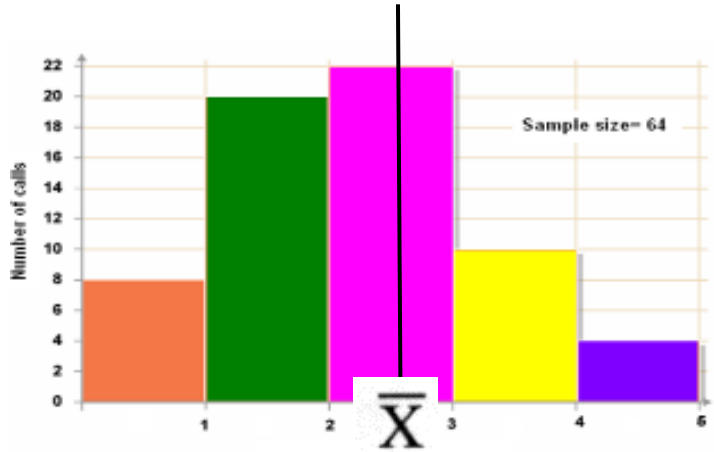
Mean Average

Mean Average:

can be calculated or estimated from the "Central" Position of the Histogram

$$\overline{X} = \frac{\sum X}{N}$$

$$\text{Mean Average} = \frac{\text{Sum of all values}}{\text{Total number of values}}$$



Measures of Location

Median is:

- The mid-point, or 50th percentile, of a distribution of data.
- Arrange the data from low to high or high to low.
  - It is the single middle value in the ordered list if there is an odd number of observations
  - It is the average of the two middle values in the ordered list if there are an even number of observations
  - A better representation of the central tendency for Skewed Data than using the mean.

1 , 3 , 4 , 10 , 12, 15 , 20 , 25, 25, 50, 50

The median in this series of numbers is 15

1 , 3 , 4 , 10 , 12, 15, 20 , 25, 25, 50, 50, 50

The median in this series of numbers is 17.5

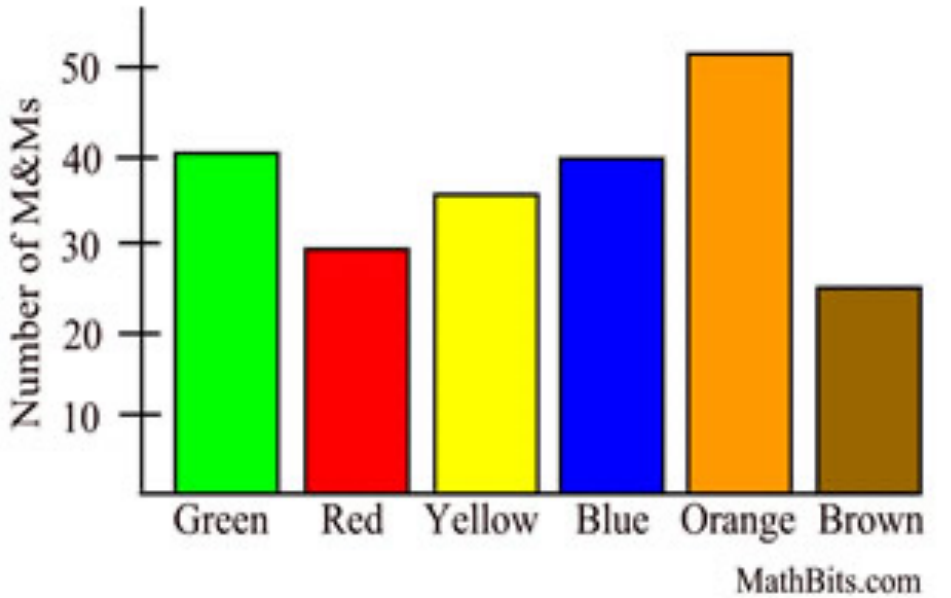
Measures of Location

Mode is:

The most frequently occurring value in a distribution of data.

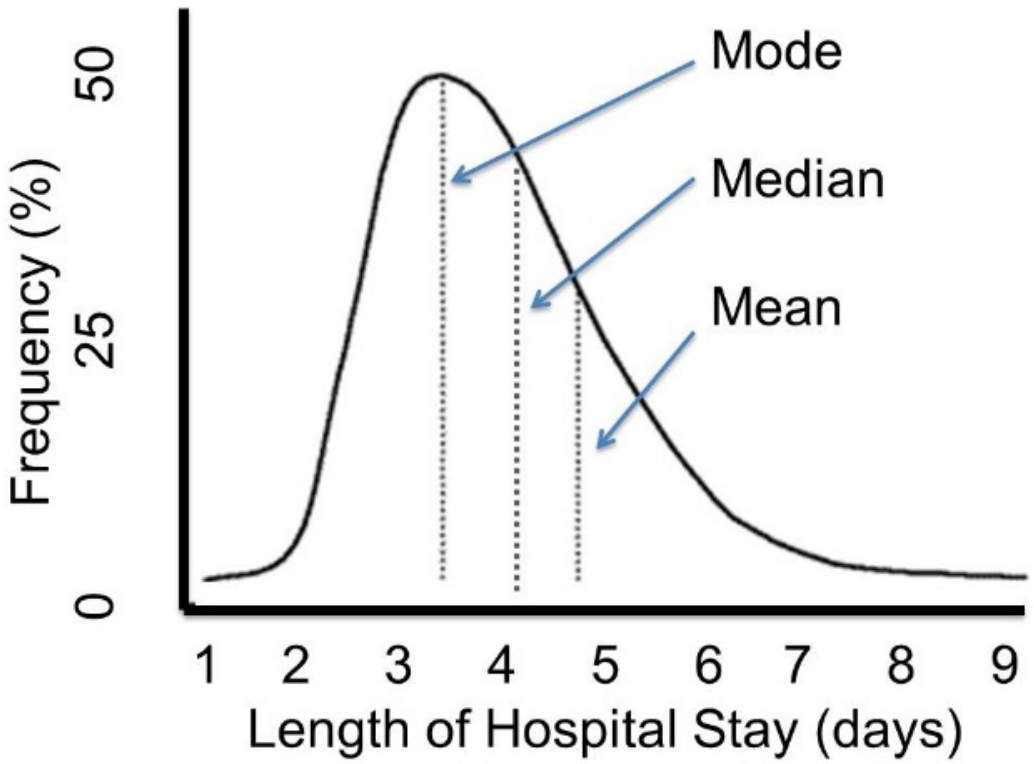
- Useful for 'Attribute Data'
- For example the most frequently occurring colour

Mode = Orange

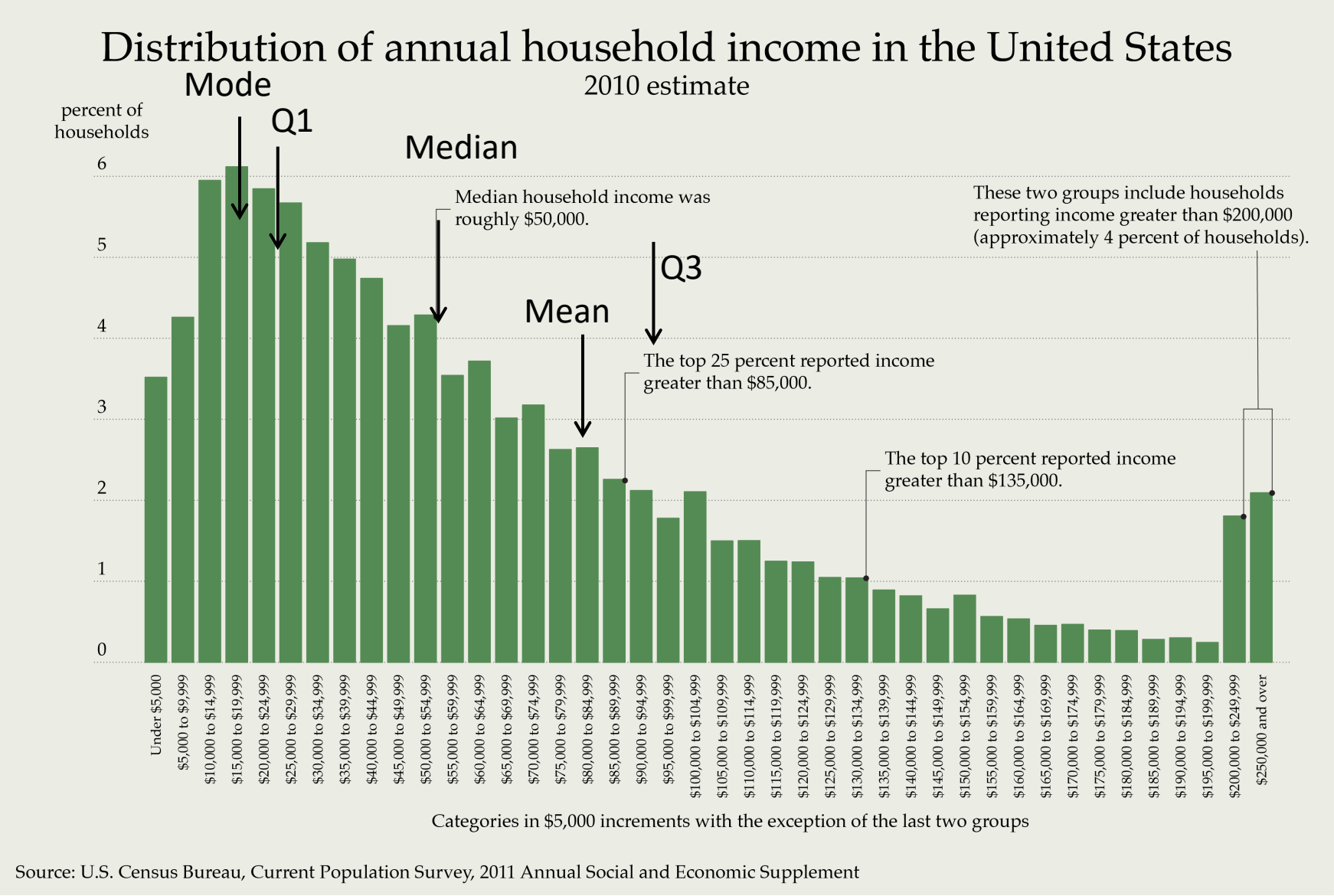


Number of Colors in Bag of M&M Candies

Measures of Location



Example of Skewed Data Distribution



Measures of Variation

Range is the:

Difference between the largest observation and the smallest observation in the data set.

- A small range would indicate a small amount of variability and a large range a large amount of variability.

$$\text{Range} = \text{Max} - \text{Min}$$

- 4.99 4.98 4.97 5.00 5.01 5.02

$$\text{Range} = 5.02 - 4.97 = 0.05$$

Interquartile Range is the:

Difference between the 75th percentile and the 25th percentile.

$$\text{Interquartile Range} = Q3 - Q1 = 5.01 - 4.99 = 0.02$$

Use Range or Interquartile Range when the data distribution is Skewed.

Measures of Variation

Standard Deviation is:

- Equivalent of the average deviation of values from the Mean for a distribution of data.
- A "unit of measure" for distances from the Mean.
- Use when data are symmetrical.

Sample

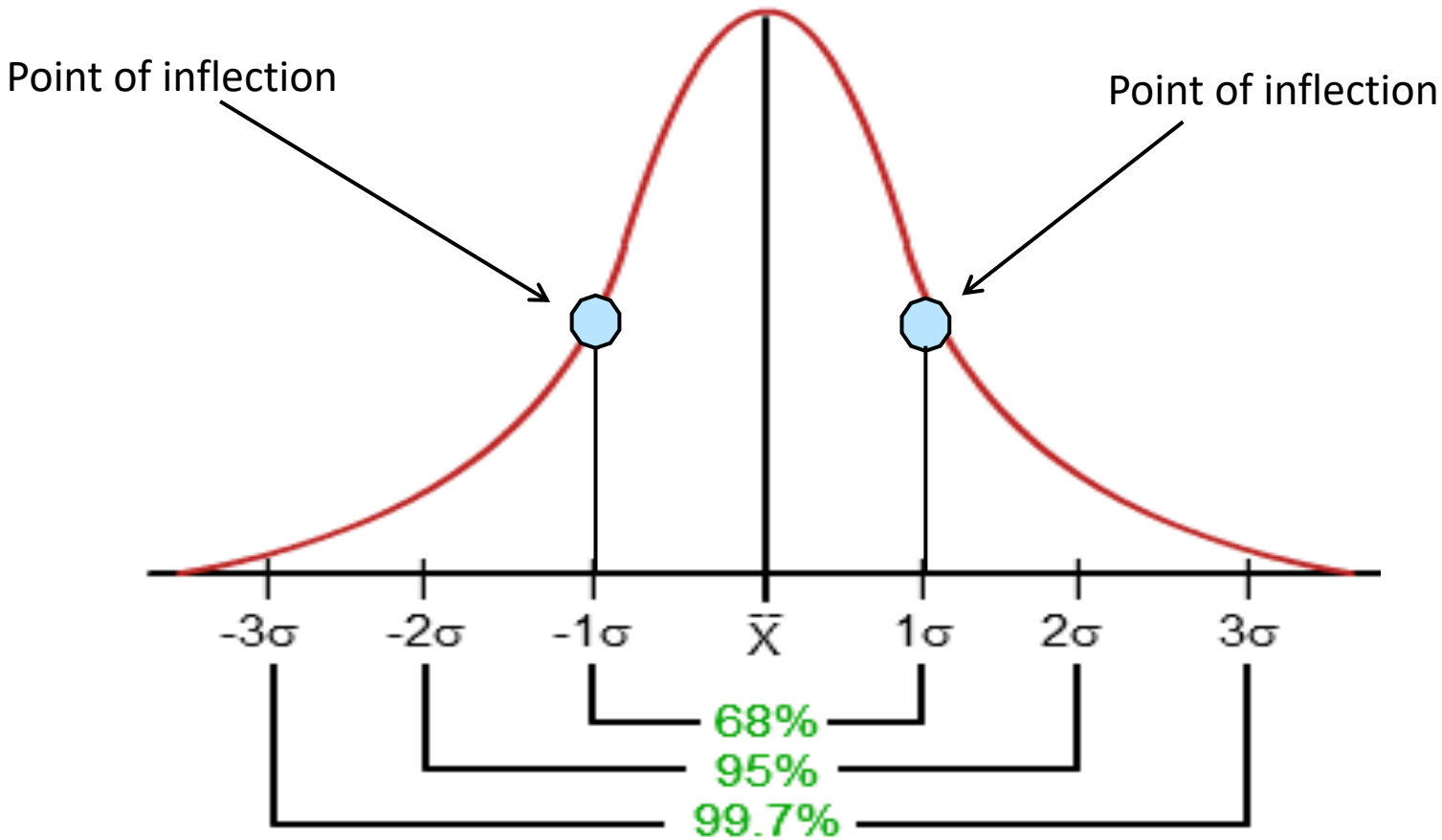
$$s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}}$$

