# Types of Data and Measurement Scales

**Data Science for Quality Management: Module 1 - Data and Measurement**

with **Wendy Martin**

**Learning objective:**
Discern between qualitative and quantitative data, continuous and discrete data

Compare / contrast measurement and underlying characteristics

# Using Data

“When you can measure what you are speaking about, and express it in numbers, you know something about it…

## Using Data

…but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind.”

Lord Kelvin (1883)

# Why Do We Need Data?

In business, we have questions that need to be answered.

- We must ask ourselves, “What do I really want to know?” and
- “Do my data help answer these questions?”

# Data Costs Money

We must make data both

- Efficient and
- Effective

# Measurement and Data

How do we study, record and communicate an event? We assign numbers.

- **Measurement** is the *process*
- **Data** is the *output*

# Two Basic Types of Data

**Quantitative** data are data measured along a numerical scale.

- Often referred to as **continuous**.

# Two Basic Types of Data

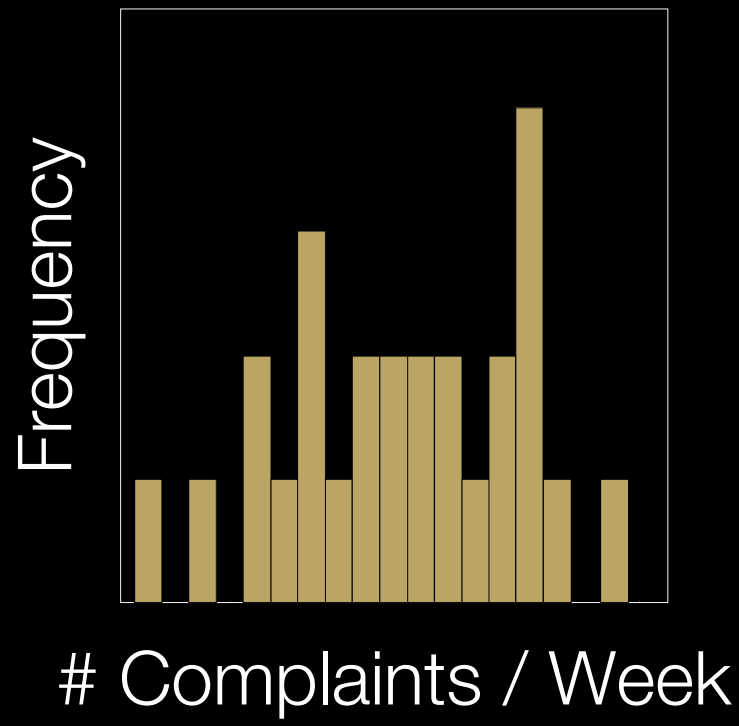
**Qualitative** data are descriptions that fall into categories.

- Often referred to as **discrete**.
- Frequencies, proportions, or rates.

# Discrete vs. Continuous Data

Discrete Data:

- Items/Units we count



# Discrete Data Examples

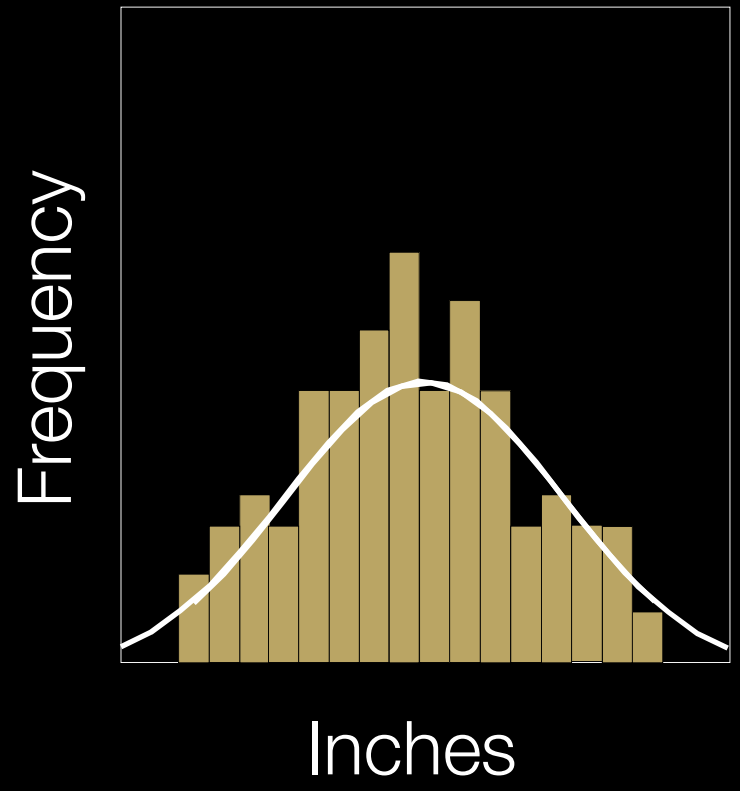
Examples of discrete data in business:

- Complaints per sales period
- Number of defects per unit
- Percent defective units
- Number of orders shipped on time

# Discrete vs. Continuous Data

Continuous Data:

- Items/Units we measure



# Continuous Data Examples

Examples of continuous data in business:

- Dimensions (height, length, width)
- Temperature
- Speed
- Volume of sales

# Measurement & Measurement Scales

Measurement is the assignment of numbers or other symbols to an underlying attribute, characteristic or property.

# Measurement & Measurement Scales

The numbers, or symbols, are assigned such that the relationships amongst the numbers or symbols reflect relationships in the attribute studied.

# Measurement & Measurement Scale Example

# Measurement & Measurement Scale Example

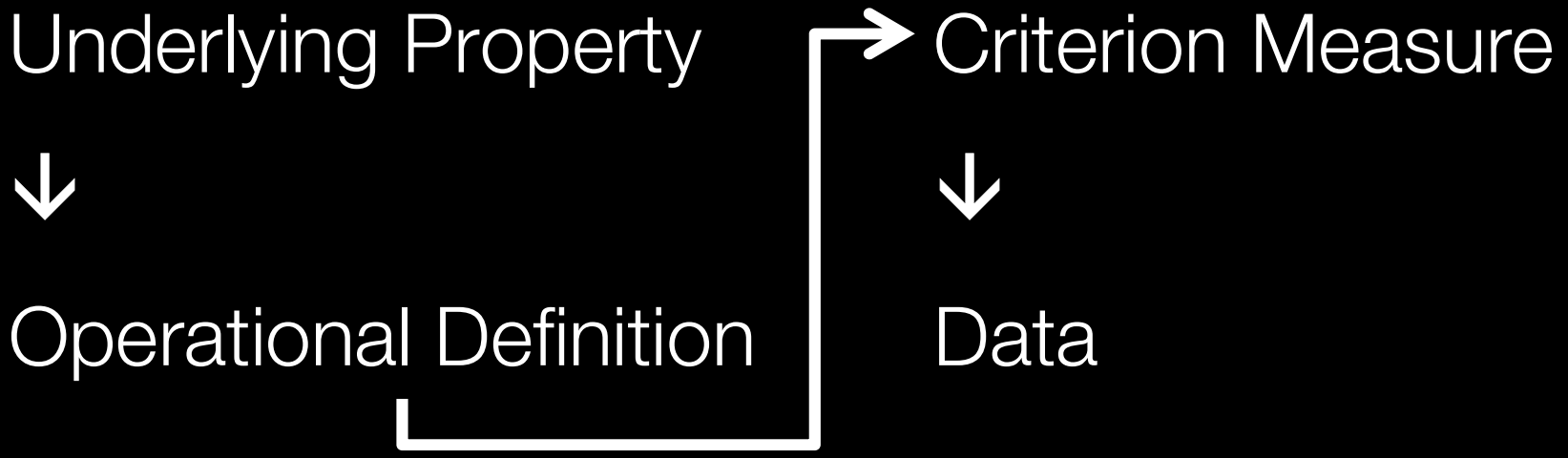


# Measurement & Measurement Scales

Measurements are not the same as the attribute studied

To draw conclusions, we must consider how the measurement maps to the attribute

# Data


Underlying Property
Criterion Measure
Operational Definition
Data

# Sources

The material used in the PowerPoint presentations associated with this course was drawn from a number of sources. Specifically, much of the content included was adopted or adapted from the following previously-published material:


