Introduction to Statistical Process Control (SPC)

Brewer's Toolbox

- Foundational knowledge
- Measurement/analyses
- ***SPC*** *should be in your toolbox!!!*

Statistical Process Control

- Statistical techniques to signal unusual events
- On-going study of a process

Why do we use SPC?

- When to act …

and when *not* to

Why do we use SPC?

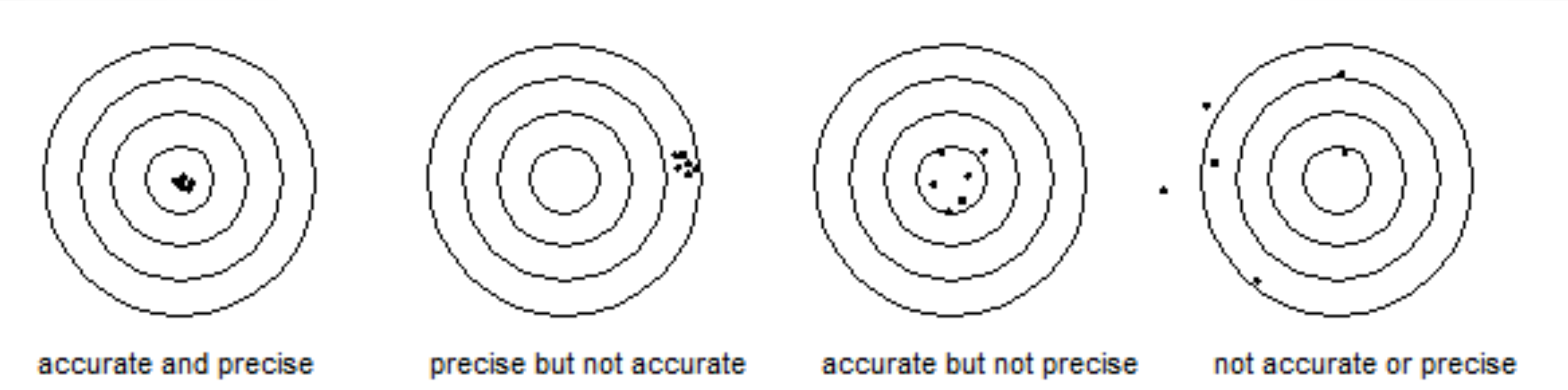
- Acting on a process that statistically requires no action is bad
- Deming calls it *"tampering"* with the process
- You can only increase the variation in the process by "tampering"
- Knockout density example

Why do we use SPC?

- Reduce variability
  - Raw materials
  - Process methods (specific gravity, temp control)
  - Packaging (fill volumes, dissolved O_2)

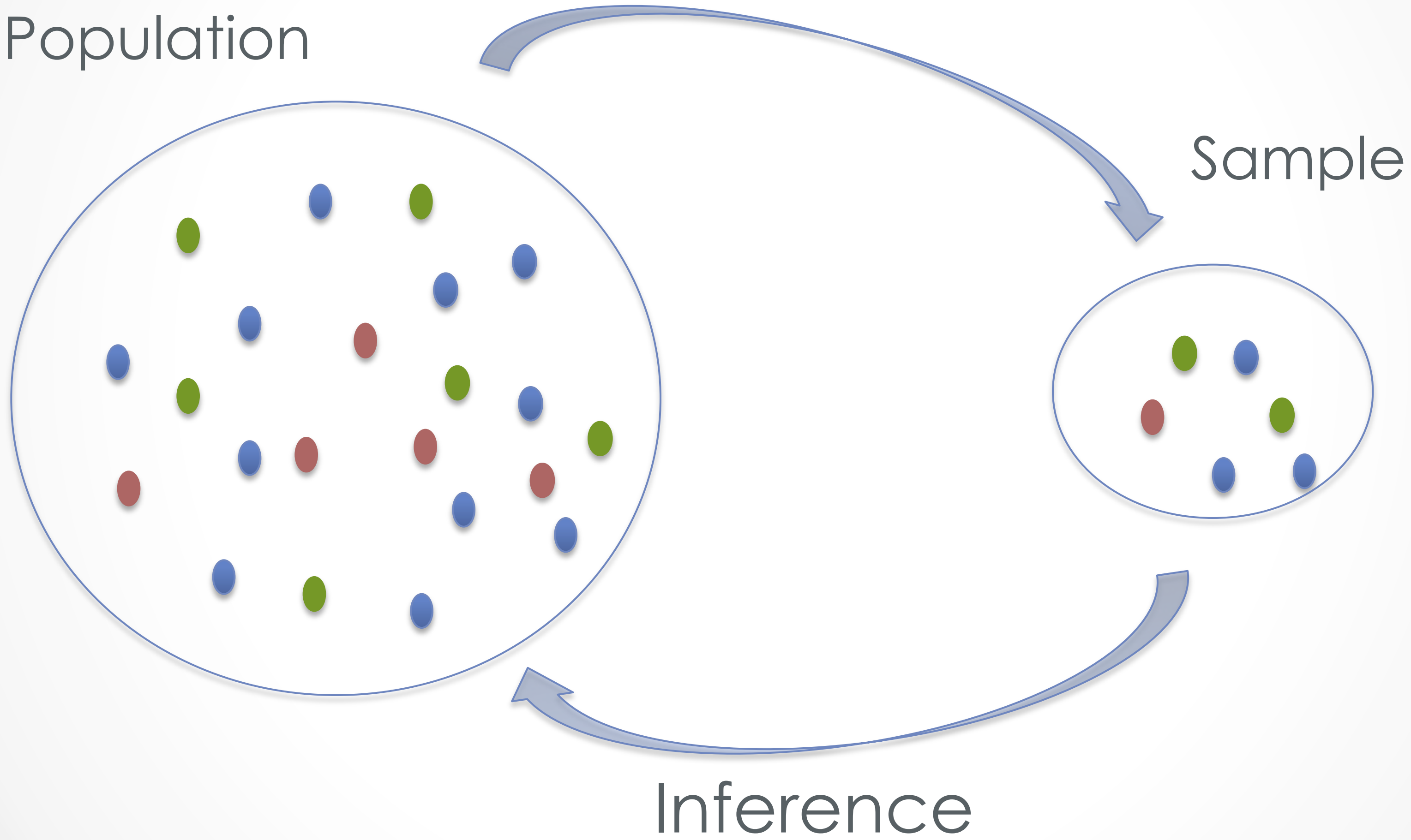
- Precision of the process
  - Equipment (maintenance, recalibration)
  - Analyses (alcohol, VA, SO_2)
  - Lab QA (technician training)

Precision vs. Accuracy



Review of Statistical Concepts

Population	*Sample*
• **Parameter** o Population characteristic o Calculated from all possible measurements • "truth"	• **Statistic** o Sample characteristic o Calculated from only members of the sample. • estimate