Population

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \mu)^2}{N}}$$

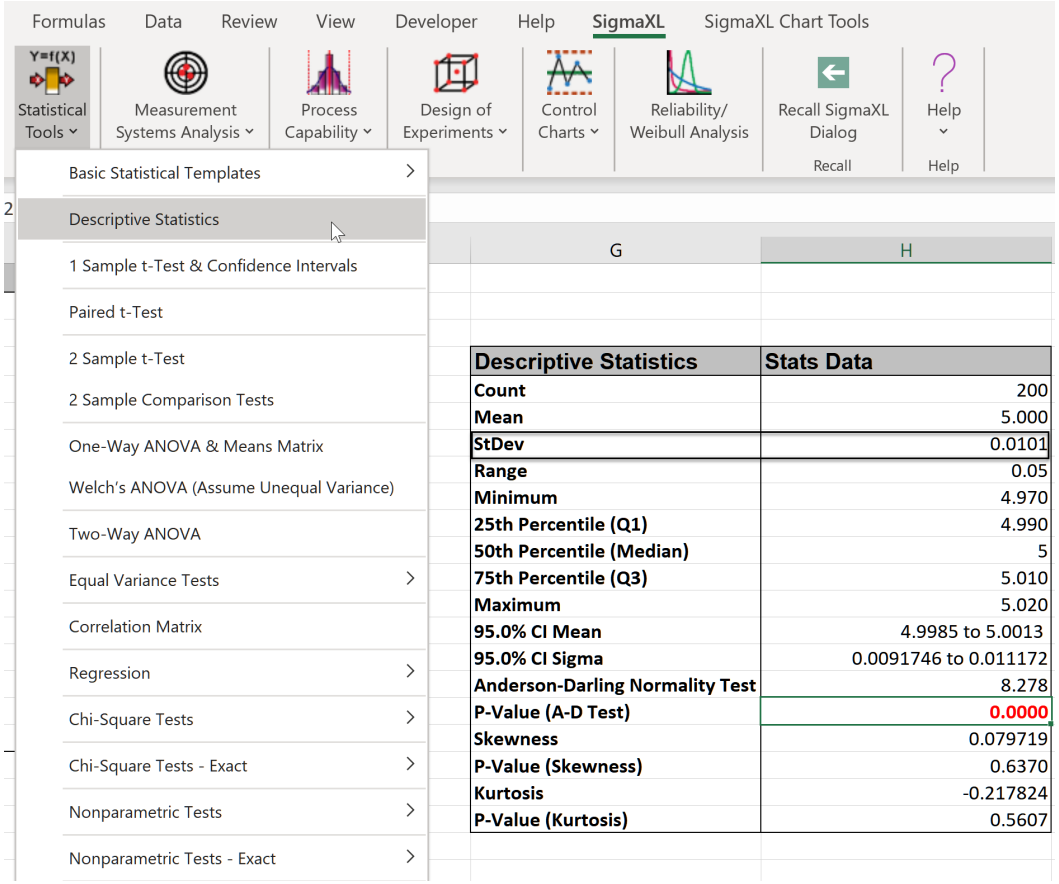
How to estimate the standard deviation

Use the **Point of inflection** of a Normal Distribution to help you estimate the Standard Deviation



How to estimate the standard deviation

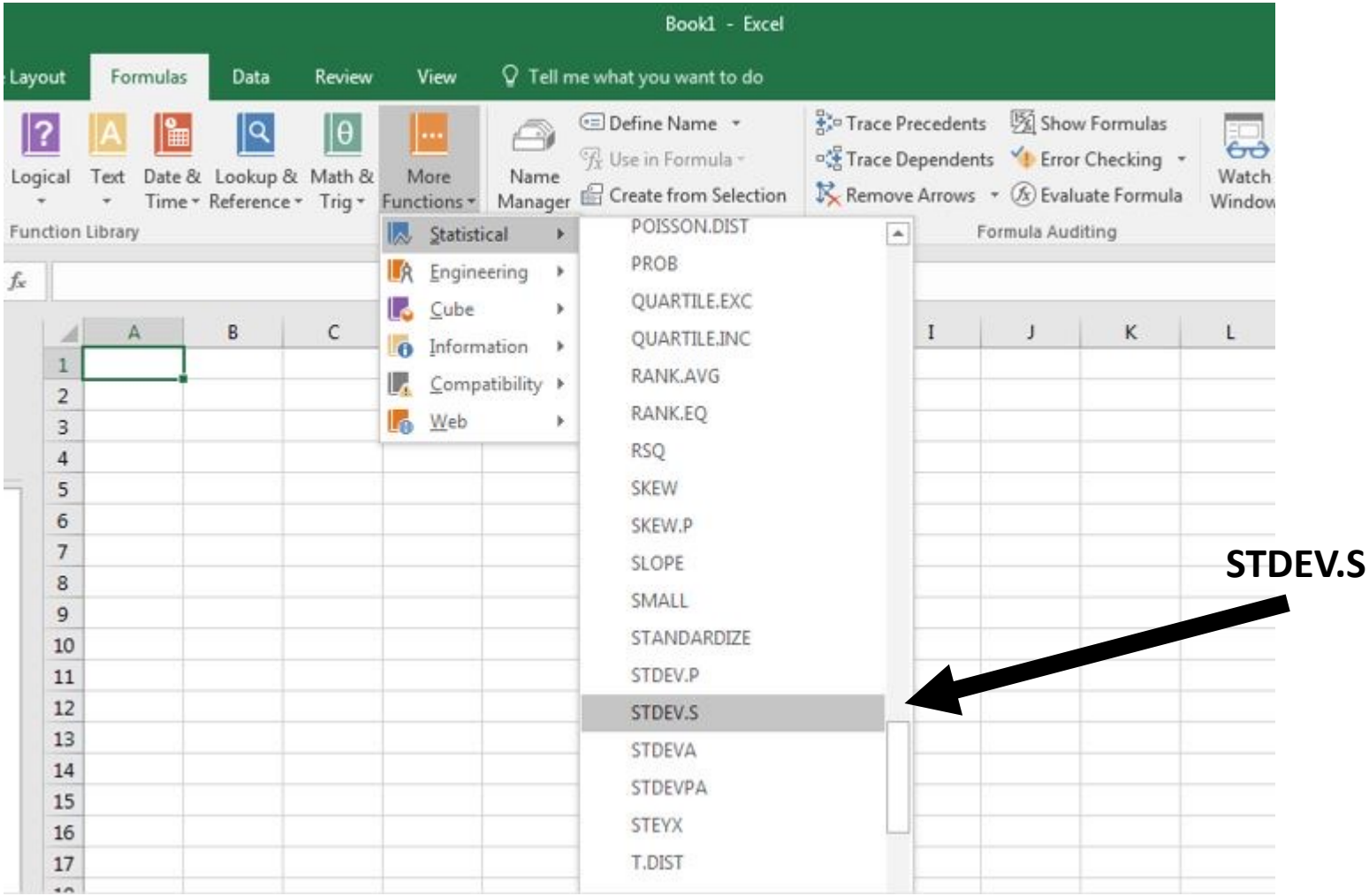
EXCEL (or other Statistical Software) can be used to calculate the Standard Deviation of a column of numbers very easily.



Descriptive Statistics	Stats Data
Count	200
Mean	5.000
StDev	0.0101
Range	0.05
Minimum	4.970
25th Percentile (Q1)	4.990
50th Percentile (Median)	5
75th Percentile (Q3)	5.010
Maximum	5.020
95.0% CI Mean	4.9985 to 5.0013
95.0% CI Sigma	0.0091746 to 0.011172
Anderson-Darling Normality Test	8.278
P-Value (A-D Test)	0.0000
Skewness	0.079719
P-Value (Skewness)	0.6370
Kurtosis	-0.217824
P-Value (Kurtosis)	0.5607

Descriptive Statistics

How to calculate the Standard Deviation



Measures of Variation

Variance is the:

Average squared deviation of each individual data point from the Mean.

Sample

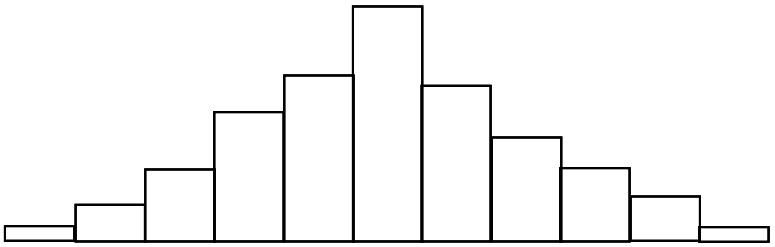
$$s^2 = \frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n-1}$$

Population

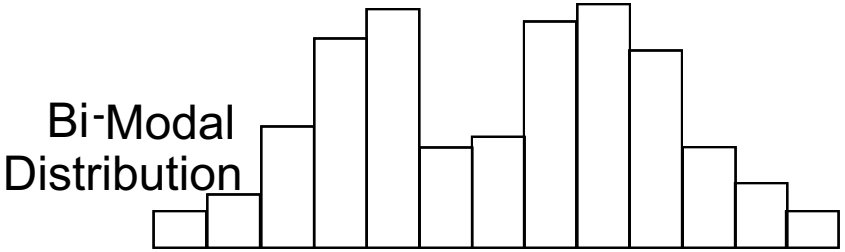
$$\sigma^2 = \frac{\sum_{i=1}^{N} (X_i - \mu)^2}{N}$$

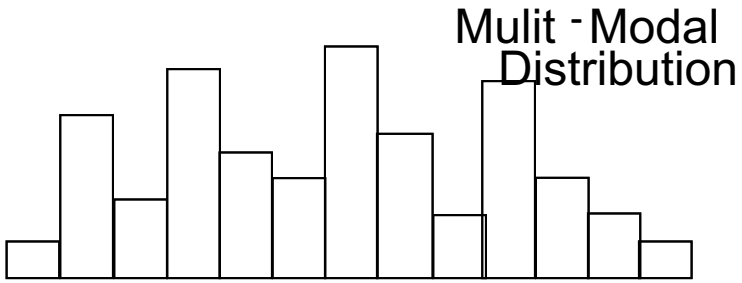
Data Distributions

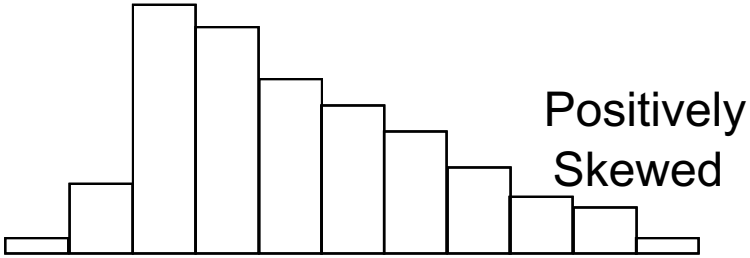
Shape / Data Distribution

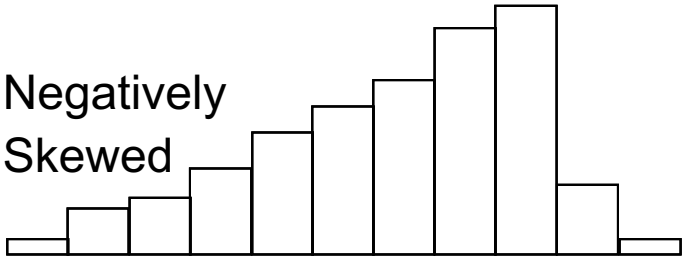


Normal Distribution



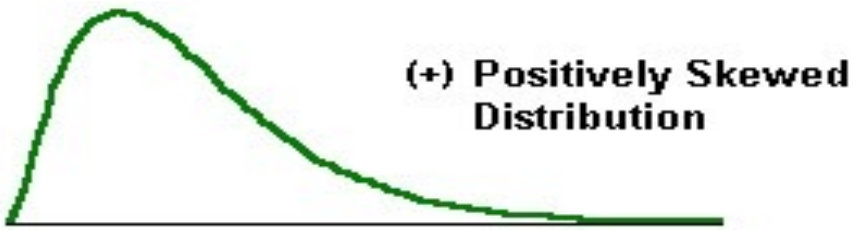






Skewed Data Distribution

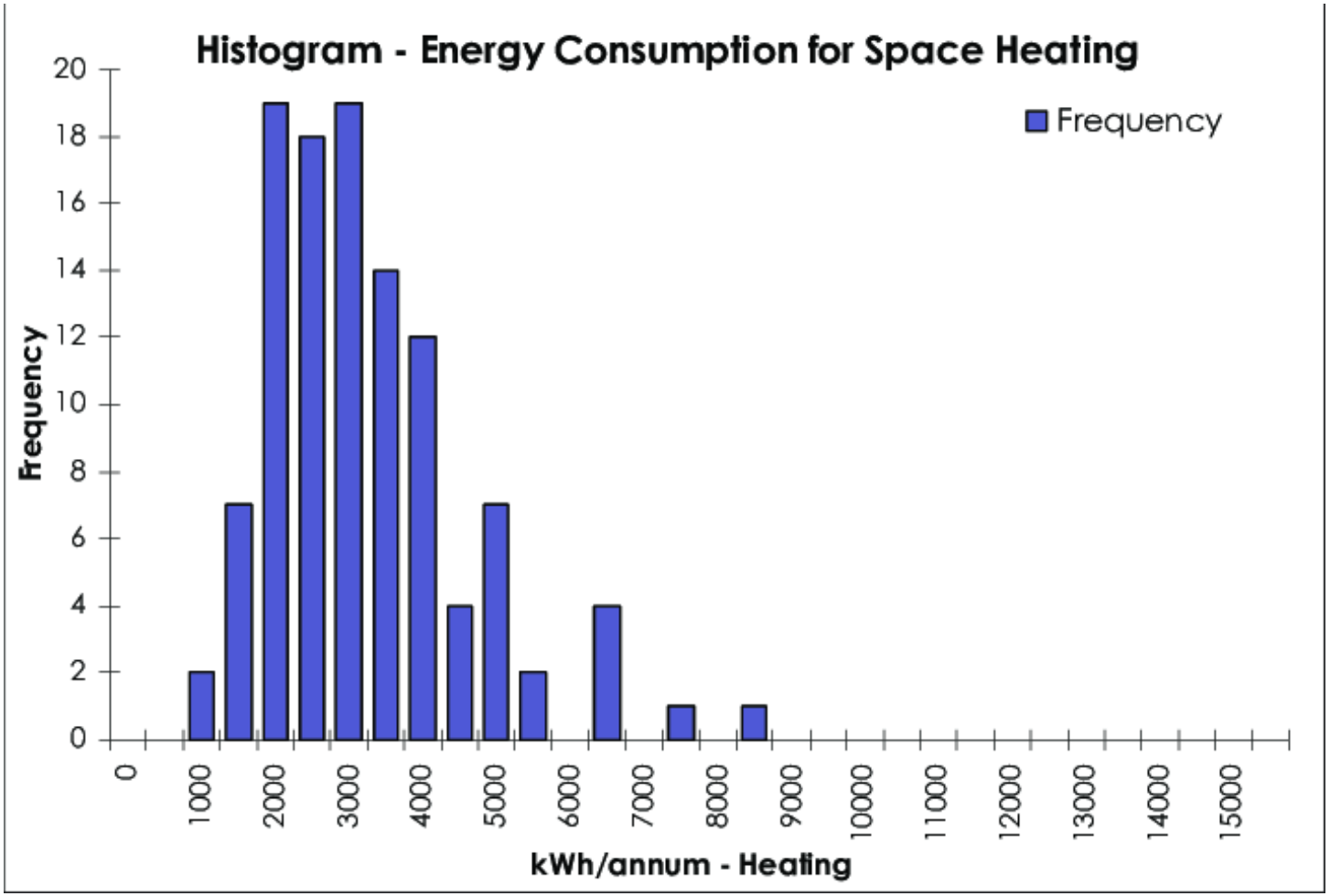
- SKEWED data distribution is not symmetrical like Normal Data
- The Mean, Median and Mode are usually different values
- The Median is the best indicator of Central Tendency
- Can be Positive Skew or Negative Skew (Right or Left)



Right Skewed

Left Skewed

Discuss : What is this histogram telling us ?