- Luftig, J. An Introduction to Statistical Process Control & Capability. Luftig & Associates, Inc. Farmington Hills, MI, 1982
- Luftig, J. Advanced Statistical Process Control & Capability. Luftig & Associates, Inc. Farmington Hills, MI, 1984.
- Luftig, J. A Quality Improvement Strategy for Critical Product and Process Characteristics. Luftig & Associates, Inc. Farmington Hills, MI, 1991
- Luftig, J. Guidelines for Reporting the Capability of Critical Product Characteristics. Anheuser-Busch Companies, St. Louis, MO. 1994
- Spooner-Jordan, V.  Understanding Variation. Luftig & Warren International, Southfield, MI 1996
- Luftig, J. and Petrovich, M. Quality with Confidence in Manufacturing. SPSS, Inc. Chicago, IL 1997
- Littlejohn, R., Ouellette, S., & Petrovich, M. Black Belt Business Improvement Specialist Training, Luftig & Warren International, 2000
- Ouellette, S. Six Sigma Champion Training, ROI Alliance, LLC & Luftig & Warren, International, Southfield, MI 2005

# Measurement Scales

**Data Science for Quality Management: Data and Measurement**

with **Wendy Martin**

**Learning objectives:**

Distinguish between nominal, ordinal, interval, ratio and absolute scales

Identify measurement level of data given background information

# Measurement & Measurement Scales

Measurements are not the same as the attribute studied

To draw conclusions, we must consider how the measurement maps to the attribute

# Measurement & Measurement Scales

The relationship between the assigned numbers or symbols and the corresponding underlying property yields a level of measurement.

# Measurement Scales

Nominal

Ordinal

Interval

Ratio

Absolute

# Nominal Scale

Numbers are assigned to categorize, identify or name attributes

- Zip codes
- Area codes
- Numbers assigned to types of nonconformity in products

## Nominal Scale

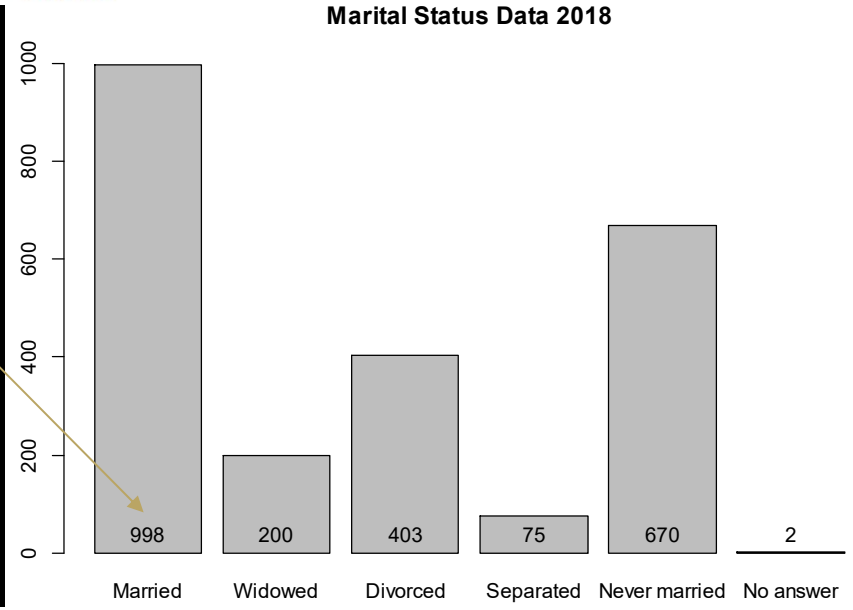
- Numbers assigned to presence or absence of an attribute (e.g., 0, 1)
- Numbers assigned to sales territories

Nominal Scale values can only be used to indicate equal or not equal

# Nominal Scale Example

```
> round.object(Nominal.Data.Example, digits = 4)
  Code          Label Response Relative.Frequency Cumulative.Frequency
1    1        Married      998              0.4250                0.4250
2    2        Widowed      200              0.0852                0.5102
3    3       Divorced      403              0.1716                0.6819
4    4      Separated       75              0.0319                0.7138
5    5  Never married      670              0.2853                0.9991
6    9      No answer        2              0.0009                1.0000
```

Be sure to compare the values in the Frequency column of the table and the bars of the Histogram.



## Ordinal Scale

Numbers are assigned to observations, such that the order of the numbers corresponds to the order of the underlying property studied

- 5-point scale to measure customer satisfaction
- Letter Grades for Academic performance

# Ordinal Scale

- Sound intensity measured in decibels
- Socio-economic status
- Project priority numbers

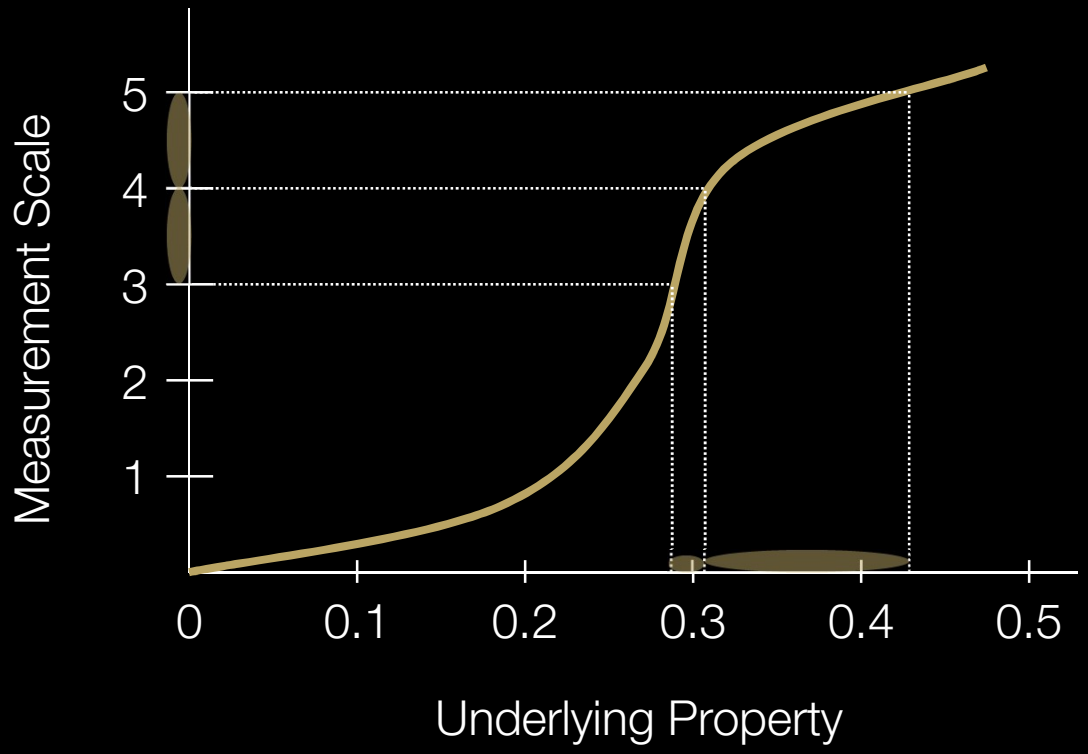
# Ordinal Scale

Ratings and rankings are ordinal

- Ratings: assign a subjective score
- Rankings: result from sorting items

Ordinal Scale values can be used to determine $=$ or $\neq$ and $>$ or $<$ as well, but NOT magnitude

# Ordinal Scale Example



## Ordinal Scale

Any order-preserving transformation may be used.

The median and mode may be used for “center” and range or interquartile range for dispersion.

## Ordinal Scale

Numerous nonparametric hypothesis tests are available, which often involve ranking the data prior to conducting the inferential statistical analysis of interest.