Population
Sample
Inference

Summarizing Data

- Center -- Mean

$$\mu_{Pop} = \frac{\sum_{i=1}^{N} x_i}{N}$$

Parameter

$$\bar{x}_{sample} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Statistic

Summarizing Data

- Spread –Standard Deviation

$$\sigma_{Pop} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$$

$$s_{sample} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

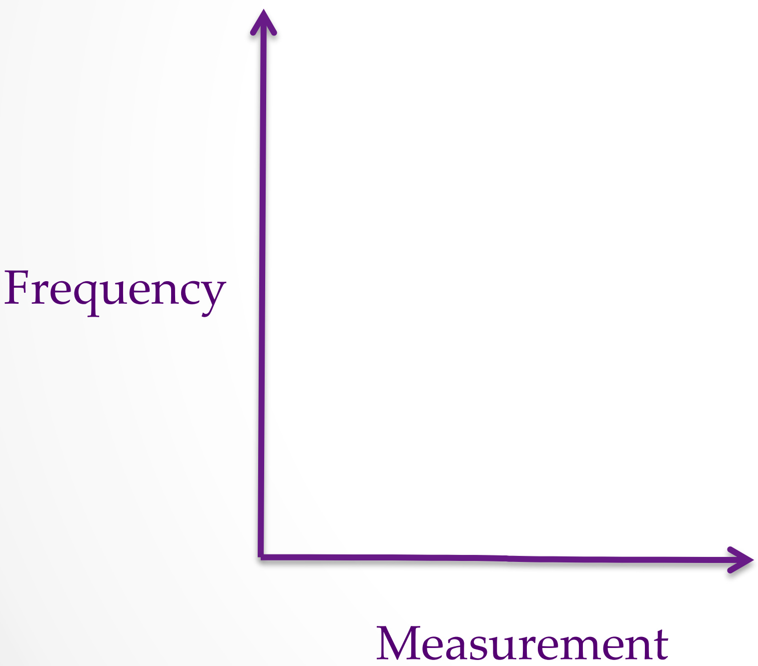
Summarizing Data

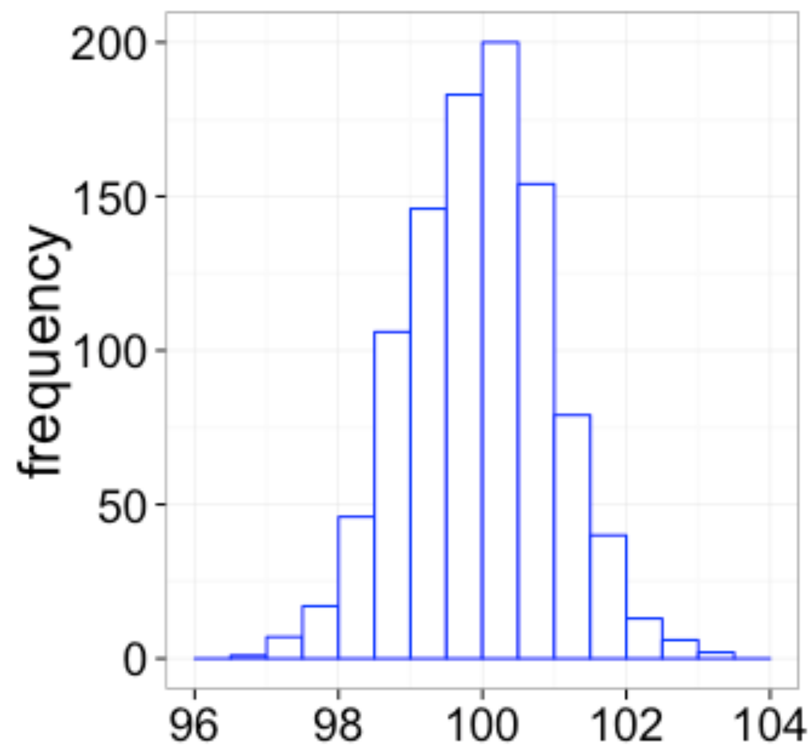
- Spread –Range

$$X_{max} - X_{min}$$

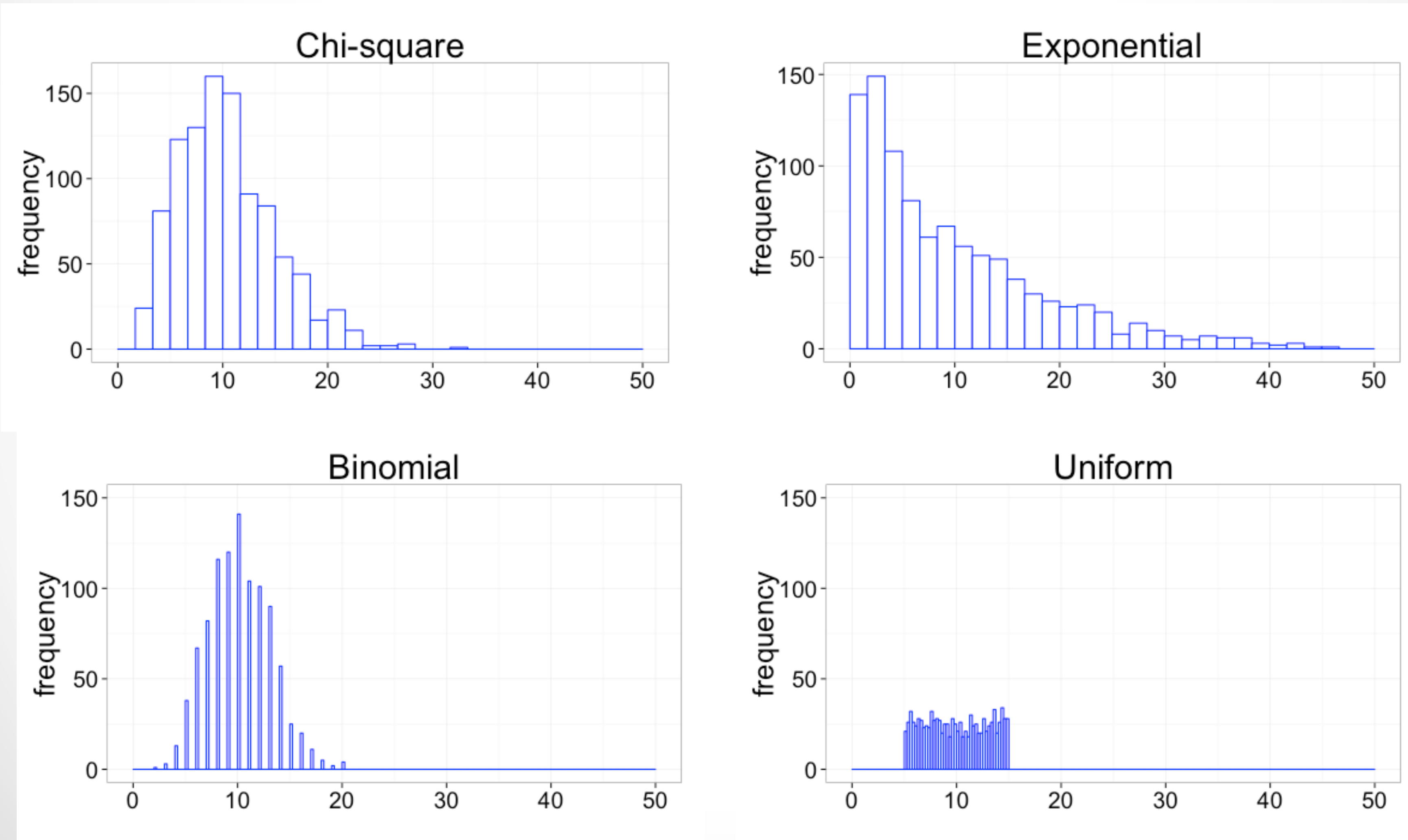
Visualizing Data

- Histograms – **Distribution** of data

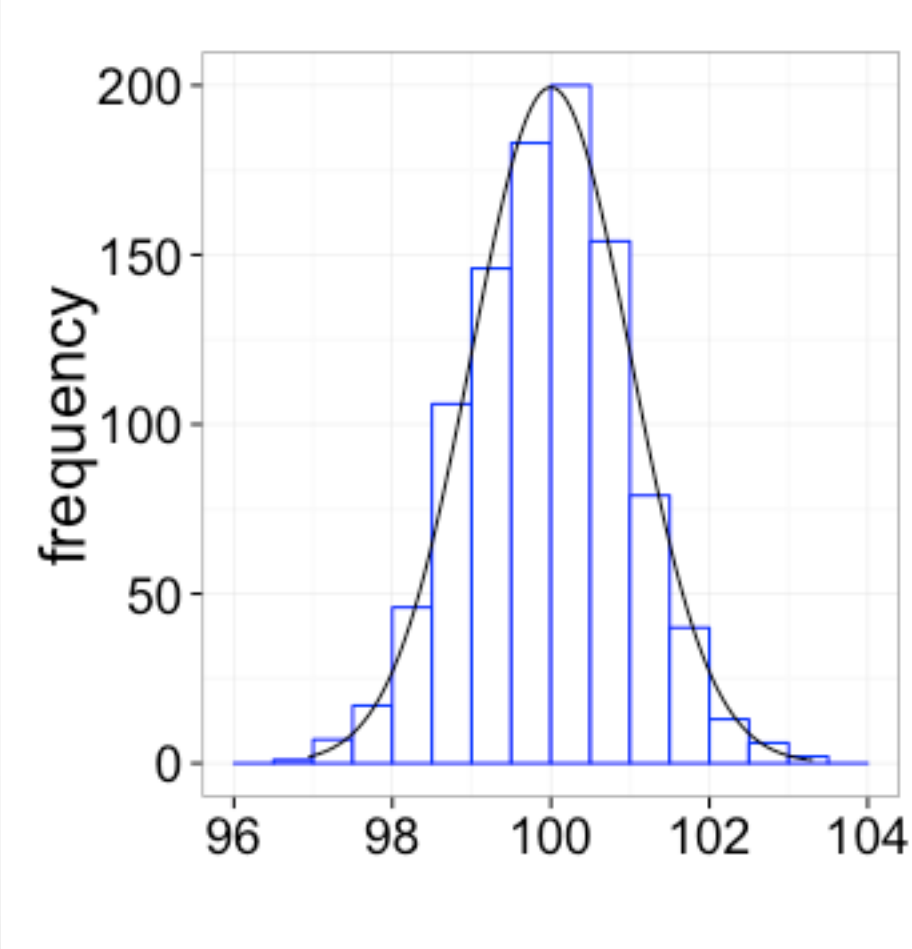




Distributions with Mean = 10



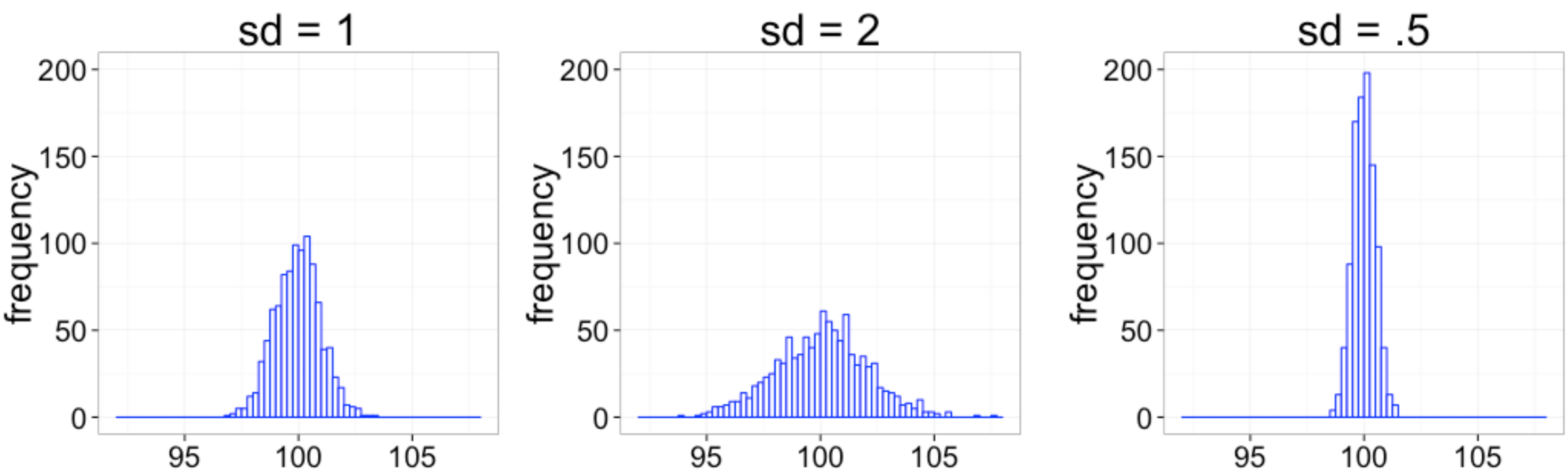
Normal Distribution as a Model



Assumptions:

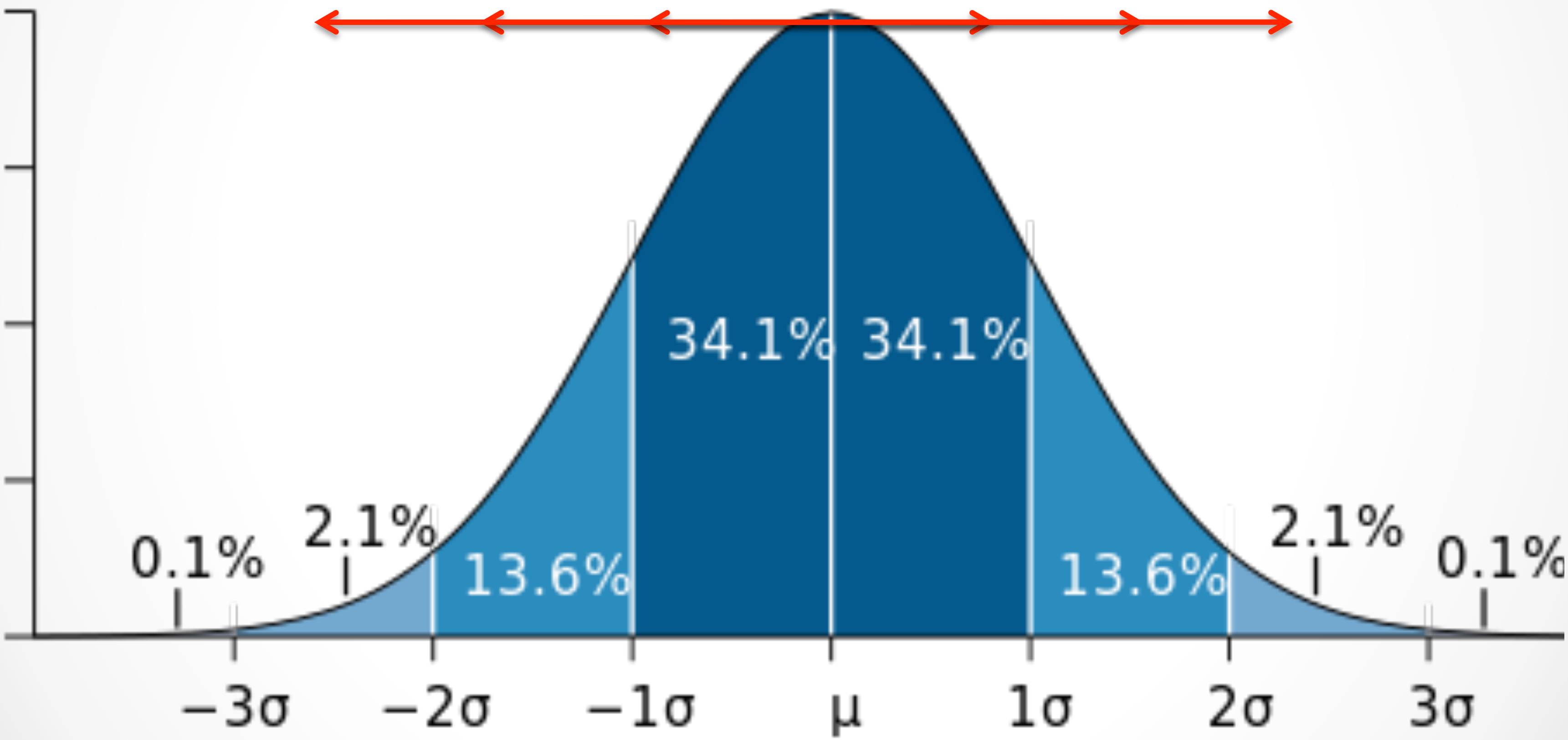
- Independent
- Identically Distributed

Normal w/Different SD



Normal Distribution Properties

±1 SD ≈ 68%
±2 SD ≈ 95%
±3 SD ≈ 99.7%



Central Limit Theorem

Sampling Demo

Take home message --

1. The mean of the sampling distribution is the mean of the population distribution

So…

We can use the sample mean for an estimate of the population mean

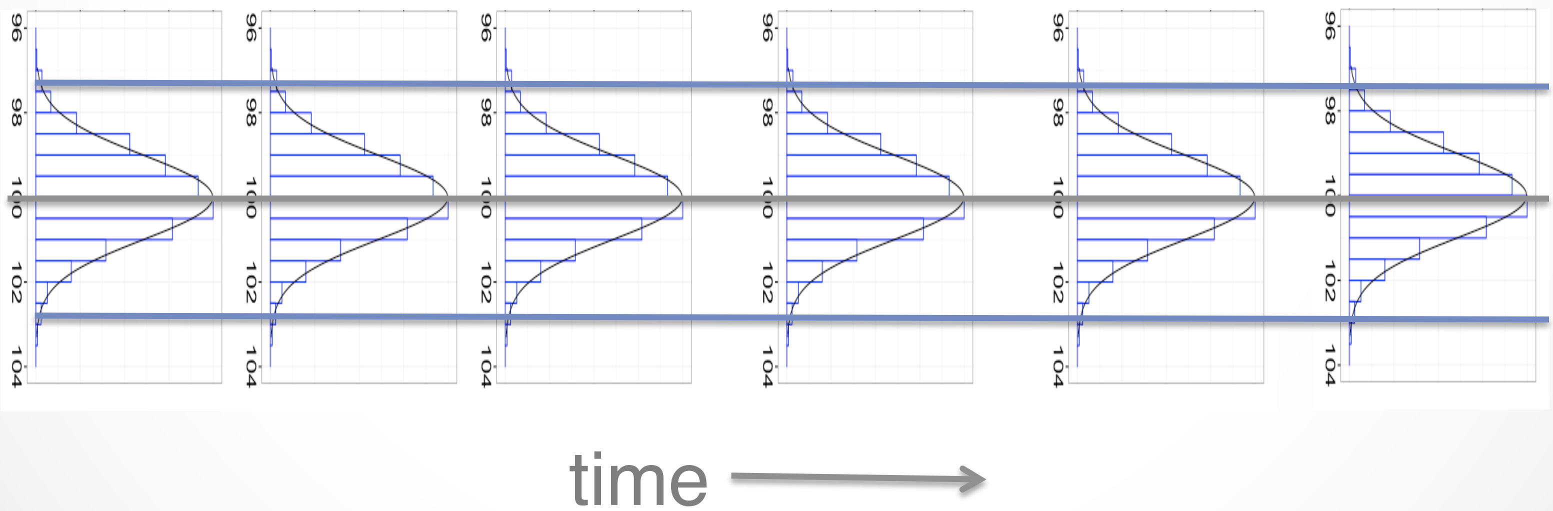
Central Limit Theorem

2. The standard deviation of the sampling distribution is called the **standard error** $= \frac{\sigma}{\sqrt{n}}$

3. The sampling distribution is **normally distributed** regardless of the shape of the population distribution.

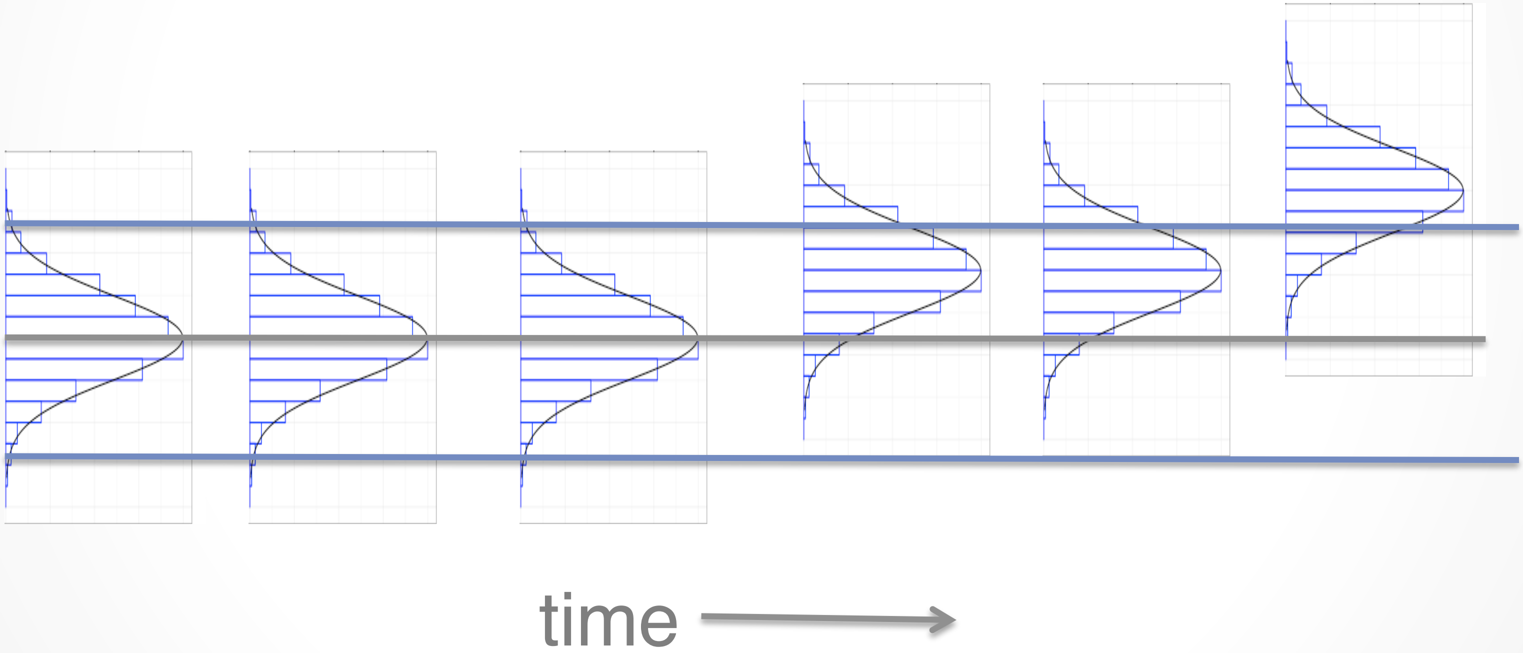
So what has this got to do with SPC?