Distribution Curves

Data Distributions are important

In order to mathematically MODEL your processes and make INFERENCES about the way they behave.

They tell you the probability of occurrence of particular values of X in the sample or population

Distribution Curves

Different types of Data Distributions are described by different mathematical equations.

You do not need to remember these, just be aware that they are the maths that describe the shape of the distribution (curve).

Sometimes called "***Probability Density Equations***'

Or '***Probability Density Functions' (PDFs)***

Probability Density Equations

Normal distribution: $$p(X) = \frac{1}{\sqrt{2\pi\sigma^2}} \quad e^{\frac{-(X-\mu)^2}{2\sigma^2}}$$

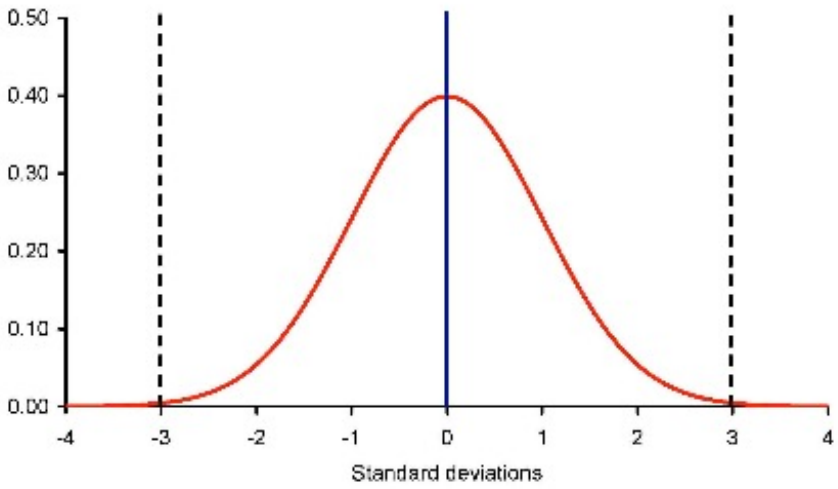
Poisson distribution: $$p(x) = \frac{\lambda^x e^{-\lambda}}{x!}$$

Binomial distribution: $$P(x) = \frac{N!}{x!(N-x)!} \pi^x (1-\pi)^{N-x}$$

Exponential distribution: $$P(x) = ab^x$$

The Normal Curve

The *Normal Distribution Curve* is a smooth, symmetrical, bell-shaped curve. Also called 'Gaussian Distribution'.

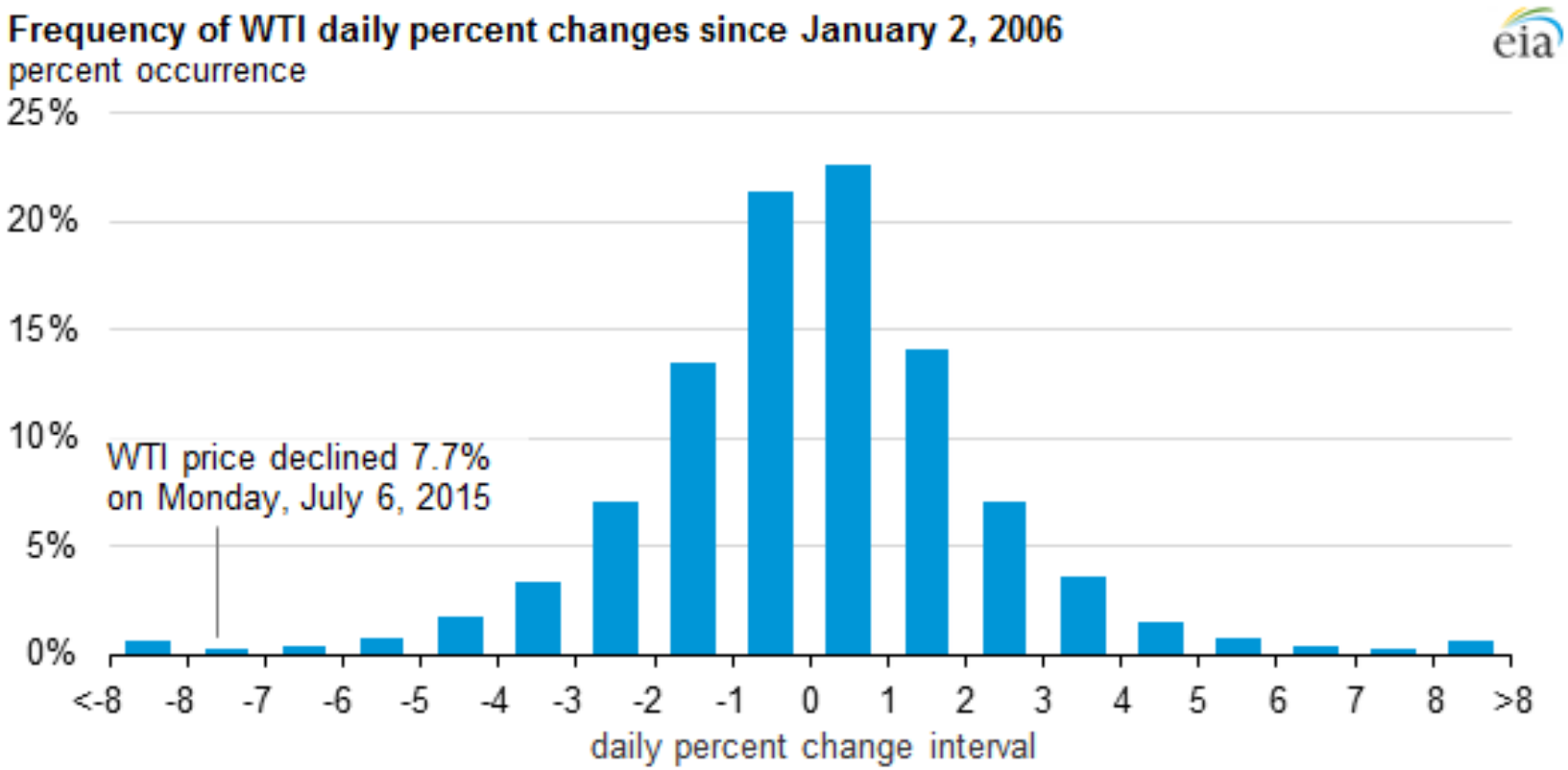


What are the characteristics of a Normal Distribution?

- **Only random (common cause) error is present**
- **Process is free of special (assignable) cause**
- **The Mean, Median and Mode are all the same value**

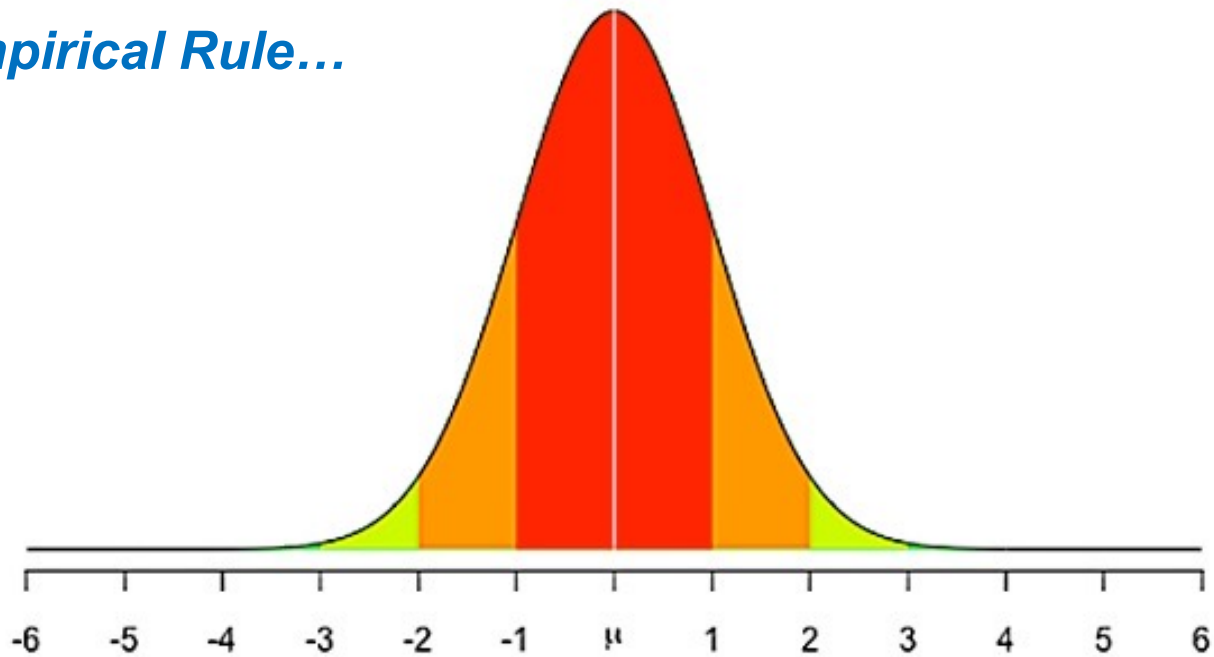
Normal Distribution example

- WEST TEXAS CRUDE OIL PRICE INDEX (WTI)
- http://www.eia.gov/todayinenergy/detail.php?id=22032



The Empirical Rule

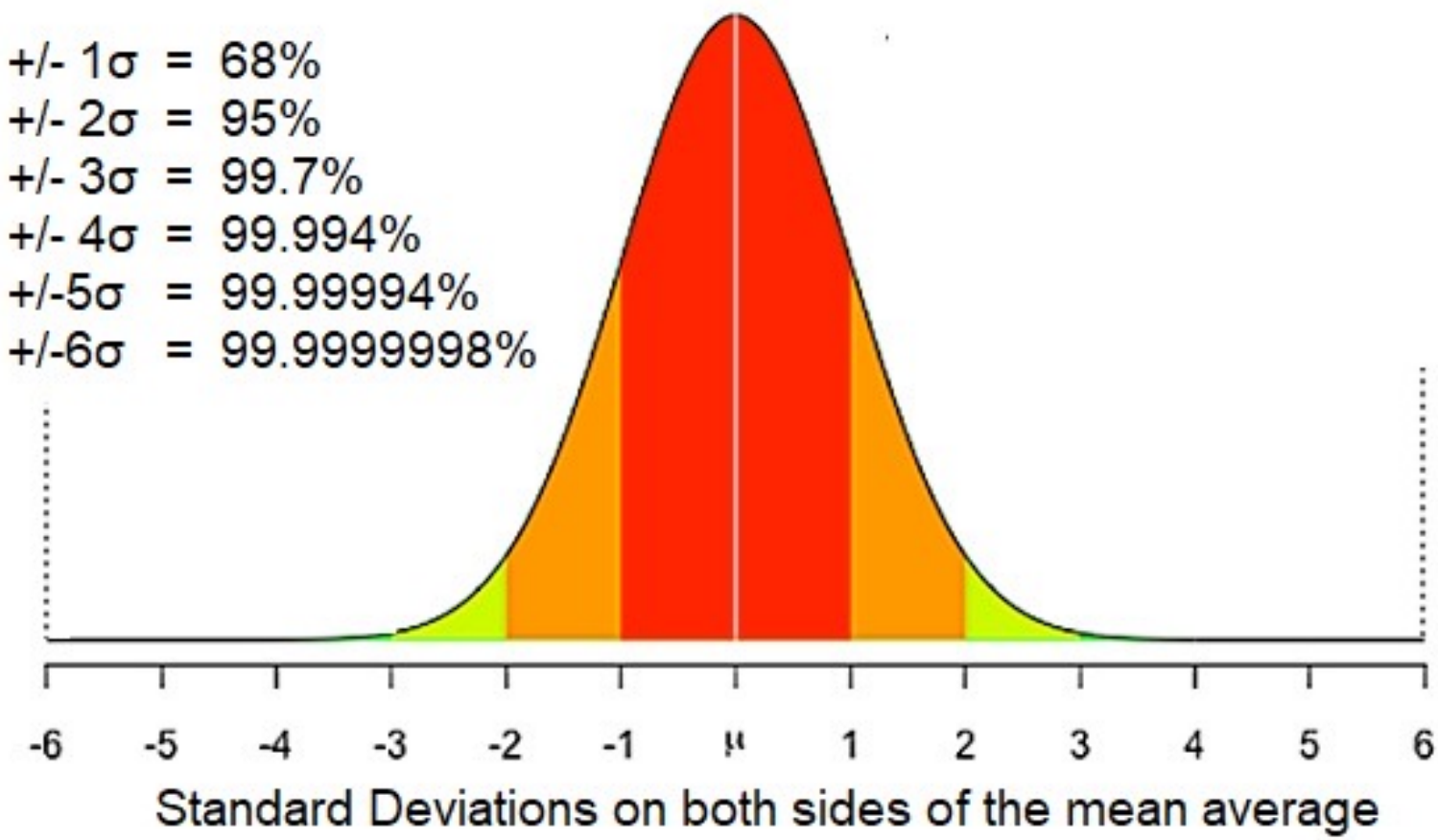
The Empirical Rule…



68.27 % of the data will fall within +/- 1 Standard Deviation
95.45 % of the data will fall within +/- 2 Standard Deviations
99.73 % of the data will fall within +/- 3 Standard Deviations
99.9937 % of the data will fall within +/- 4 Standard Deviations
99.999943 % of the data will fall within +/- 5 Standard Deviations
99.9999998 % of the data will fall within +/- 6 Standard Deviations

65 – 95 - 99.7

The **68–95–99.7 rule** is also known as the **empirical rule.**



The 1.5 Sigma Shift

The 1.5 Sigma Shift for Processes over Long Term

- Motorola allowed for a 1.5 sigma decrease in process capability for systems and processes over a LONG TERM (changes of operators, maintenance cycles, raw materials, suppliers etc)
- This is referred to as the **1.5 Sigma Shift**
- What was called a '6 Sigma' process by Motorola has only 4.5 standard deviations (Sigmas) between the mean and the nearest specification limit
- The "Motorola" definition for 6-sigma process is 99.9997% quality or 3.4 DPMO.
- A "true" 6 Sigma process only has 2 defects per billion opportunities for defects. (99.9999998 % yield)

It is not important in practice to understand why Motorola decided to introduce the 1.5 Sigma Shift but many students at Curious.