# Interval Scale

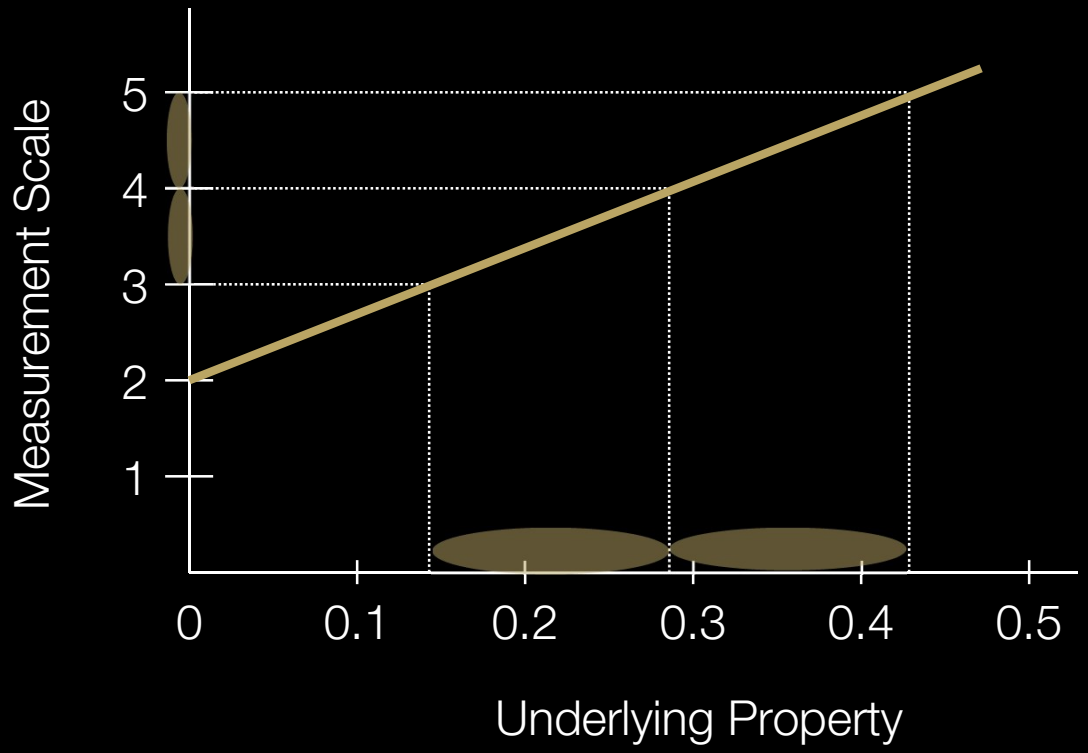
Numbers are assigned to observations such that differences between any two numbers correspond to proportional differences in the underlying property studied, and there are equal intervals along the scale.

# Interval Scale

Examples:

- Temperature measured in degrees Fahrenheit
- Directional distance from a reference point
- Calendar date
- Height above sea level

# Interval Scale Example



## Interval Scale

Permissible transformations include any linear transformation.

Statistics such as the mean and standard deviation may be used.

## Interval Scale

Most of the parametric statistical tests may be employed as long as their underlying assumptions are met.

Interval Scale values can be used to determine = or ≠, > or <, and you can use sums (+)  and differences (–) with meaning

## Ratio Scale

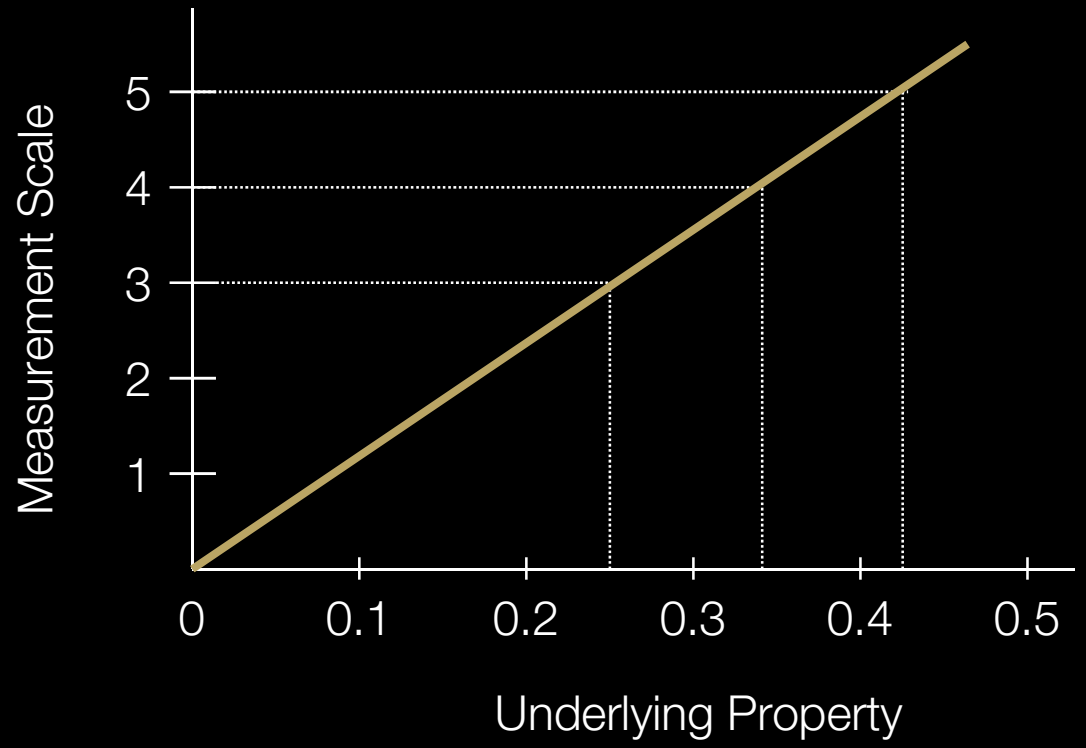
Numbers are assigned to observations such that an interval scale has been reached, and there is a zero point which corresponds to a zero, null state, or absence of the underlying property.

# Ratio Scale

Examples:

- Length, height, width, distance
- Volume, weight
- Cycle-time and time-to-repair

# Ratio Scale Example



## Ratio Scale

Permissible transformations of ratio data involve simply multiplying by a constant.

A few more statistics are available:

- The geometric mean
- The coefficient of variation

# Ratio Scale

Any parametric statistical test may be employed with ratio data as long as their underlying assumptions are met (or not significantly violated in the case of robust tests) .

# Ratio Scale vs Interval Scale

Consider a bathroom scale:

Two people are weighed on the same bathroom scale, one weighs 200 pounds and the other weighs 100 pounds, is the first twice as heavy as the second?

# Ratio Scale vs Interval Scale

What if I told you the scale was NOT set at zero to begin with, but at 50 pounds. Then what?

What are the corresponding Scales of Measurement for each situation?

# Absolute Scale (Count Data)

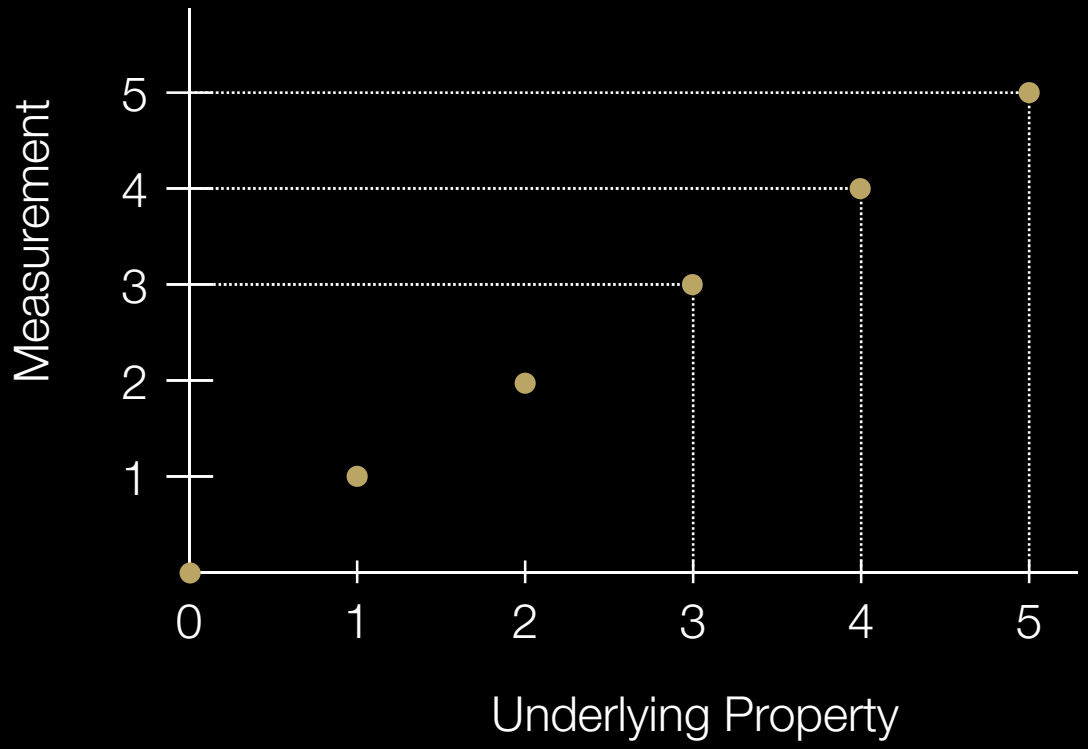
Numbers are assigned to observations such that the numbers directly correspond to the underlying property being studied.

## Absolute Scale (Count Data)

Examples:

- The number of defects
- The number of scratches observed
- The number of parts made
- The number of safety accidents
- The number of customer complaints

# Absolute Scale Example



## Absolute Scale (Count Data)

Some transformations are permissible.