- A variable in a process that continues to be described by the ***same*** distribution over time is "***In control***"



Disturbances to the Process

- Shift in mean

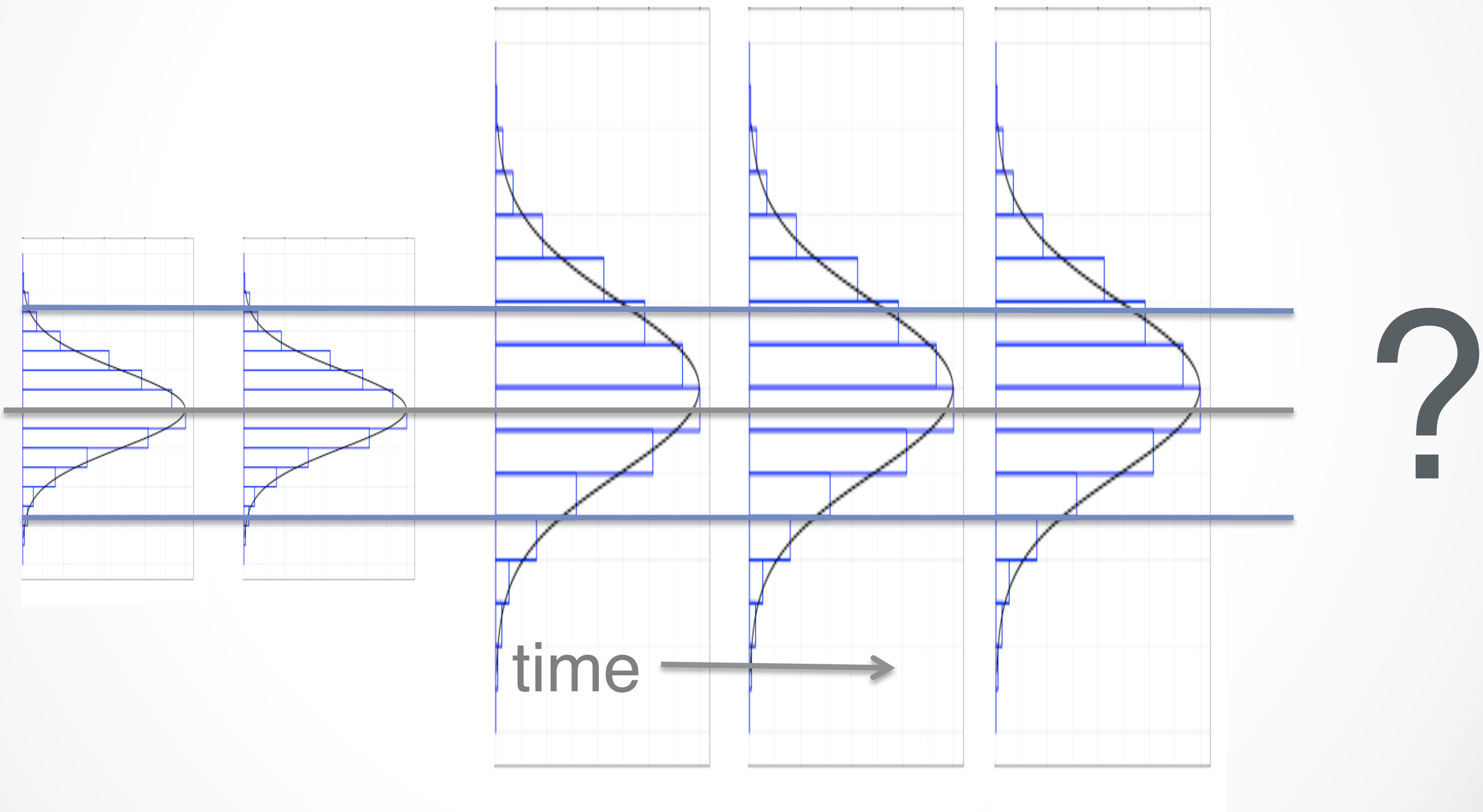


More Disturbances

- Add Variability
  - **Common** Cause vs. **Assignable** Cause
  - **Assignable** Cause variation adds to **Common** Cause variation.

A process with **assignable variation** is said to be operating **“out of control”**.

Added Variability



Control Charts

If we have a *stable* process

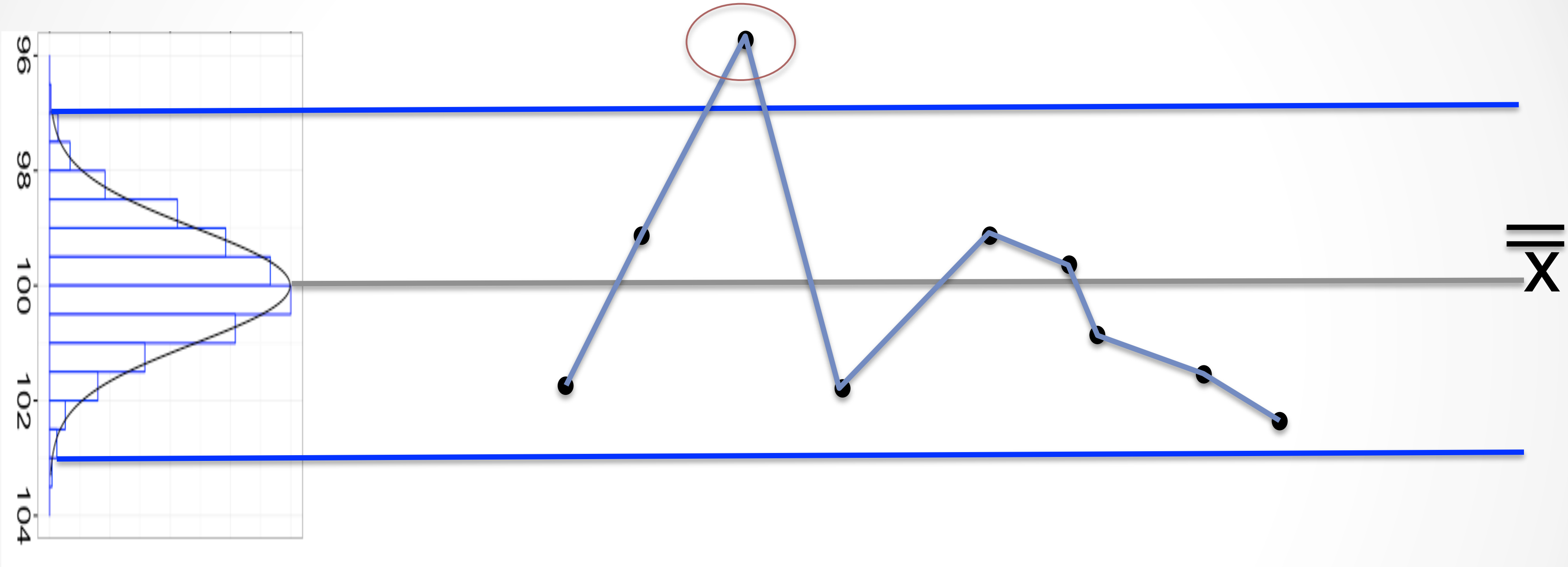
- **Sample** (25-30 or more)
  - *Size? Frequency?*
- **Model** our process with a normal curve
  - x-bar, control Limits (+/- 3 SD)
- **Compare** new measurements