So if you are curious then watch this :

https://www.articlevideorobot.com/uncategorized/six-sigma-6-the-1-5-sigma-shift-story

Video : Normal Distribution

Introduction to Graphing

The purpose of Graphing is to:

- Provide a **VISUAL** representation of the data
- Identify potential relationships between the data
- Indicated the amount of variation in the data
- Show how data changes over time

For example…

1. Histograms
2. Dot Plots
3. Box Plots (Box and Whisker plots)
4. Scatter Plots
5. Time Series Plots

Choose a Graphical Analysis

What is your objective?

Graph the distribution of data

Help Me Choose

DISPLAY A GRAPH

- Graphical Summary
- Histogram
- Boxplot
- Individual Value Plot
- Pareto Chart
- Bar Chart
- Pie Chart

Graph variables over time

Help Me Choose

DISPLAY A GRAPH

- Time Series Plot
- I Chart
- I-MR Chart
- Xbar-R Chart
- P Chart
- U Chart

Graph relationships between variables

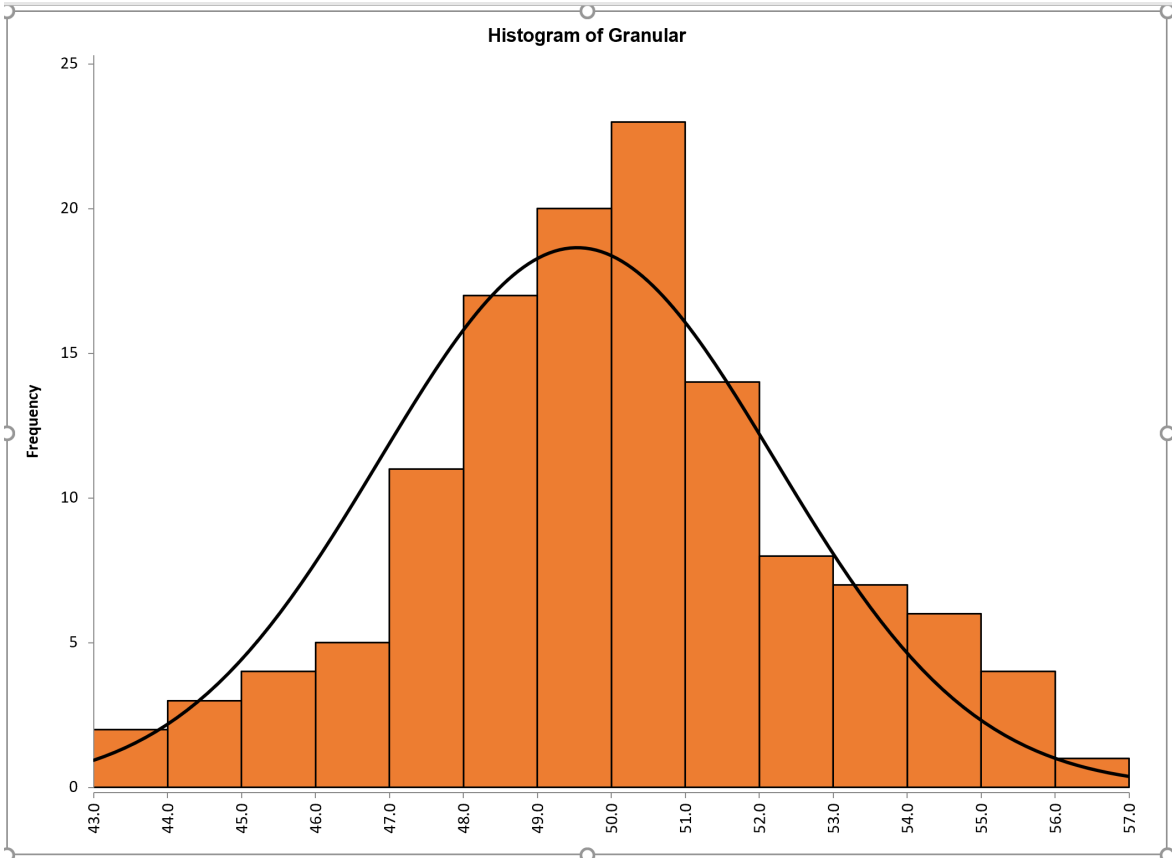
Help Me Choose

DISPLAY A GRAPH

- Scatterplot
- Scatterplot (groups)
- Scatterplot Screener
- Scatterplot Screener (groups)
- Main Effects Plot
- Main Effects Screener
- Interaction Plot

Variation on a Histogram

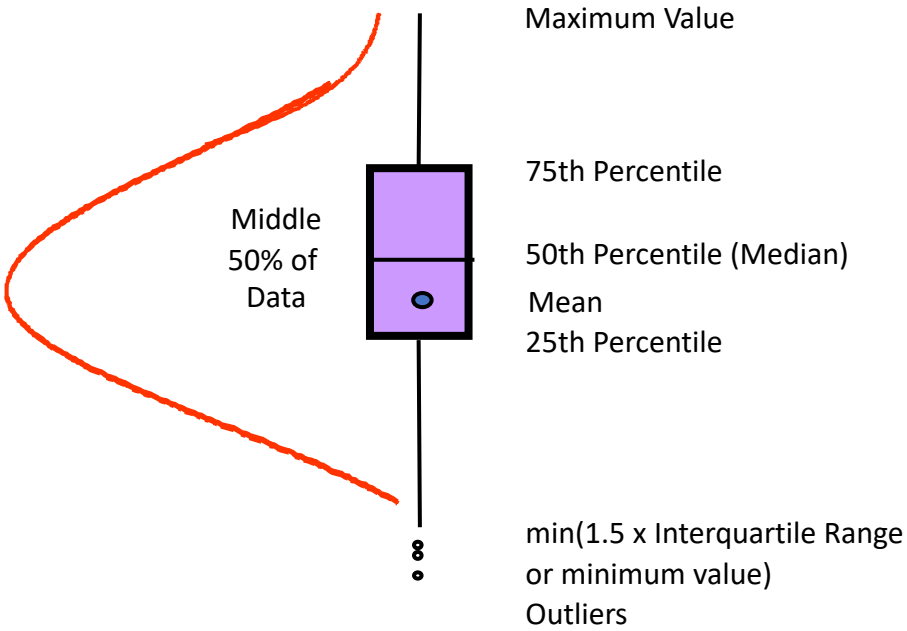
The Histogram can give an indication of the Distribution of the data.
Below is indicative of a NORMAL Distribution of variation.



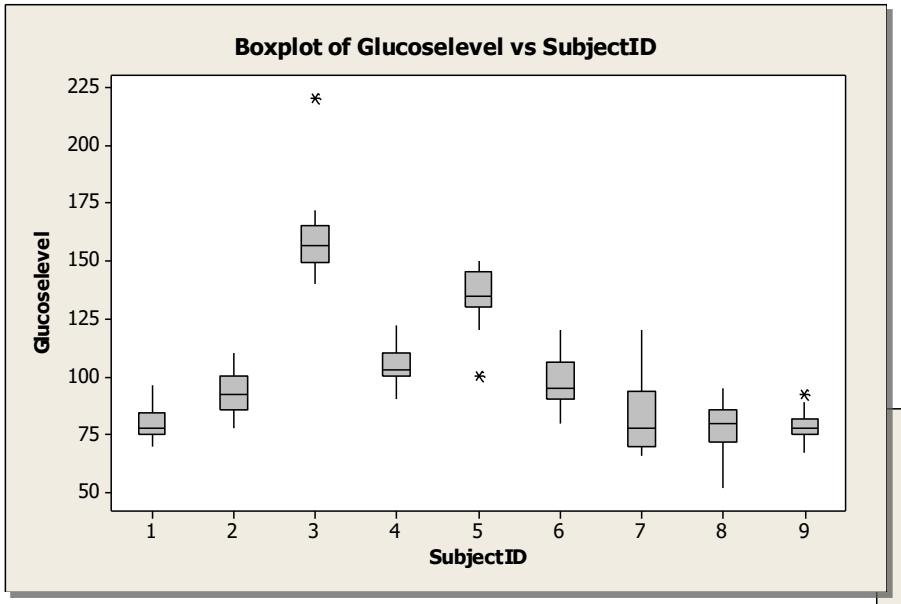
Box Plot

- Box Plots summarize data about the shape, dispersion and center of the data and also help spot Outliers.

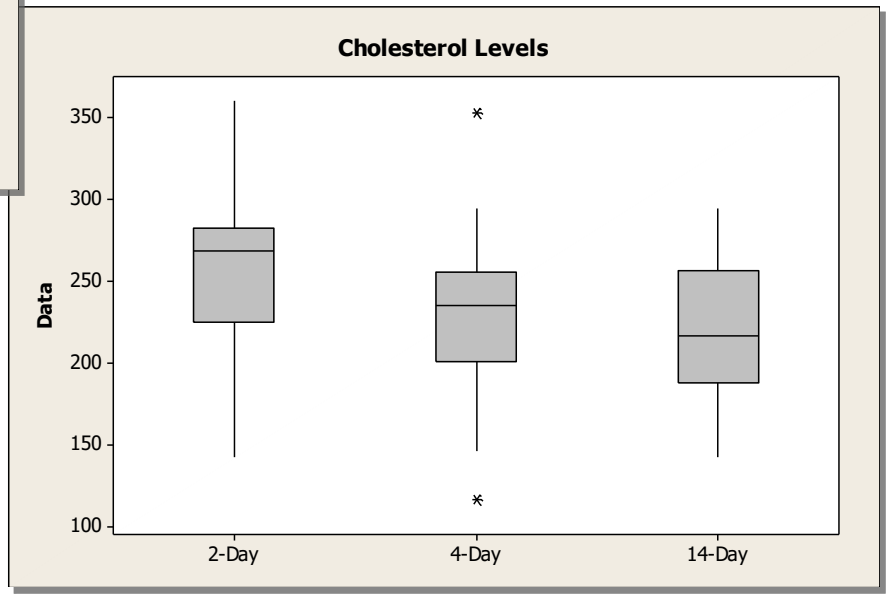
- Box Plots require one of the variables, X or Y, be categorical or Discrete and the other be Continuous.



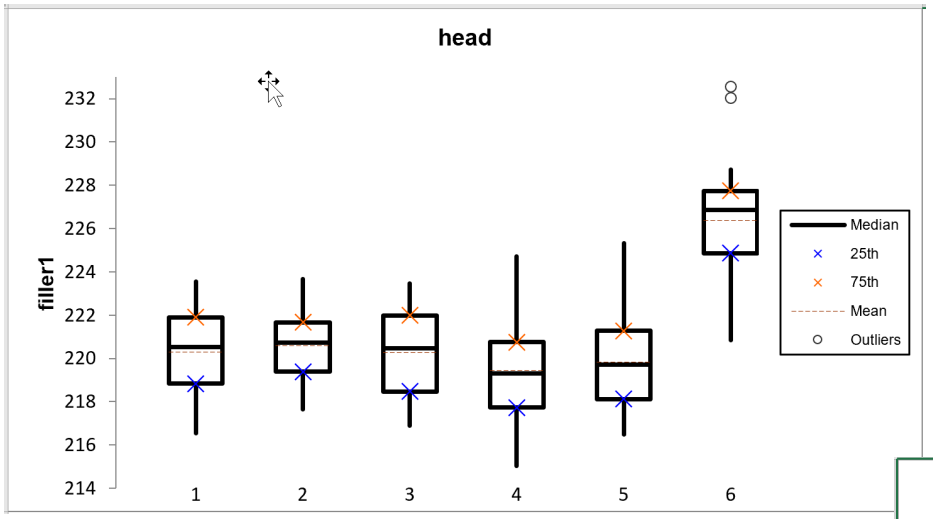
Box Plot Examples

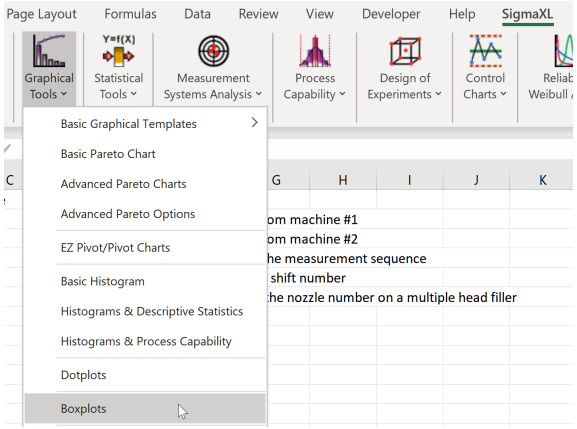


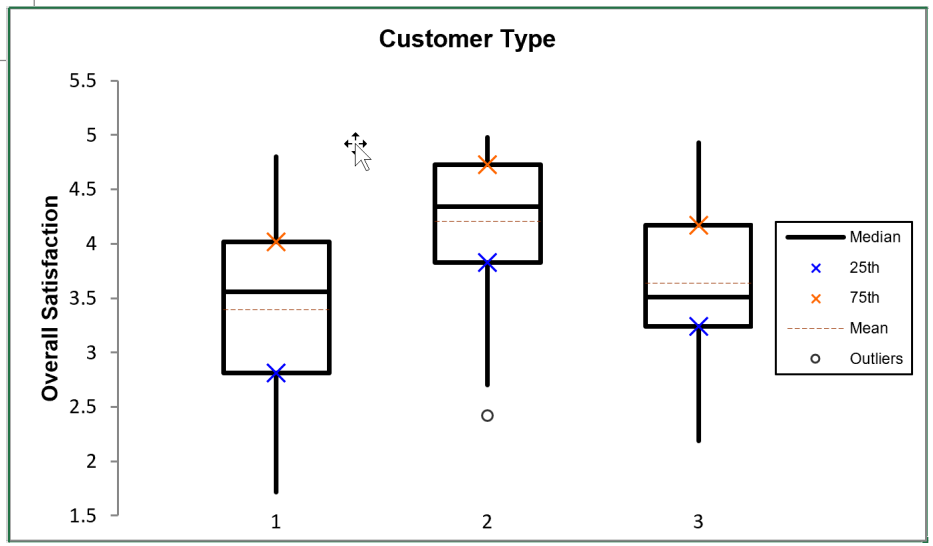
What can you tell about the data expressed in a Box Plots?