Data on an absolute scale have some of the properties of ratio data.

The mean, median and mode may be used.

## Absolute Scale (Count Data)

Various statistical procedures may be used depending on resolution.

In many cases, standard parametric methods may be used, in other cases nonparametric methods must be employed.

# Sources

The material used in the PowerPoint presentations associated with this course was drawn from a number of sources. Specifically, much of the content included was adopted or adapted from the following previously-published material:


- Luftig, J. An Introduction to Statistical Process Control & Capability. Luftig & Associates, Inc. Farmington Hills, MI, 1982
- Luftig, J. Advanced Statistical Process Control & Capability. Luftig & Associates, Inc. Farmington Hills, MI, 1984.
- Luftig, J. A Quality Improvement Strategy for Critical Product and Process Characteristics. Luftig & Associates, Inc. Farmington Hills, MI, 1991
- Luftig, J. Guidelines for Reporting the Capability of Critical Product Characteristics. Anheuser-Busch Companies, St. Louis, MO. 1994
- Spooner-Jordan, V.  Understanding Variation. Luftig & Warren International, Southfield, MI 1996
- Luftig, J. and Petrovich, M. Quality with Confidence in Manufacturing. SPSS, Inc. Chicago, IL 1997
- Littlejohn, R., Ouellette, S., & Petrovich, M. Black Belt Business Improvement Specialist Training, Luftig & Warren International, 2000
- Ouellette, S. Six Sigma Champion Training, ROI Alliance, LLC & Luftig & Warren, International, Southfield, MI 2005

# Measurement as a Process, The Big 5 Aspects of Data

**Data Science for Quality Management: Data and Measurement**

with **Wendy Martin**

**Learning objectives:**

Describe the process of measurement
Demonstrate and recall the big five (5) aspects of data

# Data Costs Money

We must make data both

- Efficient and
- Effective

# How Do We Make Data Efficient and Effective?

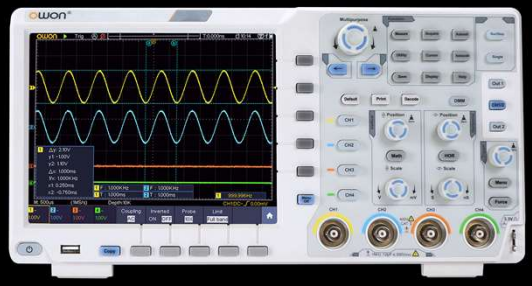
Make certain that the measurement process itself is effective:

- Capable
- Acceptable

# Measurement and Data

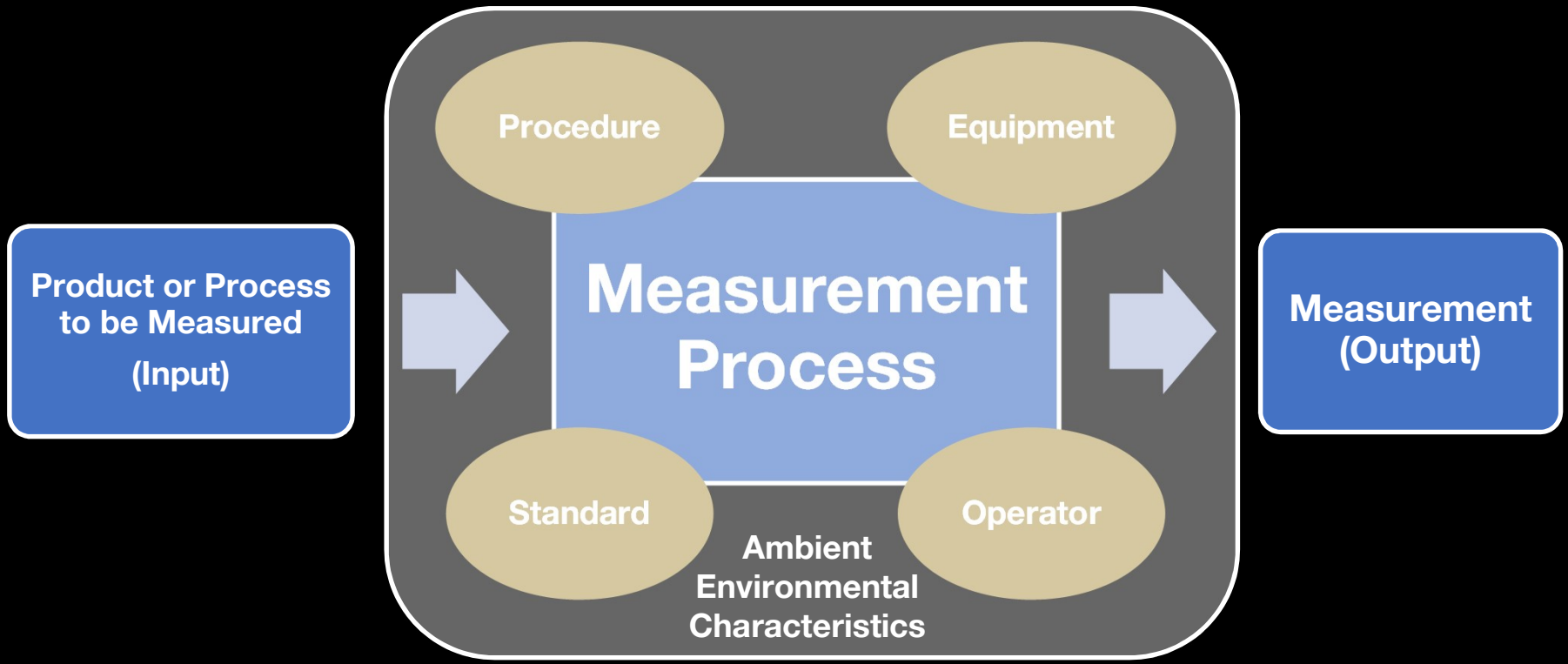
How do we study, record and communicate an event? We assign numbers.

- **Measurement** is the *process*
- **Data** is the *output*



| | | | |
|---|---|---|---|
| 1.5 | 1.3 | 1.6 | 1.5 |
| 1.6 | 1.4 | 1.2 | 1.3 |
| 1.2 | 1.7 | 1.3 | 1.2 |
| 1.4 | 1.4 | 1.1 | 1.7 |

# Measurement as a Process



# Common Myths of Measurement

The measurement system MUST be effective (capable) if it:

- Is expensive
- Has a digital readout
- Uses radiation
- Is made in Switzerland
- Is only used by a Supervisor
- Has a recent calibration sticker

# Measurement as a Process

As in any process, measurement systems must demonstrate:

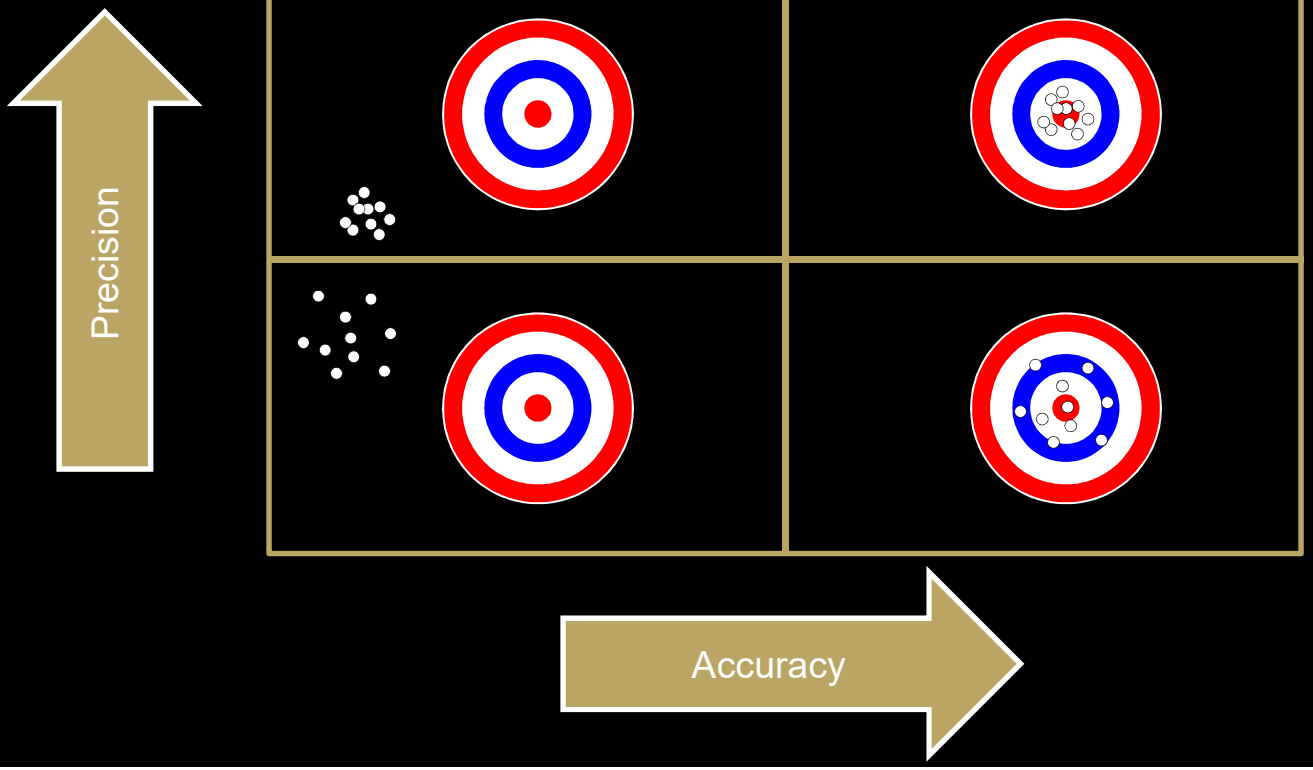
- Stability through time, or control
- The ability to generate reliable, or repeatable and reproducible measures
- The ability to generate valid measures