Phases of Control Charting

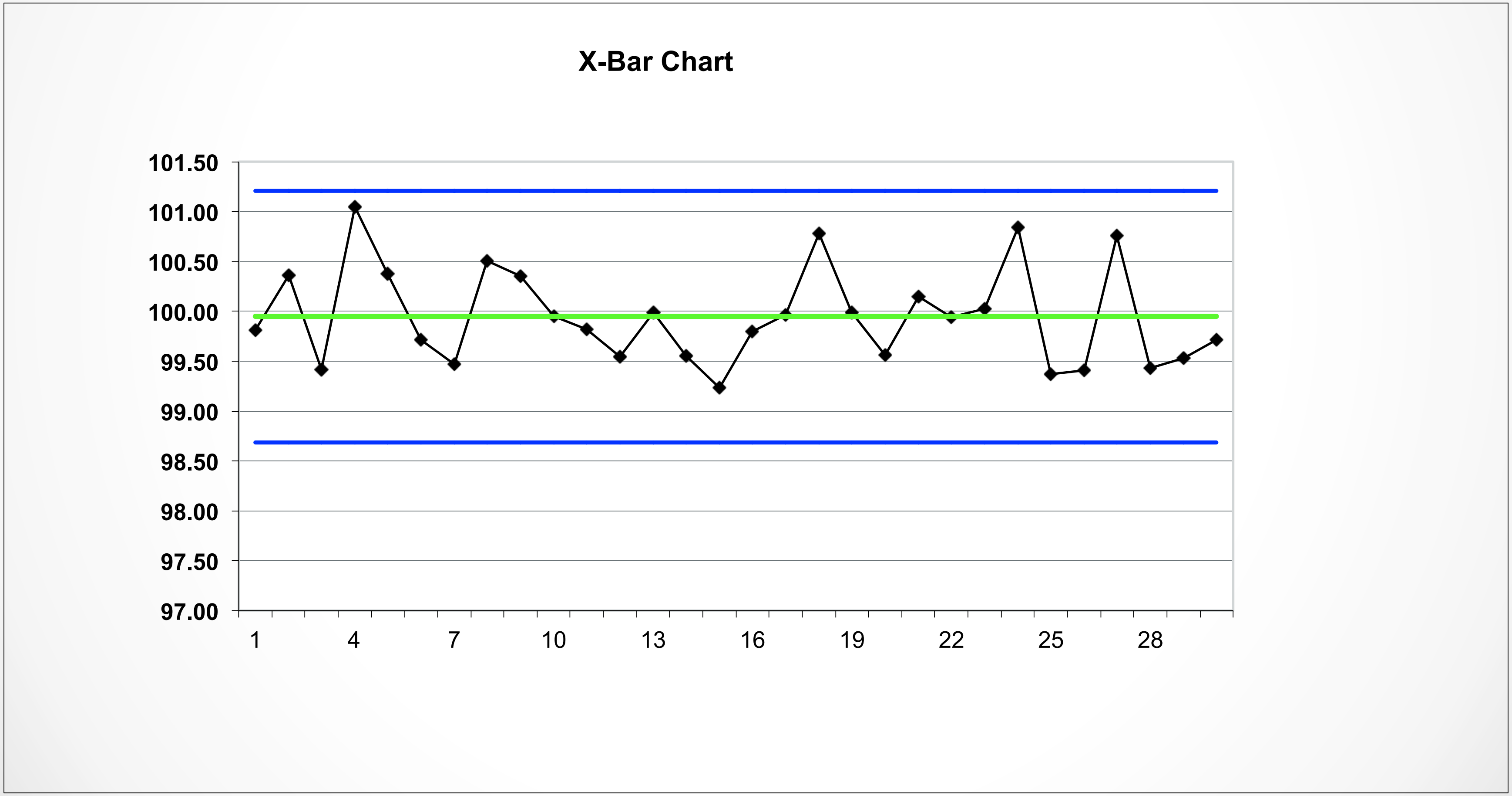
- Phase I – Setting up control limits
    - Start with process you believe is in control
    - Sample, Model (calculate CLs), Graph