SigmaXL Boxplot Examples

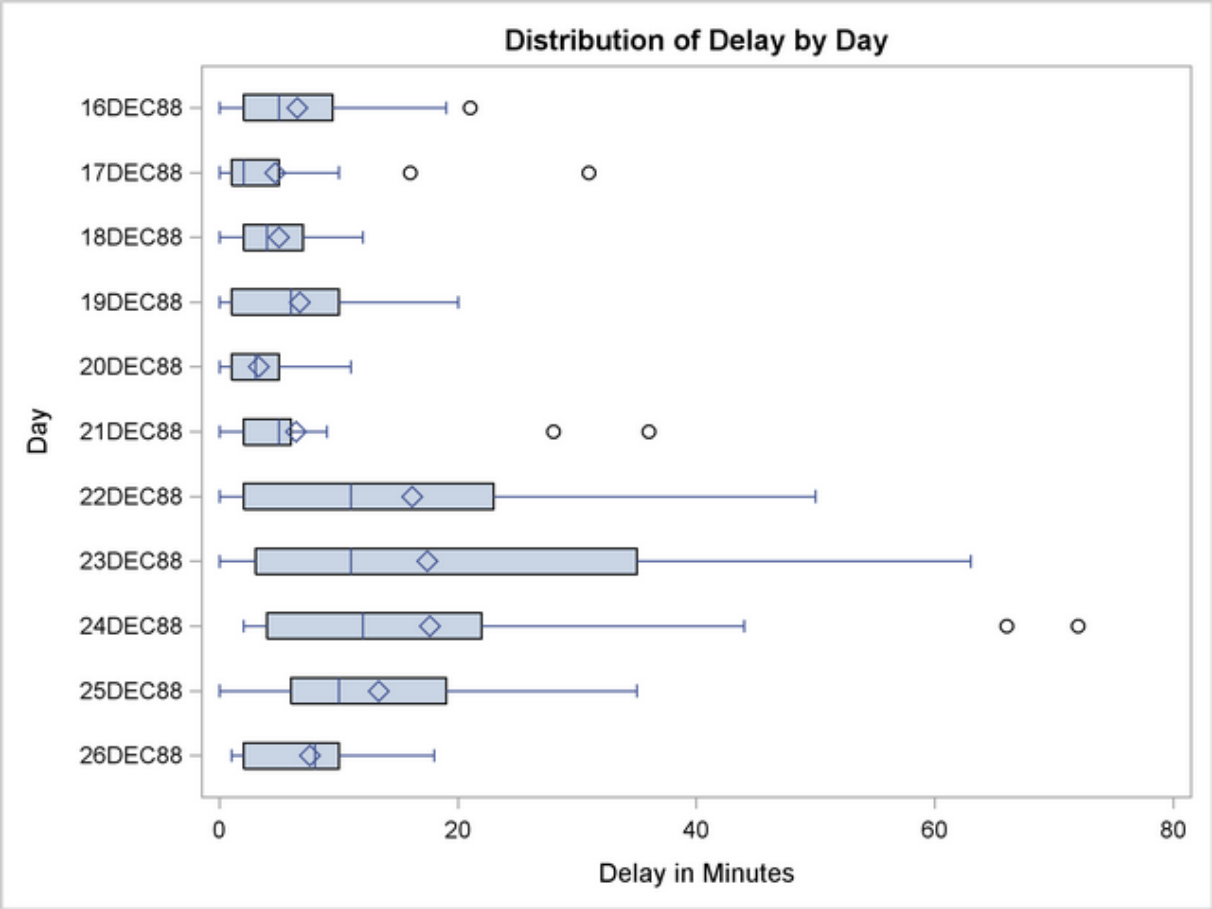




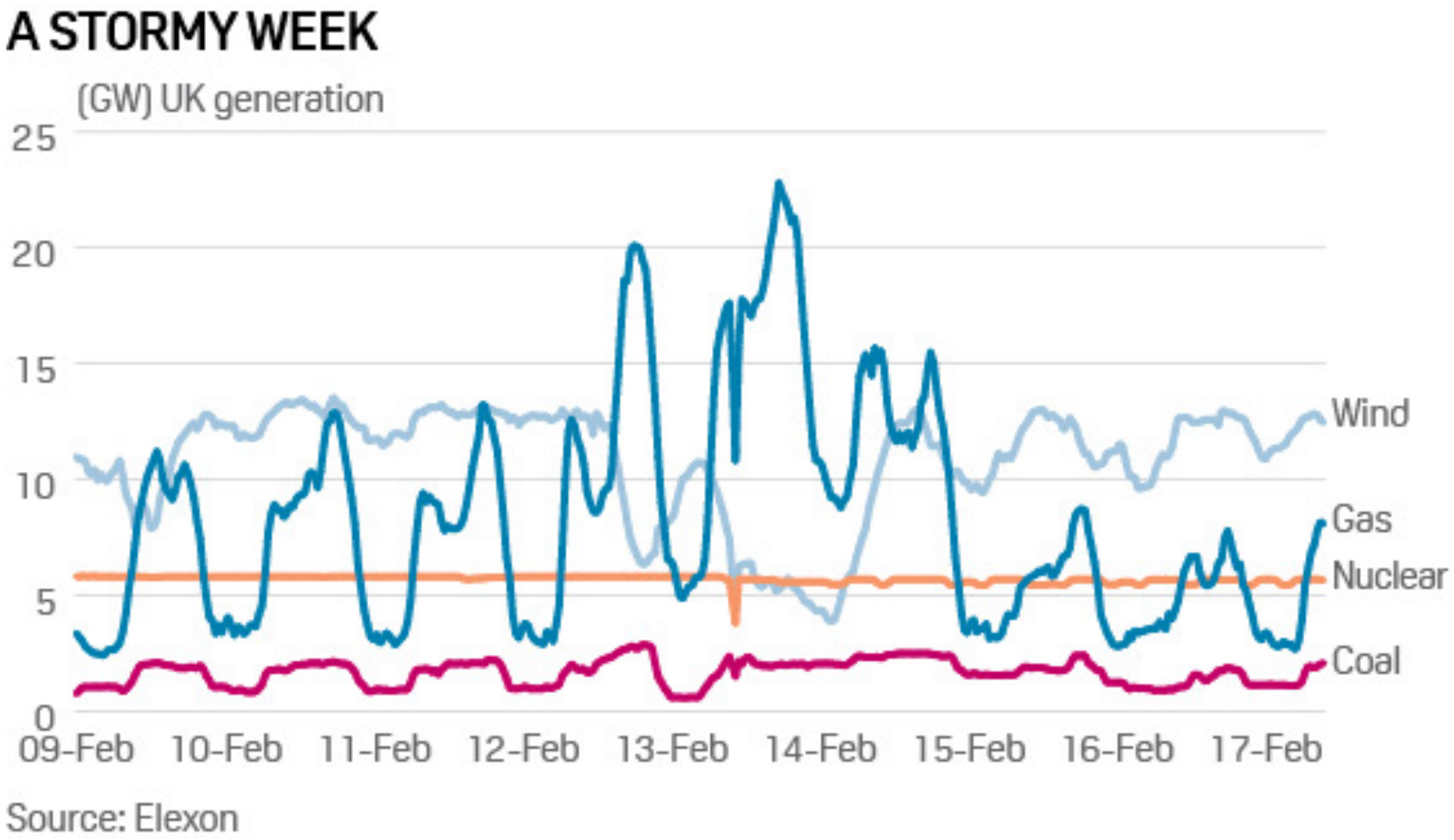


Box Plot Examples

Data from Major UK Retail Food Store.
Delays in Arrivals of Trucks from Suppliers to Central Warehouse



Time Series Plots and Run Charts

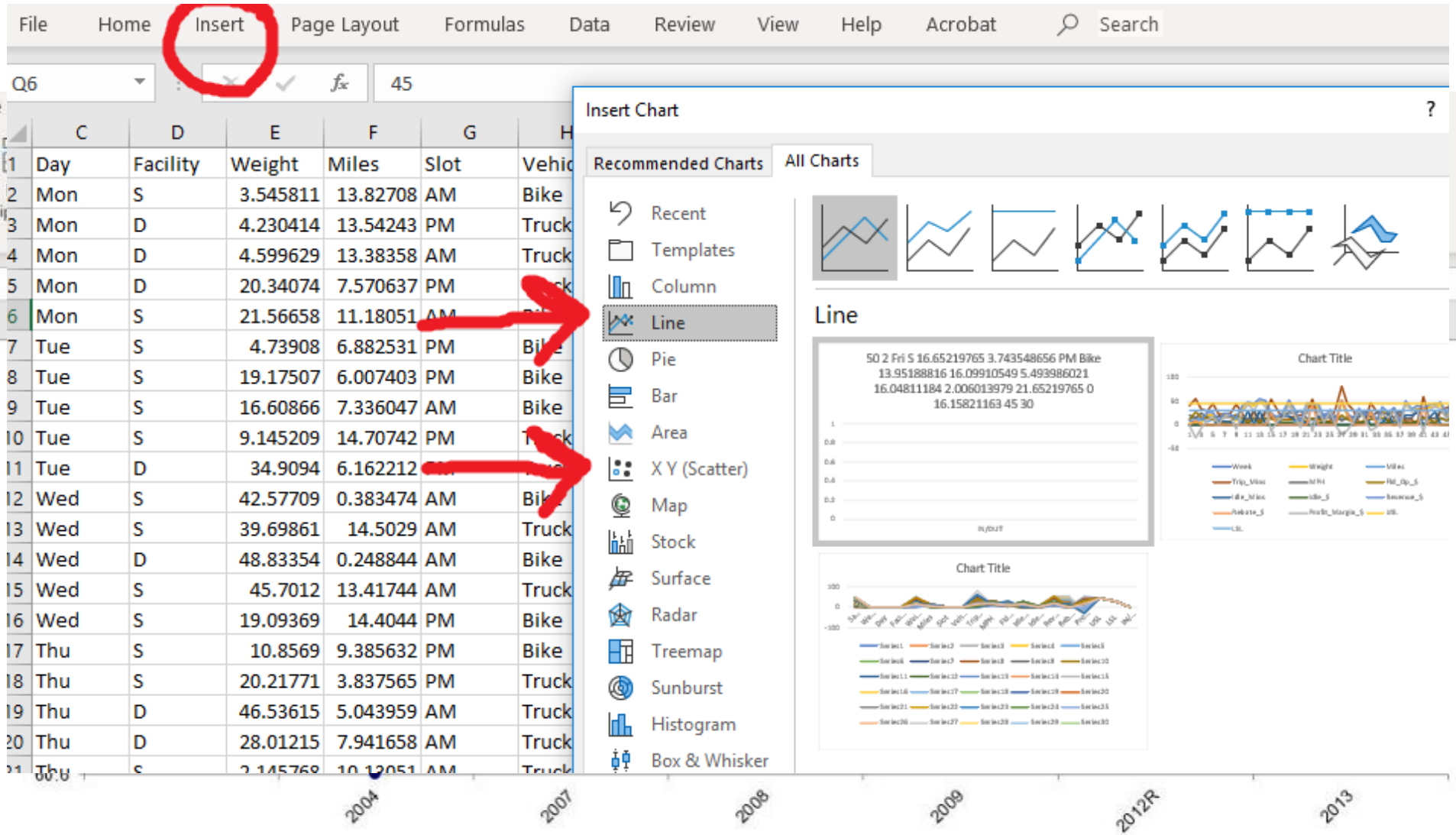


Energy in Switzerland

https://en.wikipedia.org/wiki/Energy_in_Switzerland

	Population (million)	Prim. energy (TWh)	Production (TWh)	Import (TWh)	Electricity (TWh)	CO_2-emission (Mt)
2004	7.48	316	137	179	60.6	44.6
2007	7.51	299	147	164	61.6	42.2
2008	7.71	311	148	180	63.5	43.7
2009	7.80	313	149	182	62.1	42.4
2012	7.87	295	143	167	62.7	39.9
2012R	7.93	298	148	170	63.06	41.3
2013	8.09	311	151	177	63.16	41.5
Change 2004-09	4.3%	-0.7%	8.0%	1.9%	2.5%	-4.8%
Mtoe = 11.63 TWh.						