# Measurement as a Process

Reliability in measurement is a measure of the Precision of the device / method

Validity in metrology is a measure of the Accuracy of the device / methods

# Precision vs. Accuracy



# Tools for Understanding Data

Once the measurement process is found to be capable and acceptable (more on this later), we can begin to analyze the generated data

# Tools for Understanding Data

There are many tools to help us understand what data are telling us, including

- Probability and statistics; to quantify and summarize data
- Control charts; to determine if a process is stable

# Tools for Understanding Data

- Experimental design; to allow us to identify root causes of a problem so we can eliminate it; or to identify and properly manipulate Special and Common Causes of Variability to improve optimize the process output

# Big 5 Aspects of Data

Location

Spread

Shape

Time Sequence

Relationship

# 5 Aspects of Data

Location

Spread

Shape

Time Sequence

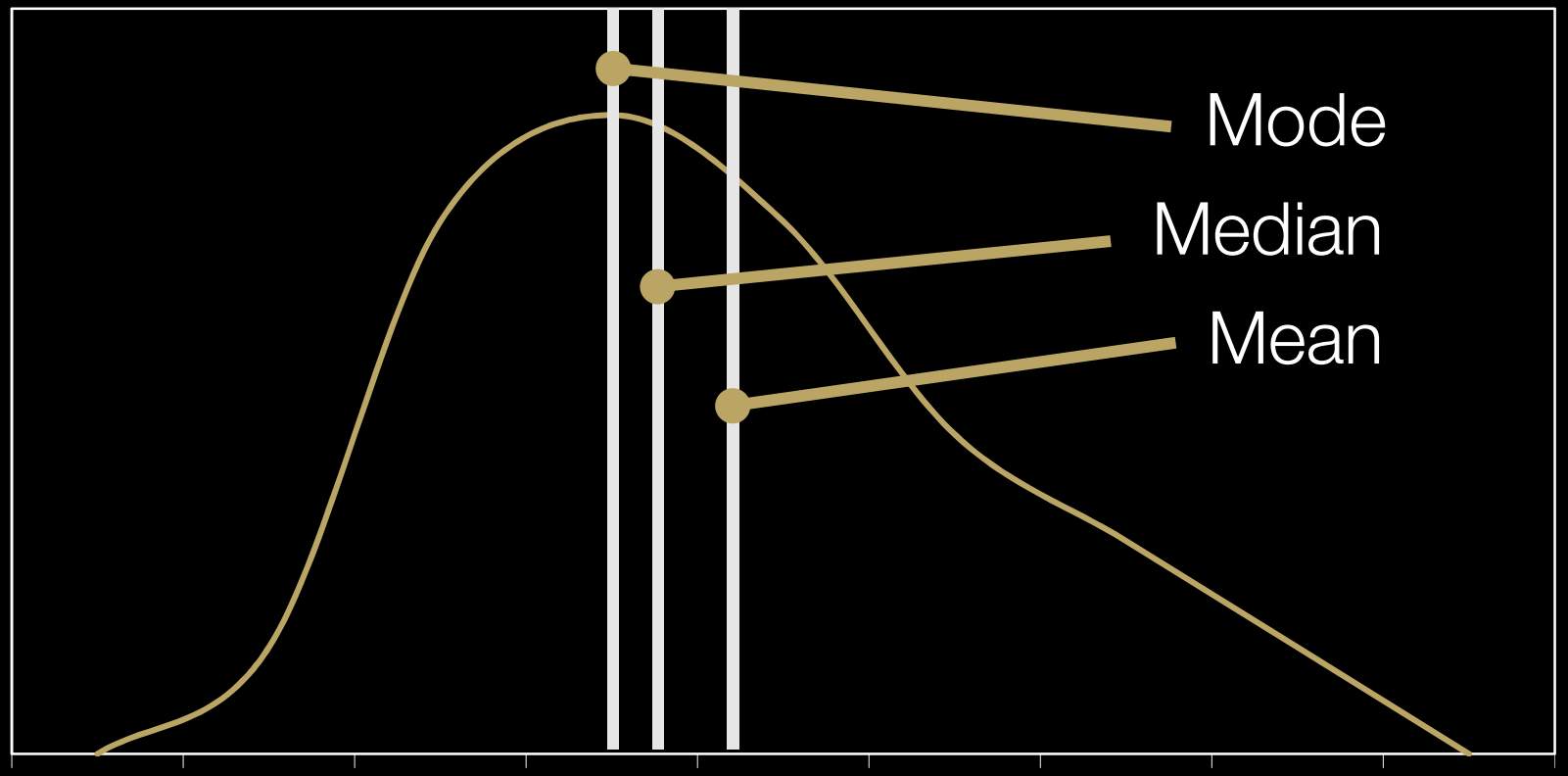
Relationship

# Measures of Location

Measures of location, sometimes called measures of central tendency, describe a middle or central point or tendency of a distribution.