- Phase II – Monitor process

Phase I – Control Charting



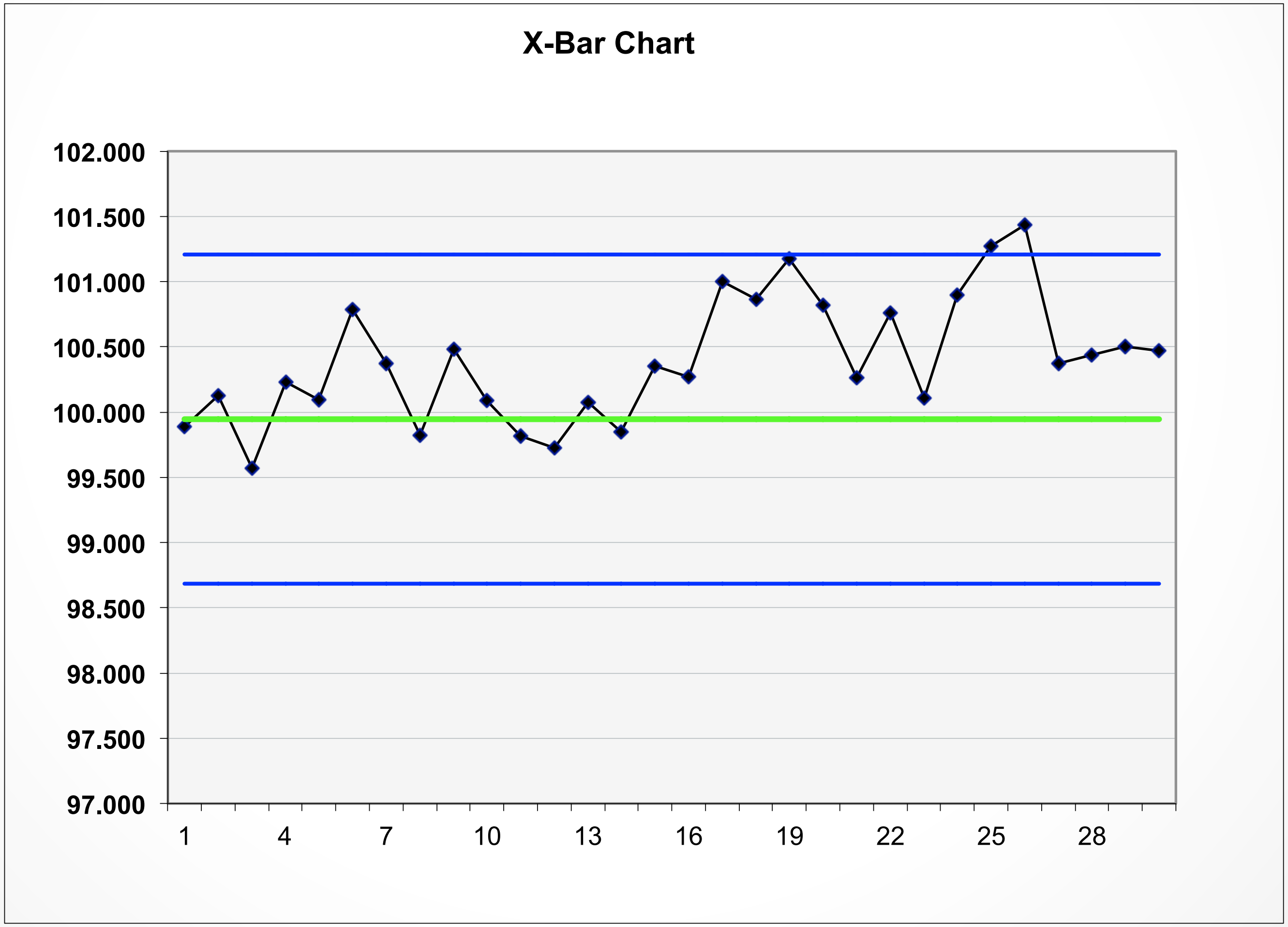
Control Chart of Stable Process



Sensitizing Rules

- 4 of 5 points beyond 1 σ
- 6 points increasing (decreasing)
- Run of 8 on one side of the center line
- 2 of 3 points outside 2 σ but still within control limits
- 14 points alternating up and down.