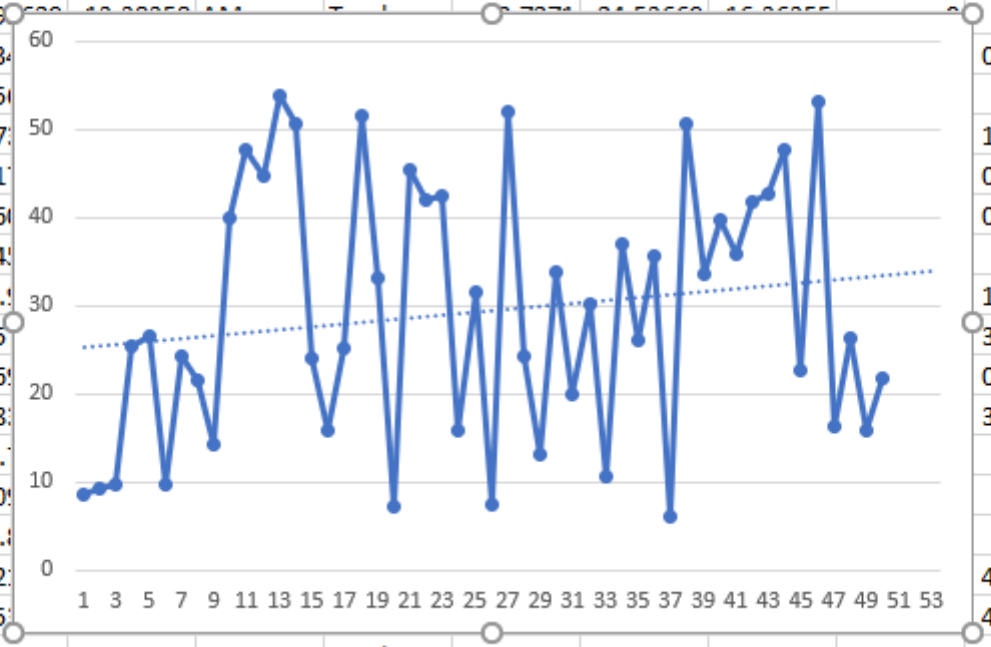
Run Charts in Excel
Do not show Control Limits



Run Chart (Excel)

Insert Page Layout Formulas Data Review View Help Acrobat Chart Design Format Search

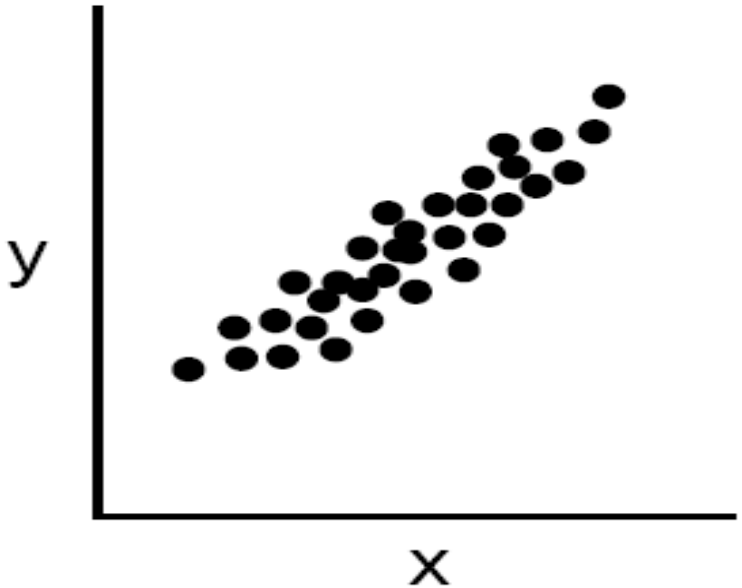
	C	D	E	F	G	H	I	J	K	L	M	N	O
k	Day	Facility	Weight	Miles	Slot	Vehicle	Trip_Mins	MPH	Fld_Op_$	Idle_Mins	Idle_$	Revenue	Rebat
1	Mon	S	3.545811	13.82708	AM	Bike	40.7951	20.33638	10.19877	0	0	8.545811	
1	Mon	D	4.230414	13.54243	PM	Truck	54.10339	15.01839	27.05169	0	0	9.230414	9.230
1	Mon	D	4.59								0	9.599629	
1	Mon	D	20.34								0.[illegible]53	25.34074	
1	Mon	S	21.5								0	26.56658	
1	Tue	S	4.7								1.[illegible]66	9.73908	
1	Tue	S	19.1								0.[illegible]09	24.17507	
1	Tue	S	16.6								0.[illegible]167	21.60866	
1	Tue	S	9.14								0	14.14521	
1	Tue	D	34.								1.218714	39.9094	
1	Wed	S	42.5								3.509524	47.57709	
1	Wed	S	39.6								0.386476	44.69861	
1	Wed	D	48.8								3.570781	53.83354	
1	Wed	S	45.								0.95992	50.7012	
1	Wed	S	19.0								0	24.09369	24.09
1	Thu	S	10.								0	15.8569	
1	Thu	S	20.2								4.640036	25.21771	
1	Thu	D	46.5								4.532734	51.53615	
1	Thu	D	28.01215	7.941658	AM	Truck	18.96362	25.12703	12.24091	11.03638		33.01215	



Scatter Diagrams

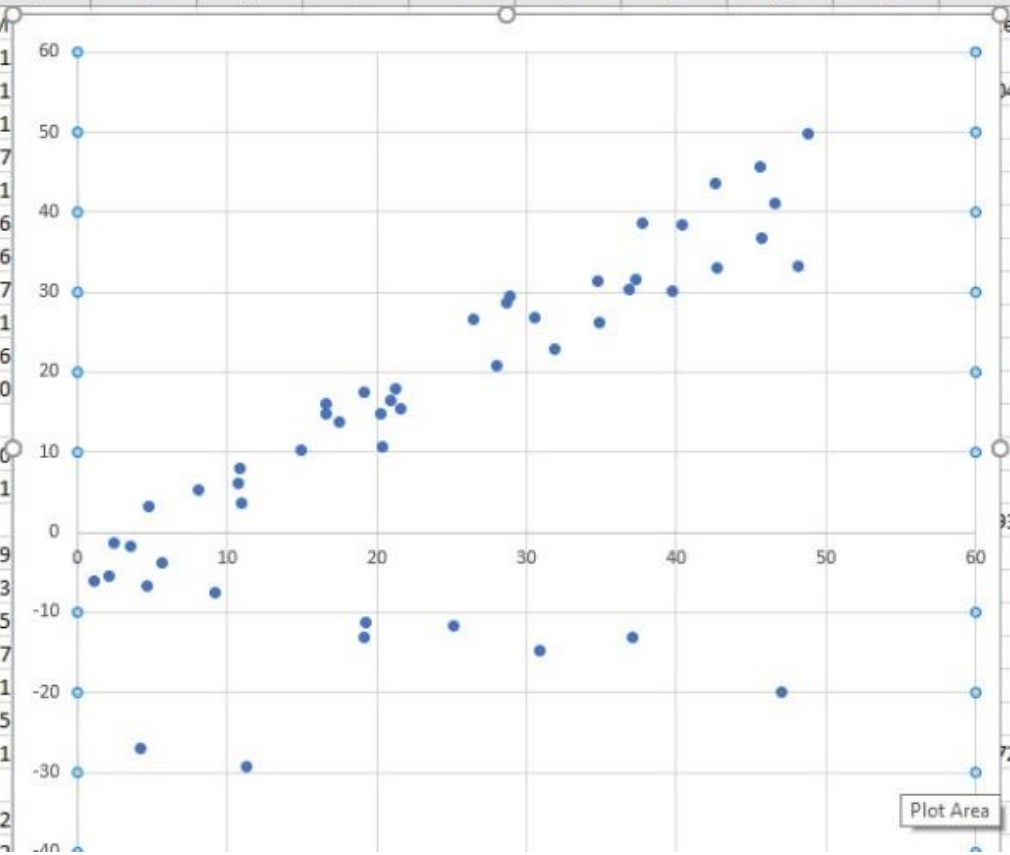
Purpose:

- To identify the correlations that might exist between a quality characteristic and a factor that might be driving it
- A scatter diagram shows the **correlation** between two variables in a process.



Scatter Plot (Excel)

Day	Facility	Weight	M	ofit_Ma	USL	LSL
Mon	S	3.545811	1	-1.65296	45	
Mon	D	4.230414	1	27.0517	45	
Mon	D	4.599629	1	-6.76392	45	
Mon	D	20.34074	7	10.6873	45	
Mon	S	21.56658	1	15.35059	45	
Tue	S	4.73908	6	3.327546	45	
Tue	S	19.17507	6	17.57328	45	
Tue	S	16.60866	7	14.77983	45	
Tue	S	9.145209	1	-7.58402	45	
Tue	D	34.9094	6	26.12811	45	
Wed	S	42.57709	0	43.58662	45	
Wed	S	39.69861		30.08508	45	
Wed	D	48.83354	0	49.90432	45	
Wed	S	45.7012	1	36.66112	45	
Wed	S	19.09369		-13.095	45	
Thu	S	10.8569	9	7.972703	45	
Thu	S	20.21771	3	14.85775	45	
Thu	D	46.53615	5	41.06889	45	
Thu	D	28.01215	7	20.77125	45	
Thu	S	2.145768	1	-5.46127	45	
Fri	S	40.35617	5	38.31539	45	
Fri	D	37.07265	1	-13.1796	45	
Fri	D	37.30436		31.59902	45	
Fri	D	10.77627	2	6.168283	45	



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2012R	7.93	298	148	170	63.06	41.3
2013	8.09	311	151	177	63.16	41.5
Change 2004-09	4.3%	-0.7%	8.0%	1.9%	2.5%	-4.8%
Mtoe = 11.63 TWh.						

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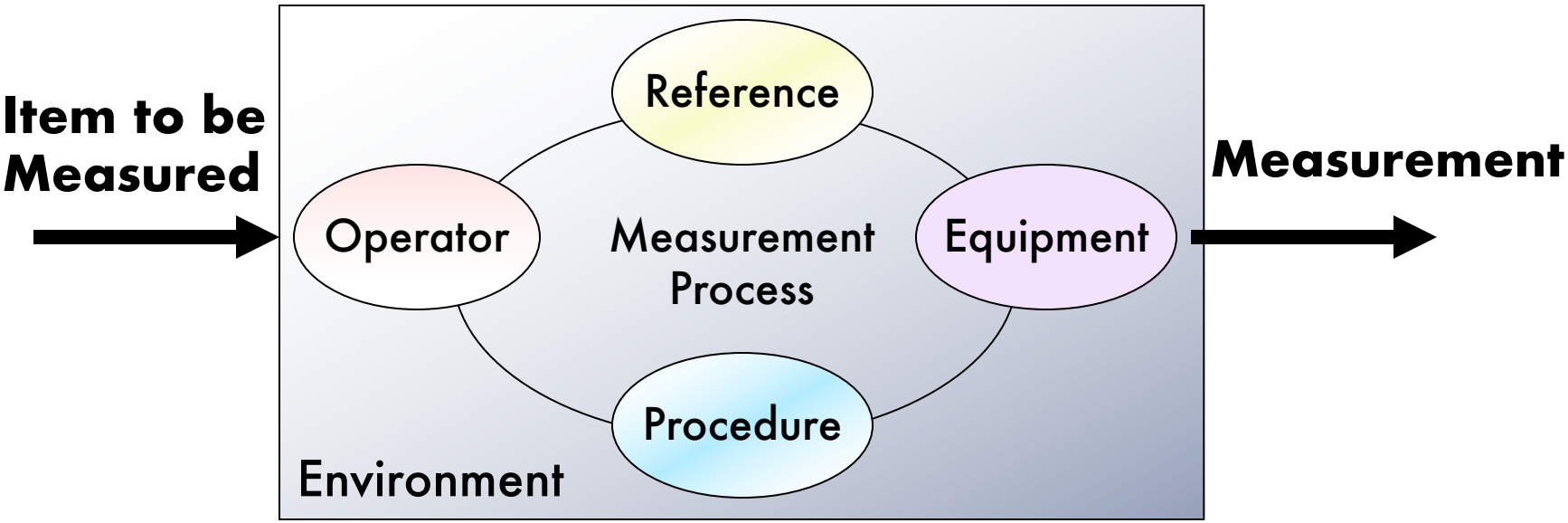
Measure Phase

Measurement System Analysis

Measurement System Analysis

MSA is a procedure to quantify variation and error introduced into the measure by the act of measuring.



FIVE FACTORS CAN EFFECT THE MEASUREMENT

1. Operator: the person doing the measurement
2. Equipment: the device used to measure
3. Procedure: how the operator uses the equipment
4. Reference : what the equipment was calibrated against
5. Environment : what the physical environment is around the measurement (temp etc)

Variation

Variation is additive and the overall variation in a system or process is the sum of all sources of variation

$$\sigma^2_{Total} = \sigma^2_{process} + \sigma^2_{measurement\ system}$$

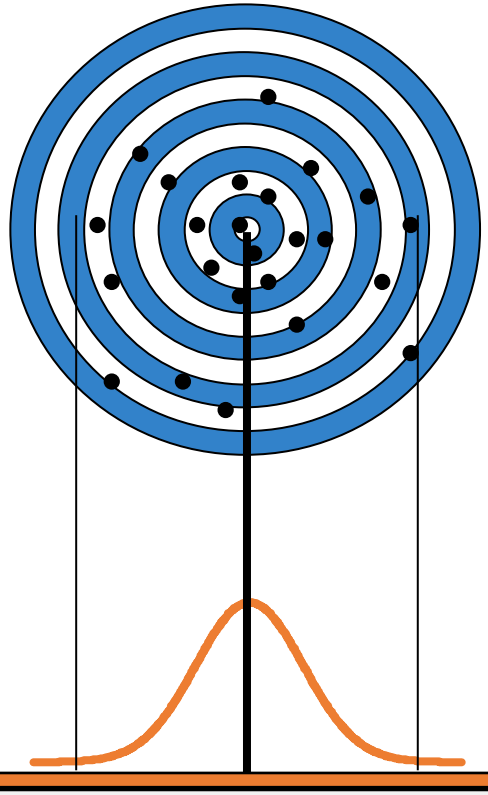
Purpose

MSA classifies the sources of error in the following way:

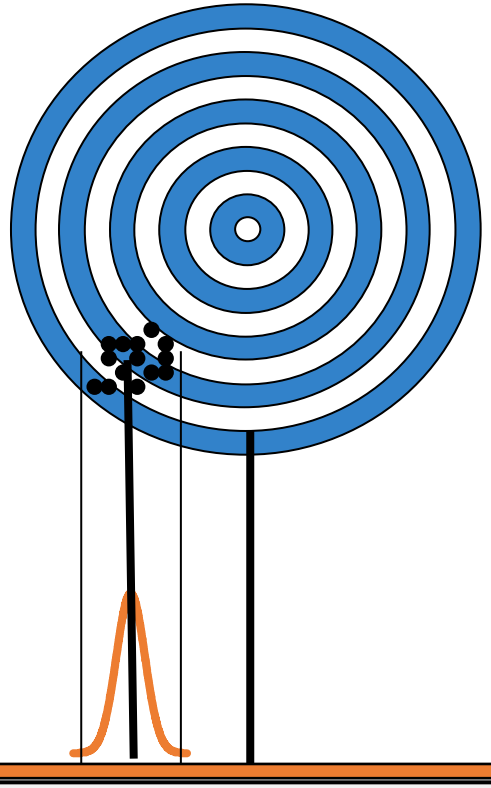
- **Precision**
  - Repeatability - within an operator or piece of equipment
  - Reproducibility - operator to operator or attribute gage to attribute gage
- **Accuracy**
  - Stability - accuracy over time
  - Linearity- accuracy throughout the measurement range
  - Resolution – how detailed is the information
  - Bias – Off-set from true value
    - Constant Bias
    - Variable Bias – typically seen with electronic equipment, amount of Bias changes with setting levels