- Mean, Median, Mode

# Measures of Location

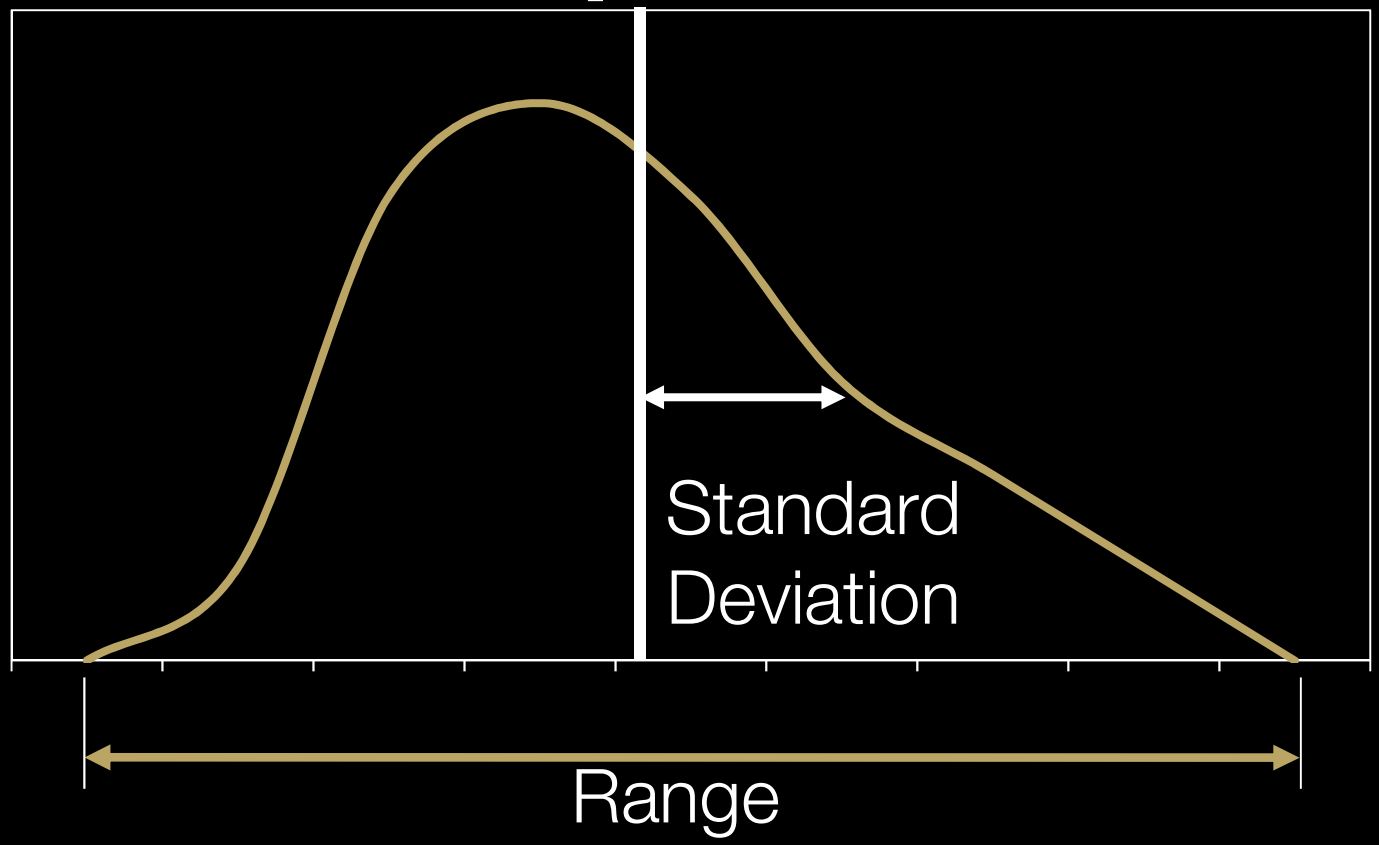


# Measures of Spread

Measures of dispersion reflect the variation or spread in a data set or distribution. Some of the common measures of dispersion are:

- Range, Standard Deviation, Variance

# Measures of Spread



# Measures of Shape

Measures of shape reflect the type of distribution sampled. There are two measures:

- Skewness
- Kurtosis

# Skewness

Skewness is concerned with the symmetrical nature of the distribution, and is the degree of departure from symmetry of a distribution.

# Skewness

Basically measures “lopsidedness.”

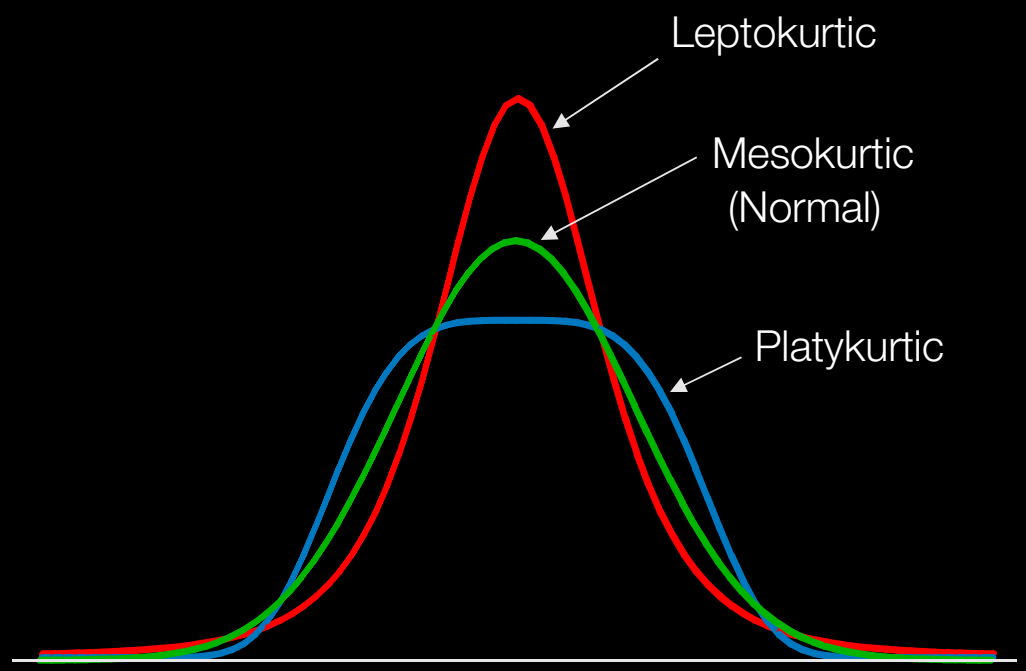
Symmetric distributions have zero skewness.


Positively skewed

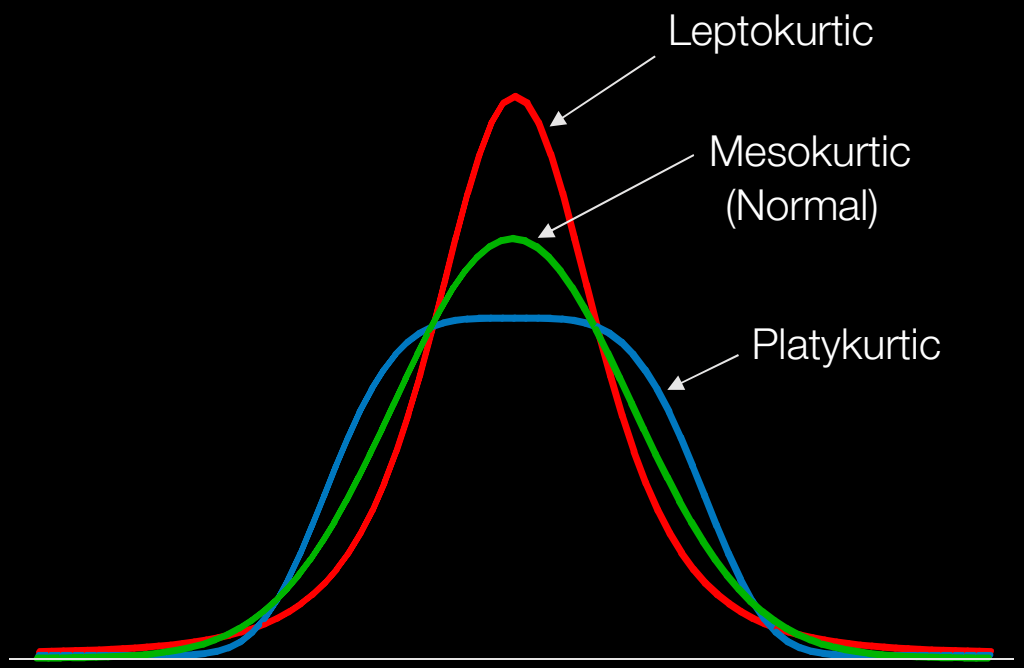
Negatively skewed

# Kurtosis

Kurtosis is concerned with the peakedness of the distribution.



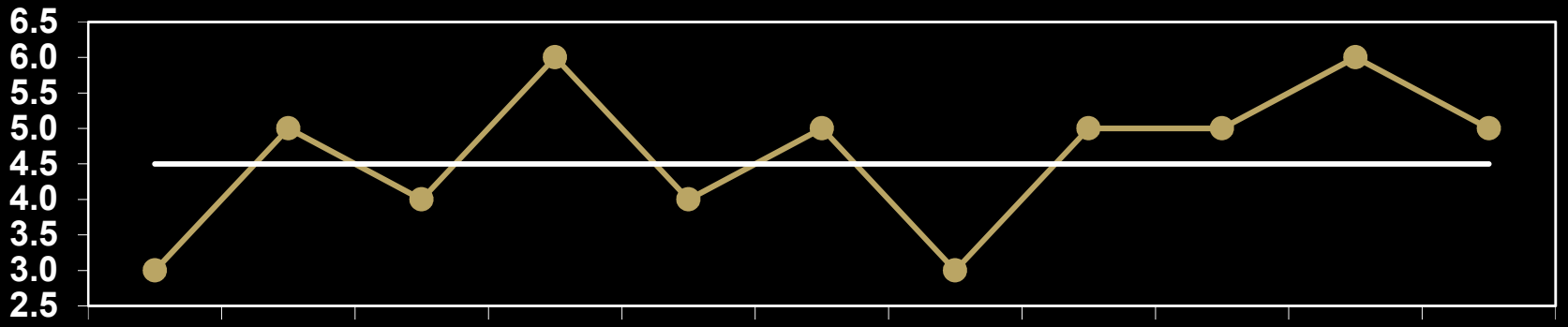
# Kurtosis

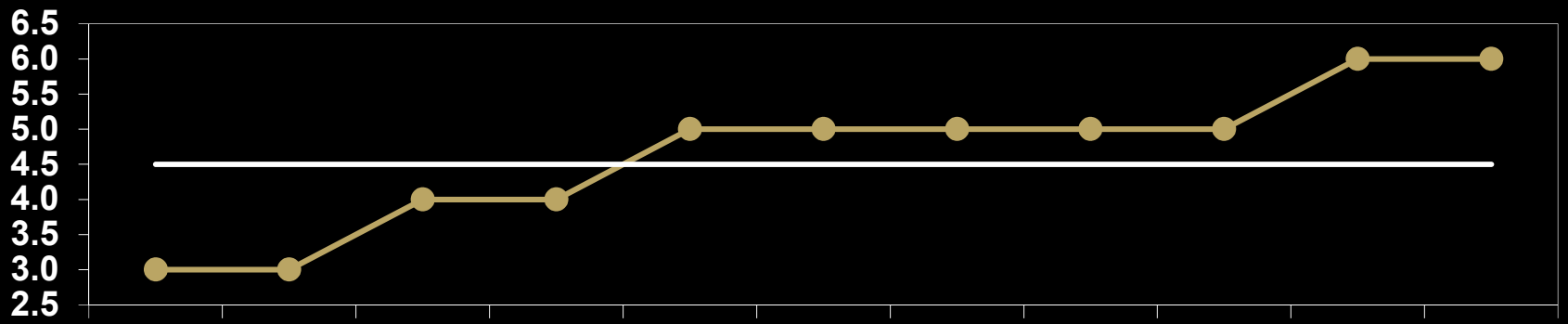


# Time Sequence

Time ordered data indicates the stability of the process through time.

# Time Sequence



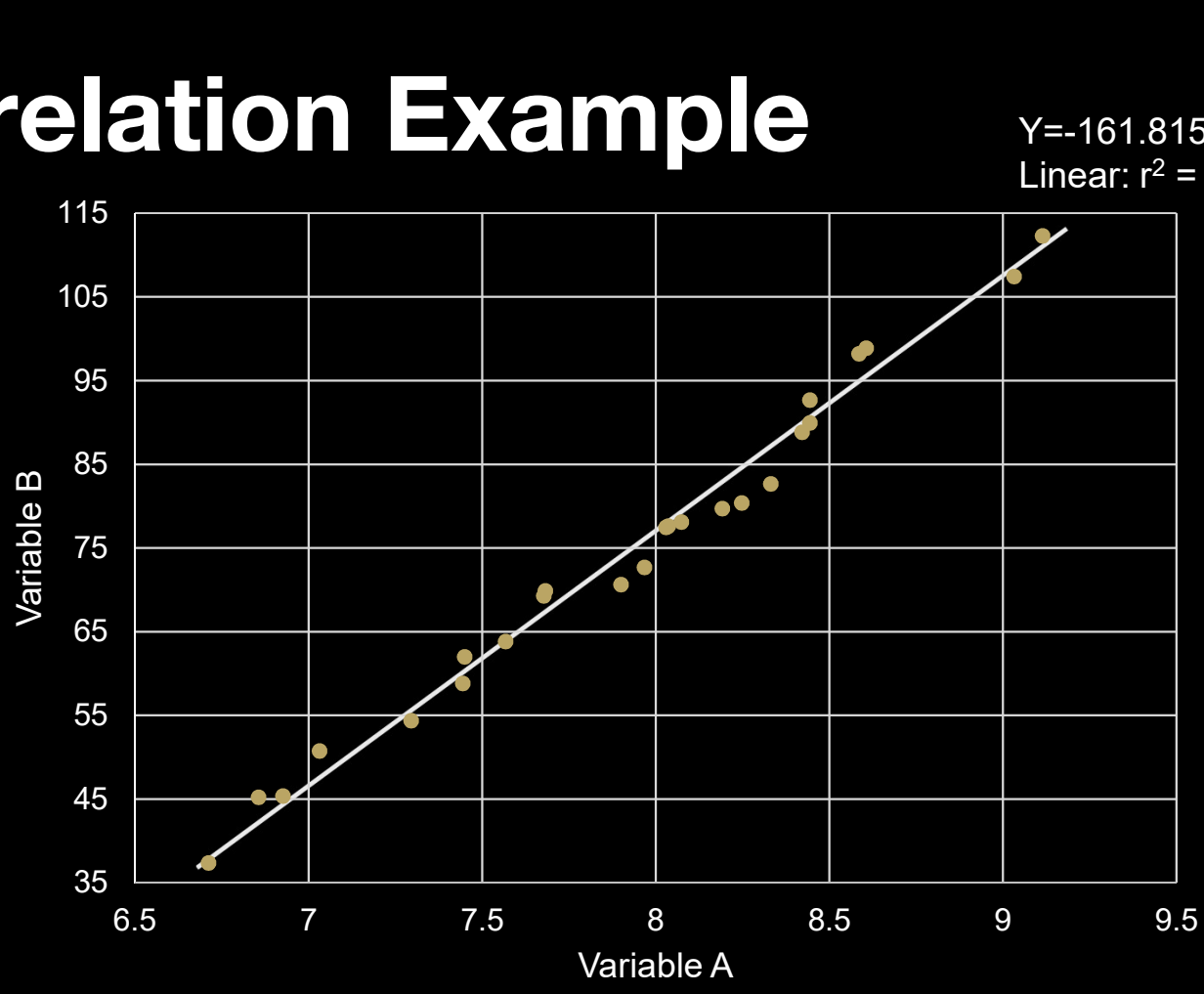



# Measures of Relationship

Measures of relationship quantify the "strength" of the relationship between two variables.

- Correlation
- Association

# Correlation Example



# Sources

The material used in the PowerPoint presentations associated with this course was drawn from a number of sources. Specifically, much of the content included was adopted or adapted from the following previously-published material:


- Luftig, J. An Introduction to Statistical Process Control & Capability. Luftig & Associates, Inc. Farmington Hills, MI, 1982
- Luftig, J. Advanced Statistical Process Control & Capability. Luftig & Associates, Inc. Farmington Hills, MI, 1984.
- Luftig, J. A Quality Improvement Strategy for Critical Product and Process Characteristics. Luftig & Associates, Inc. Farmington Hills, MI, 1991
- Luftig, J. Guidelines for Reporting the Capability of Critical Product Characteristics. Anheuser-Busch Companies, St. Louis, MO. 1994
- Spooner-Jordan, V.  Understanding Variation. Luftig & Warren International, Southfield, MI 1996
- Luftig, J. and Petrovich, M. Quality with Confidence in Manufacturing. SPSS, Inc. Chicago, IL 1997
- Littlejohn, R., Ouellette, S., & Petrovich, M. Black Belt Business Improvement Specialist Training, Luftig & Warren International, 2000
- Ouellette, S. Six Sigma Champion Training, ROI Alliance, LLC & Luftig & Warren, International, Southfield, MI 2005

# Sampling Concepts

**Data Science for Quality Management: Data and Measurement**

with **Wendy Martin**

**Learning objectives:**

Recall the approaches to sampling
Discern between population and sample statistics

# Populations and Samples

Population (Target Population)

- The entire group of objects, all with one characteristic of interest in common, and about which we want to make decisions
- Infinite, or finite but relatively huge

# Populations and Samples

Research Population

- That portion of the Target Population available for sampling

# Populations and Samples

Sample

- A subgroup of the population of interest, usually selected randomly.
- Random sampling is a prerequisite to using any type of inferential statistics!