Accuracy and Precision

Accurate but not precise -
On average these shots are in the center of the target but there is a lot of variability

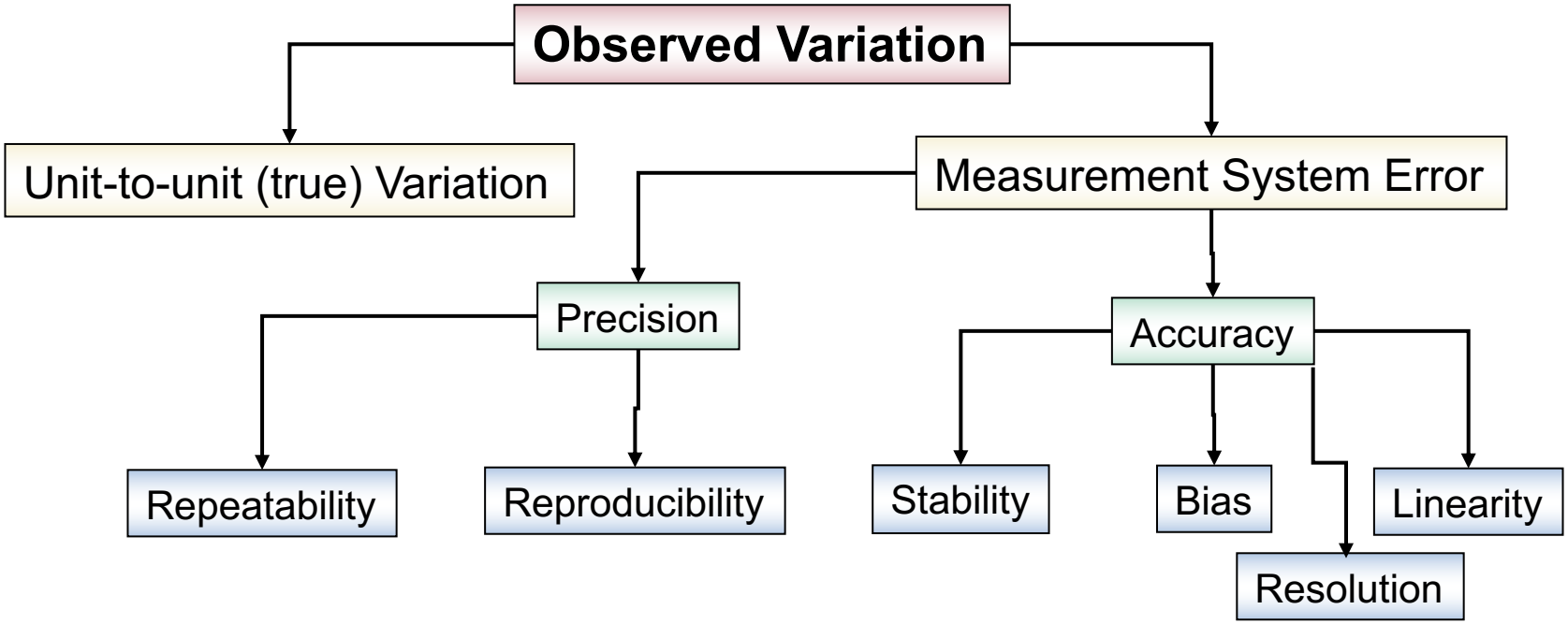


Precise but not accurate -
The average is not on the center but the variability is small



Components of Variation

Whenever you measure anything the variation you observe can be segmented into the following components…



All measurement systems have error. If you do not know how much of the variation you observe is contributed by measurement system error you cannot make confident decisions.

Precision

PRECISION returns the same value of a given measurement every time the measurement is made.

Precise measurements are independent of who measures them or when the measurement is made.

Precision can be partitioned into two components:

- Repeatability
- Reproducibility

- This is sometimes called “Gauge R & R”

Repeatability

DEFINITIONS:

Repeatability is the variation in measurements obtained with **One measurement instrument** used several times by

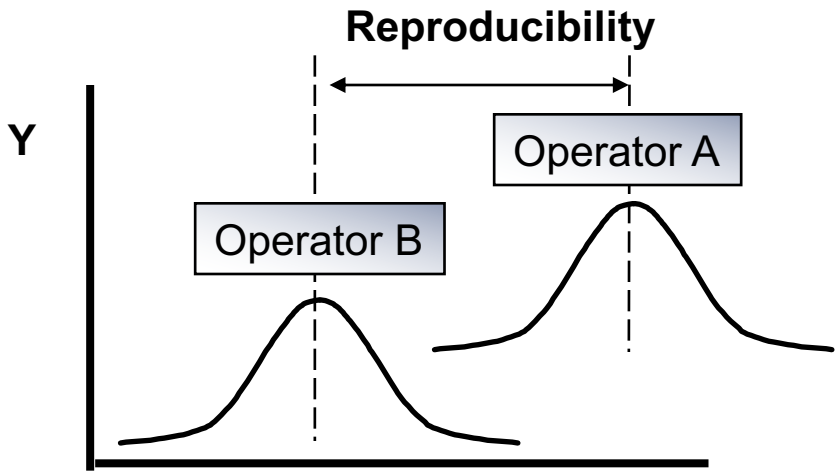
One Operator while measuring the identical characteristic on the **same part.**

For example:

- ***Manufacturing:*** One person measures the purity of multiple samples of the same vial and gets different purity measures.
- ***Transactional:*** One person evaluates a contract multiple times (over a period of time) and makes different determinations of errors.

Reproducibility

Reproducibility is the variation in the average of the measurements made by **DIFFERENT OPERATORS** using the **same measuring instrument** when measuring the identical characteristic on the **same part.**



For example:

- ***Manufacturing:*** Different people perform purity test on samples from the same vial and get different results.
- ***Transactional:*** Different people evaluate the same contract and make different determinations.

Accuracy

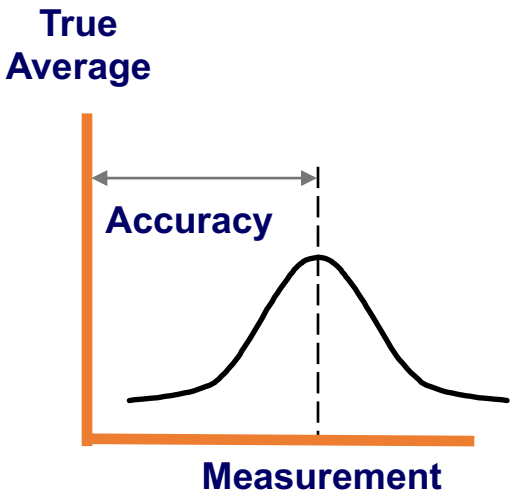
ACCURACY is the difference between the observed average of the measurement and a reference value.

The reference value can be:

- Measurement of a known standard
- Comparison with another known measurement method
- Prediction of a theoretical value

Accuracy is influenced by 4 different factors:

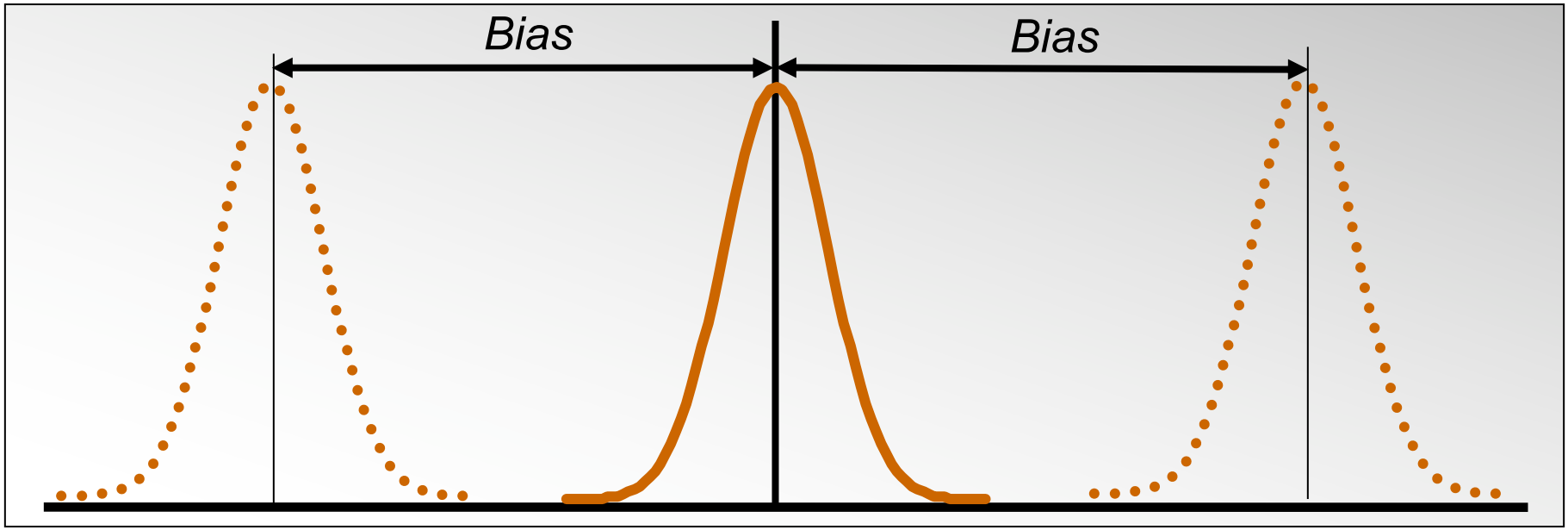
- Stability
- Linearity
- Resolution
- Bias



Bias

Bias is defined as the deviation of the measured value from the actual value.

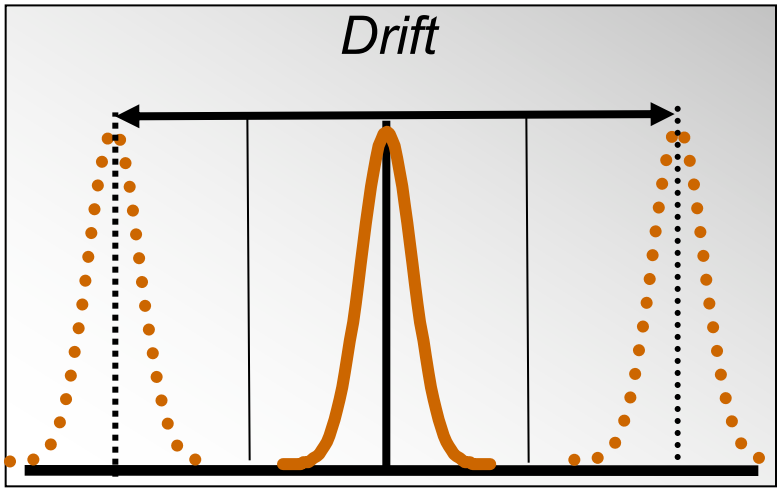
Calibration procedures can minimize and control bias within acceptable limits. Ideally Bias can never be eliminated due to material wear and tear!



Stability

Stability of a gage is defined as error (measured in terms of Standard Deviation) as a function of time. Environmental conditions such as cleanliness, noise, vibration, lighting, chemical, wear and tear or other factors usually influence gage instability

Control Charts are commonly used to track the Stability of a measurement system over time.



Stability is Bias characterized as a function of time!

(Self Reading) Repeatability and Reproducibility Problems

Repeatability Problems:

- Calibrate or replace gage.
- If only occurring with one operator, re-train.

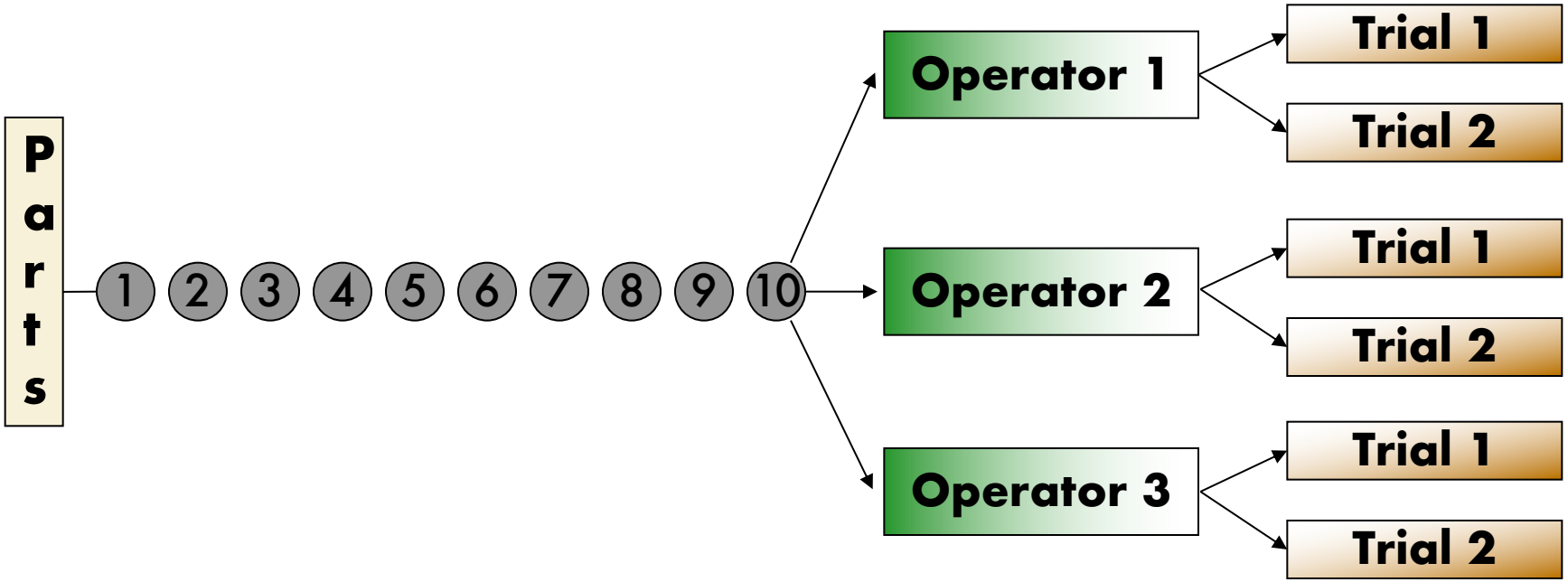
Reproducibility Problems:

- Measurement machines
  - Similar machines
    - Ensure all have been calibrated and the standard measurement method is being utilized.
  - Dissimilar machines
    - One machine is superior.
- Operators
  - Training and skill level of the operators must be assessed.
  - Operators should be observed to ensure standard procedures are followed.
- Operator/machine by part interactions
  - Understand why the operator/machine had problems measuring some parts and not others.
    - Re-measure the problem parts
    - Problem could be a result of gage linearity
    - Problem could be poor gage design

Crossed Design Example

Example of a Crossed Design / Crossed Study

10 x 3 x 2 Crossed Design is shown
A minimum of two measurements/part/operator is required.
Three is better!