# General Approaches to Sampling

- Nonrandom or judgment sampling
- Random or probability sampling
  - Simple random Sampling
  - Systematic random sampling
  - Stratified random sampling
  - Cluster sampling

# Nonrandom or Judgment Sampling

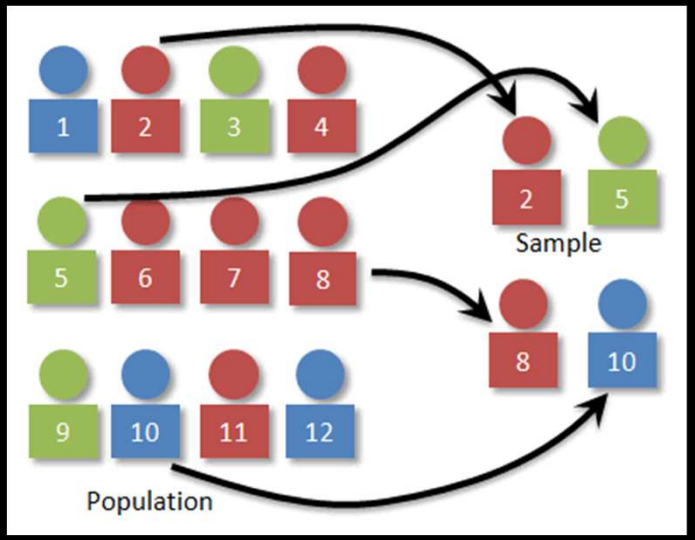
- Specimens or items are selected using personal judgment, reasoning, opinion, or convenience

# Random or probability sampling

- All specimens or items have a probability of being included in the sample

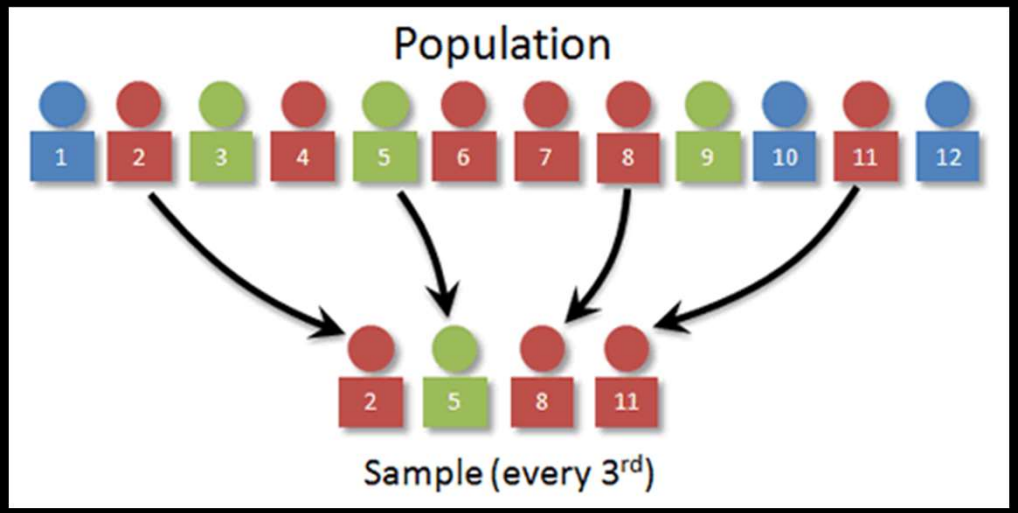
# Simple Random Sampling

- Every possible sample of size n has an equal chance of being selected



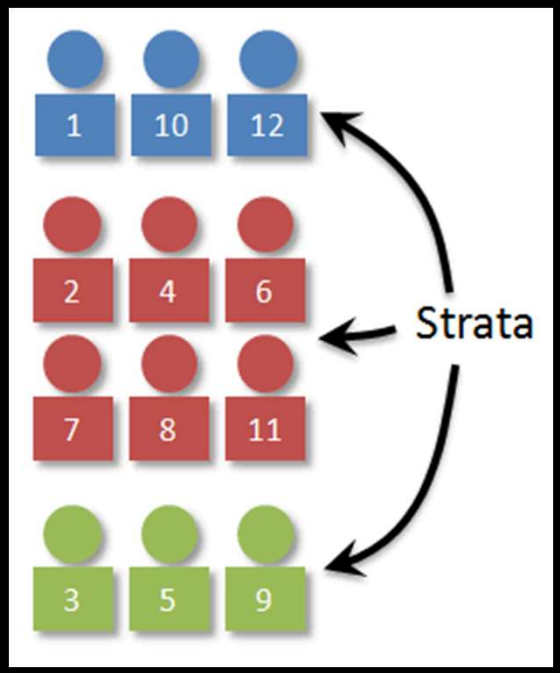
# Systematic Random Sampling

- Specimens or items are selected at an interval



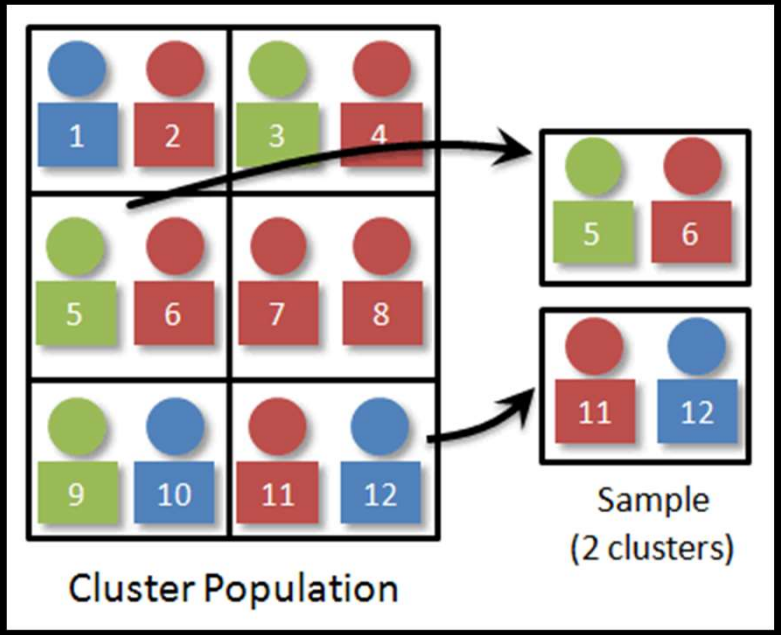
# Stratified Random Sampling

- Specimens or items are divided into homogenous subsets, or strata



# Cluster Sampling

- Specimens or items are divided into groups that are homogenous between each other, but heterogeneous within



# Statistics and Variation

A statistic is a measure calculated from sample data that may be used to make inferences about a population

- The average is a “statistic”
- The range is another “statistic”
- There are many more...

# Statistics and Parameters

Descriptive Statistics

- Describe a characteristic of a sample
- Frequently used to make inferences about population parameters
- Represented by letters in English

# Statistics and Parameters

Population parameters

- Describes a characteristic of the population
- Represented by Greek letters (with few exceptions)

# Statistics and Parameters

| Sample Statistics | Population Parameters | Description |
|---|---|---|
| $\bar{X}$ | $\mu$ | Mean |
| $\tilde{X}$ | M | Median |
| s | $\sigma$ | Standard Deviation |
| $s^2$ | $\sigma^2$ | Variance |
| R | NT’ | Range / Natural Tolerance |
| p | $\pi$ | Count Per Unit |
| $g_3$ | $\gamma_3$ | Skewness |
| $g_4$ | $\gamma_4$ | Kurtosis |

# Sources

The material used in the PowerPoint presentations associated with this course was drawn from a number of sources. Specifically, much of the content included was adopted or adapted from the following previously-published material:


- Luftig, J. An Introduction to Statistical Process Control & Capability. Luftig & Associates, Inc. Farmington Hills, MI, 1982
- Luftig, J. Advanced Statistical Process Control & Capability. Luftig & Associates, Inc. Farmington Hills, MI, 1984.
- Luftig, J. A Quality Improvement Strategy for Critical Product and Process Characteristics. Luftig & Associates, Inc. Farmington Hills, MI, 1991
- Luftig, J. Guidelines for Reporting the Capability of Critical Product Characteristics. Anheuser-Busch Companies, St. Louis, MO. 1994
- Spooner-Jordan, V.  Understanding Variation. Luftig & Warren International, Southfield, MI 1996
- Luftig, J. and Petrovich, M. Quality with Confidence in Manufacturing. SPSS, Inc. Chicago, IL 1997
- Littlejohn, R., Ouellette, S., & Petrovich, M. Black Belt Business Improvement Specialist Training, Luftig & Warren International, 2000
- Ouellette, S. Six Sigma Champion Training, ROI Alliance, LLC & Luftig & Warren, International, Southfield, MI 2005

# Working in RStudio

**Data Science for Quality Management: Data and Measurement**

with **Wendy Martin**

**Learning objectives:**

Create and import a data file into RStudio
Access R packages
Work with data frames

# Introduction to R and RStudio

- R is the programming language
- RStudio is the user interface

# Step 1: Install R

- Download R at http://www.r-project.org
- Once downloaded, double click to install R

# Step 2: Install RStudio

- Download RStudio at http://www.rstudio.com
- Once downloaded, double click to install RStudio

# Step 3: Open RStudio

# Step 4: Install lolcat

```
install.packages("devtools")
require(devtools)
install_github(“burrm/lolcat”)
```

# Packages

Once you have installed a package, it needs to be loaded any time you open RStudio

- require( )
- library( )

# R Syntax

- Case sensitive
- Assignment operator: <-

# Import Data into RStudio

# Import Data into RStudio

The datasets we will be using in our course will be imported as a dataframe, with different variable names.

To select a variable: Dataframe$variable