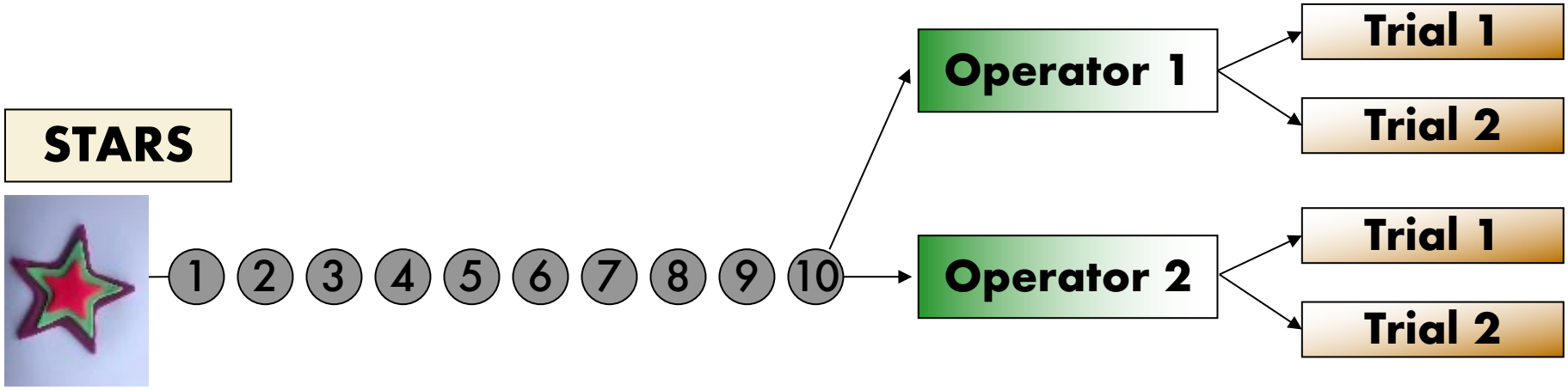


OPTIONAL : Crossed Design Class Practical

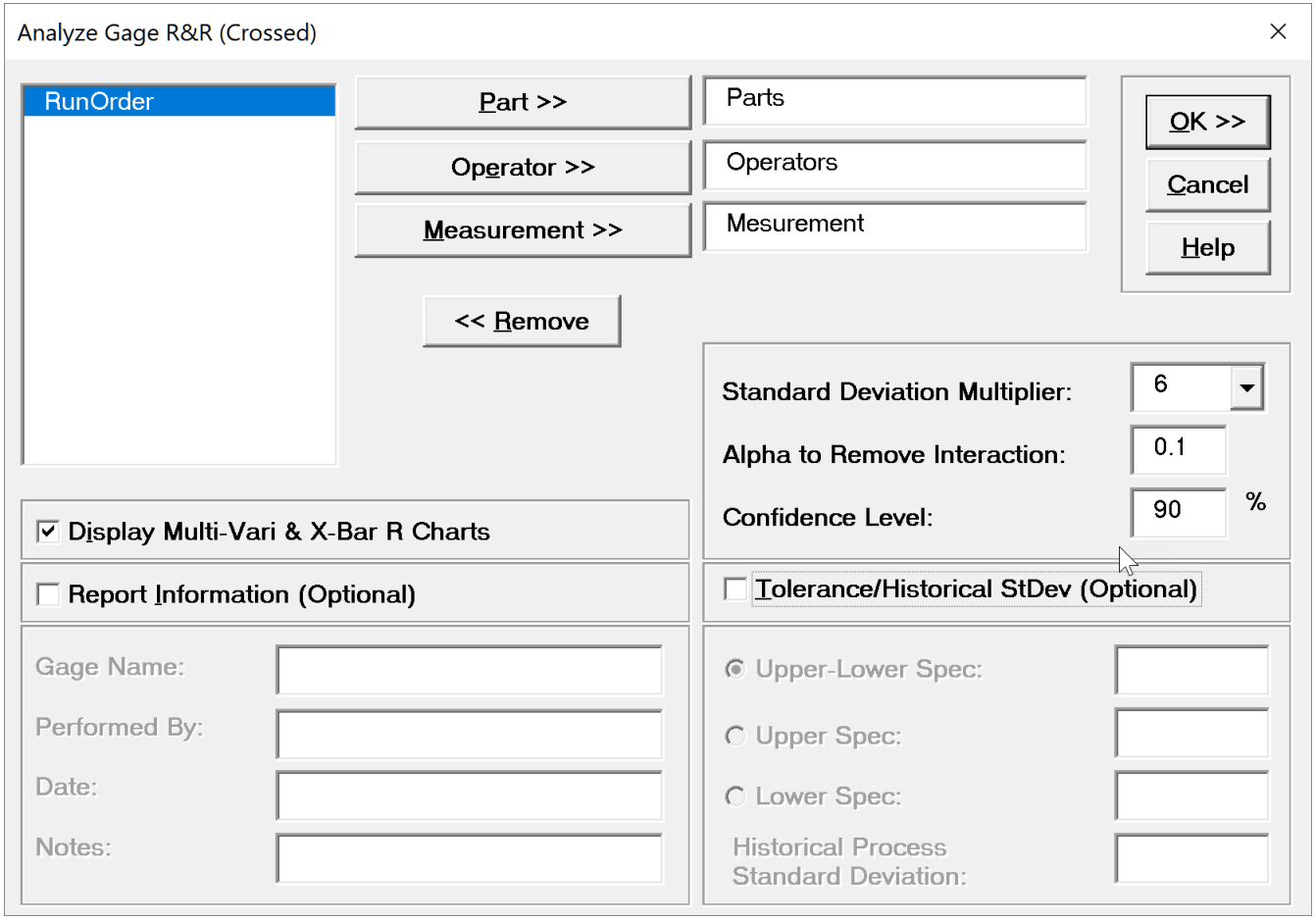
Gauge R&R Crossed Study on Star Weights

10 x 2 x 2 Crossed Study

1. Create worksheet in SigmaXL
2. Carry out measures and enter data
3. Analyze data using SigmaXL



SigmaXL Gage R&R Dialogue



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Gauge R&R Study Output

Measurement Systems Analysis > Analyze Gage R&R (Crossed)

Gage R&R Study (Crossed) Report

Gage Name:	
Date of Study:	
Performed By:	
Notes:	

Process Tolerance (USL - LSL):	
Historical Process Standard Deviation:	
Standard Deviation Multiplier:	6
Alpha to Remove Interaction:	0.1
Confidence Level:	90.0
Number of Parts:	10
Number of Operators:	2
Number of Replicates:	2
Design Type:	Balanced

What is the method used in Gauge R and R studies to analyse the results?

Analysis of Variance with Part * Operator Interaction:

Source	DF	SS	MS	F	P
Part:	9	86.296	9.588	305.75	0.0000
Operator:	1	0.707560	0.707560	22.563	0.0010
Part * Operator:	9	0.282240	0.03136	0.974821	0.4886
Repeatability:	20	0.643400	0.03217		
Total:	39	87.929	2.255		

Analysis of Variance without Part * Operator Interaction (P for Interaction >= 0.1):

Source	DF	SS	MS	F	P
Part:	9	86.296	9.588	300.40	0.0000
Operator:	1	0.707560	0.707560	22.168	0.0001
Repeatability:	29	0.925640	0.031918621		
Total:	39	87.92924	2.254595897		

Gage R&R Metrics	StDev	StDev Lower 90% CI	Upper 90% CI	6 * StDev	Variation (TV)	Lower 90% CI	% TV Upper 90% CI
Gage R&R:	0.256321	0.194438	3.005	1.538	16.36	8.67	88.46
Operator (AV Appraiser Variation):	0.183799	0.086918434	2.999	1.102793944	11.73		
Part * Operator (INT Interaction):	0	0	0	0	0.00		
Reproducibility (SQRT(AV^2 + INT^2)):	0.183799	0.086918434	2.999	1.102793944	11.73		
Repeatability (EV Equipment Variation):	0.178658	0.147481	0.228629	1.071946988	11.40		
Part Variation (PV):	1.546	1.126	2.546	9.274	98.65		
Total Variation (TV):	1.567	1.154	3.508	9.401	100.00		

Gage R&R Metrics	Variance Component	% Contribution of Variance Component
Gage R&R:	0.06570069	2.68
Operator:	0.033782069	1.38
Part * Operator:	0	0.00
Reproducibility:	0.033782069	1.38
Repeatability:	0.031918621	1.30
Part Variation:	2.389	97.32
Total Variation:	2.455	100.00

Analysis of Variance
ANOVA

Gage R&R Metrics	NDC	NDC Lower 90% CI	NDC Upper 90%
Number of Distinct Categories (Signal-to-Noise Ratio: 1.41 * PV/(R&R)):	8.5	0.7	16.3

Note: Due to the complexity of calculations, SigmaXL must be loaded and appear on the menu in order for this template to function.

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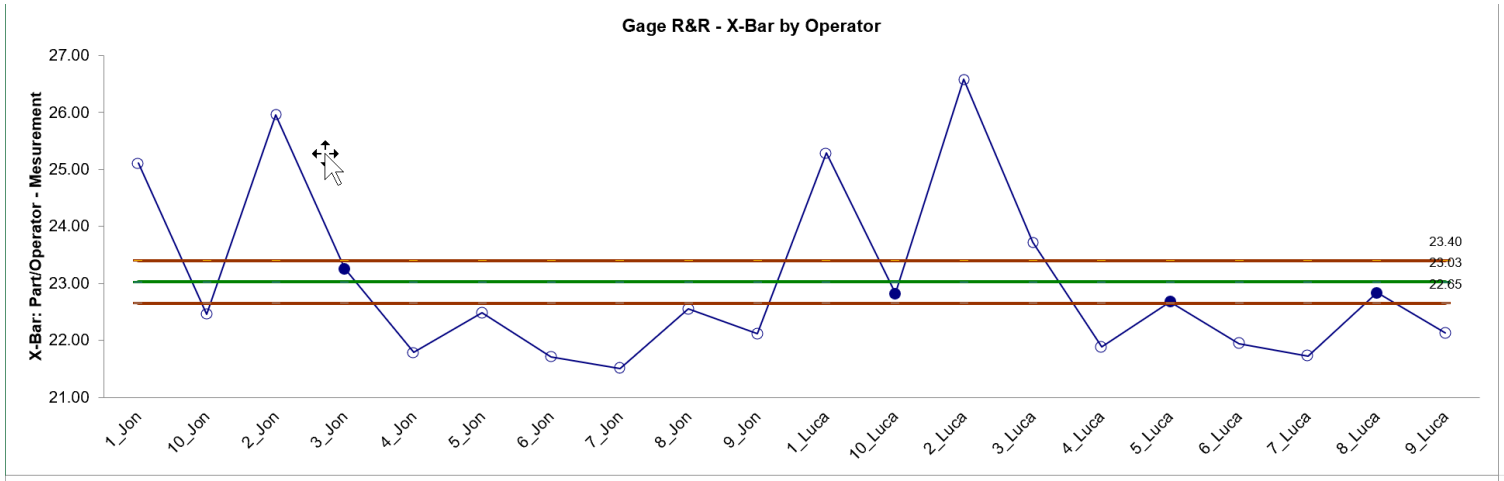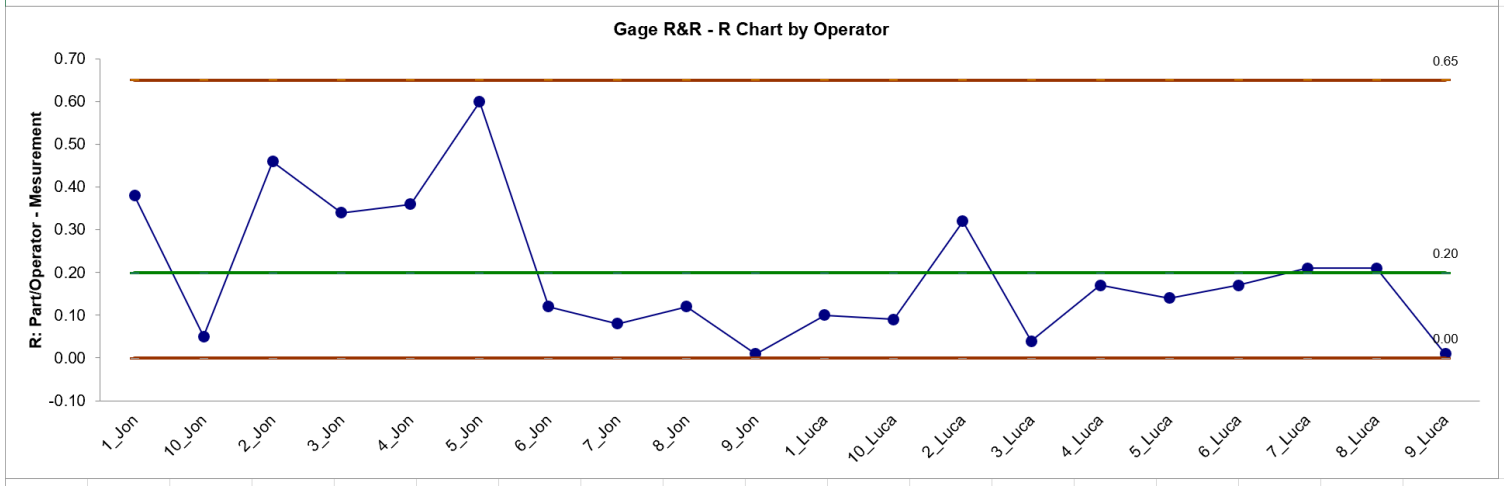
Gage R&R Output - Graphs