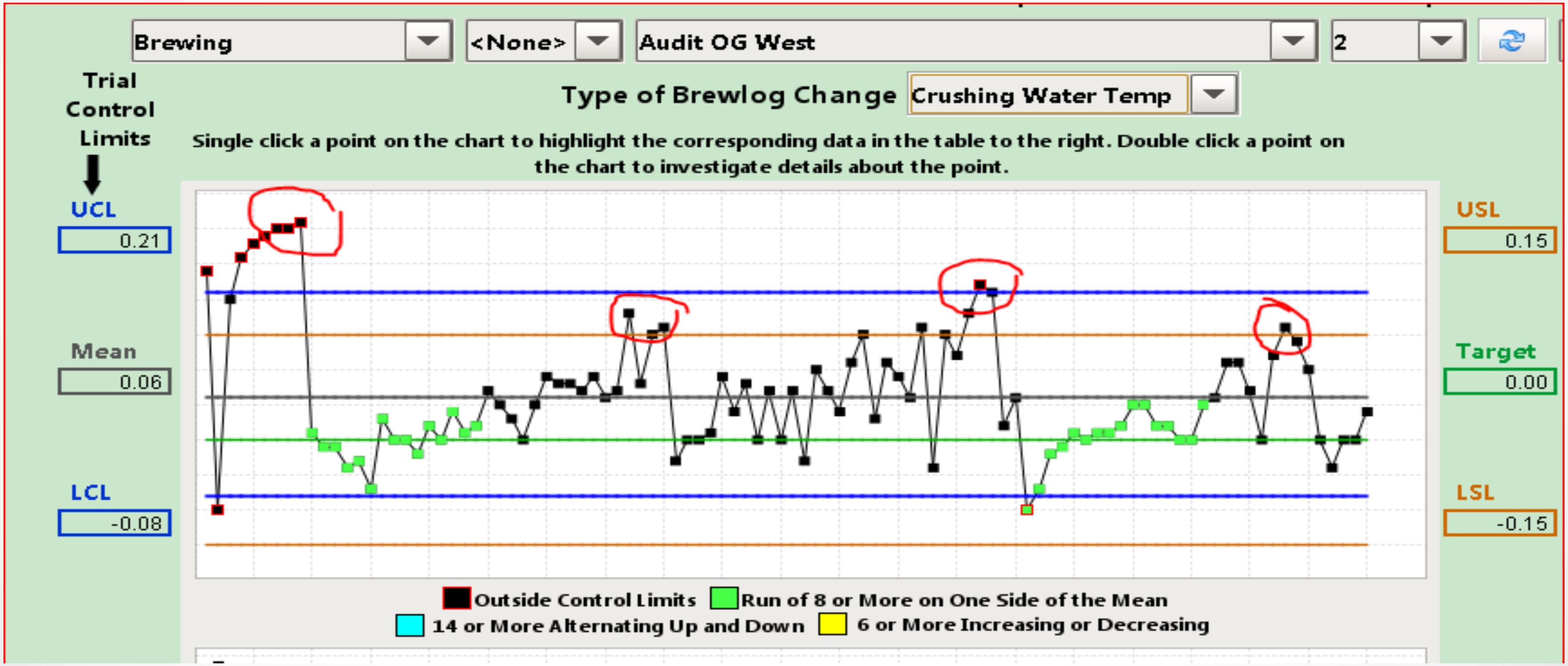
Sensitizing Rules



Patterns - Trends

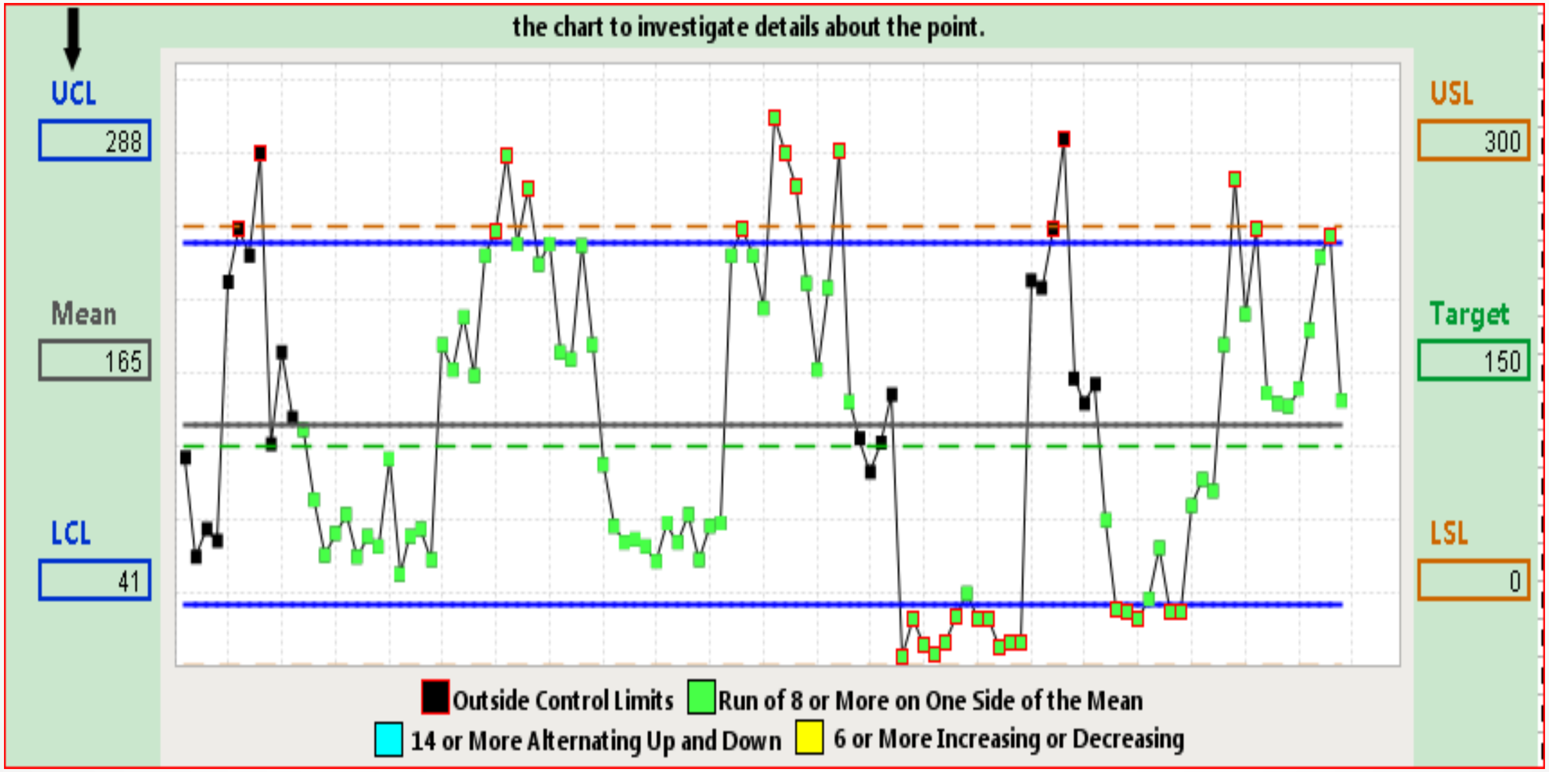
Patterns - Cycles

- Systematic change

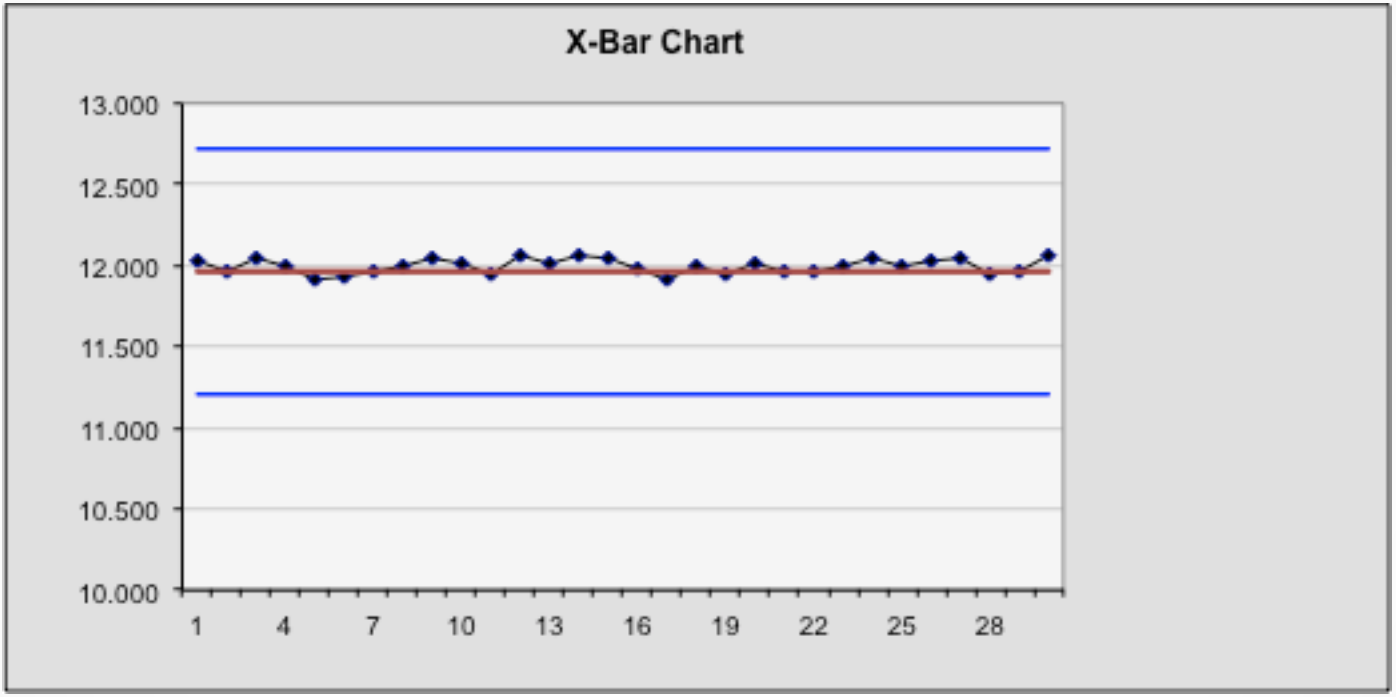


Patterns- Mixture

- Two or more overlapping distributions



Patterns - Lack of natural variability



Types of Control Charts

Variable chart are for measurements on a continuous scale

- **xbar**, **R** and **S** charts are variable charts
- **I-MR Charts**

Attribute charts are charts for non-continuous or discrete data.

- **p** monitors proportion nonconforming, constant n
- **np** monitors proportion, varying n

xbar-R Control Chart

- Xbar-R charts are valuable for monitoring discrete samples over time by evaluating several samples each time at certain time intervals
- Common example would be packaging/ packaged product measurements (e.g., package fill volumes, dissolved O_2 and any finished packaged product analytical measurements)

xbar-R Control Chart

Xbar

- Center line = x_{barbar} (the mean of the means)
- UCL = x_{barbar} + A_2*R_{bar}
- LCL = x_{barbar} – A_2*R_{bar}

R

- R_{bar} is the mean range
- UCL = D_3 * R_{bar}
- LCL = D_4 * R_{bar}

Simulating Data in Excel Control Chart

= NORMINV(probability, mean, std_dev)

=NORMINV(RAND(), 12, 0.5)

RAND() randomly generates a proportion between 0 and 1

Sampling --"Rational Subgroups"

- Each sample contains only common cause variation from a stable process
- Observations within a sample are independent
- Spacing of samples (frequency) minimize within sample variation and maximize between sample variation

Putting it together

1. What will happen to our control chart if we have ***assignable cause*** variation within our Phase I sampling? Why?

2. What will happen if our Phase I samples are not independent? Why?

I – MR Chart

I

- Center line = x_{bar} (mean of the measures)
- UCL = x_{bar} + 2.66*Mr_{bar}
- LCL =x_{bar} + 2.66*MR_{bar}

MR

- Moving Range = | $x_i - x_{i-1}$ |

I – MR Chart

- Sampling variable data at a single point in time
- Need to compare apples to apples (e.g., same point in the process comparing two batches)
- Very common for any analytical result from a tank
- Fermentation vessels, maturation vessels, bright beer tanks, etc.

p-Charts

Proportion Nonconforming

- Center Line = p
- UCL = p + 3* $\sqrt{\frac{p * (1 - p)}{n}}$
- LCL = p – 3* $\sqrt{\frac{p * (1 - p)}{n}}$

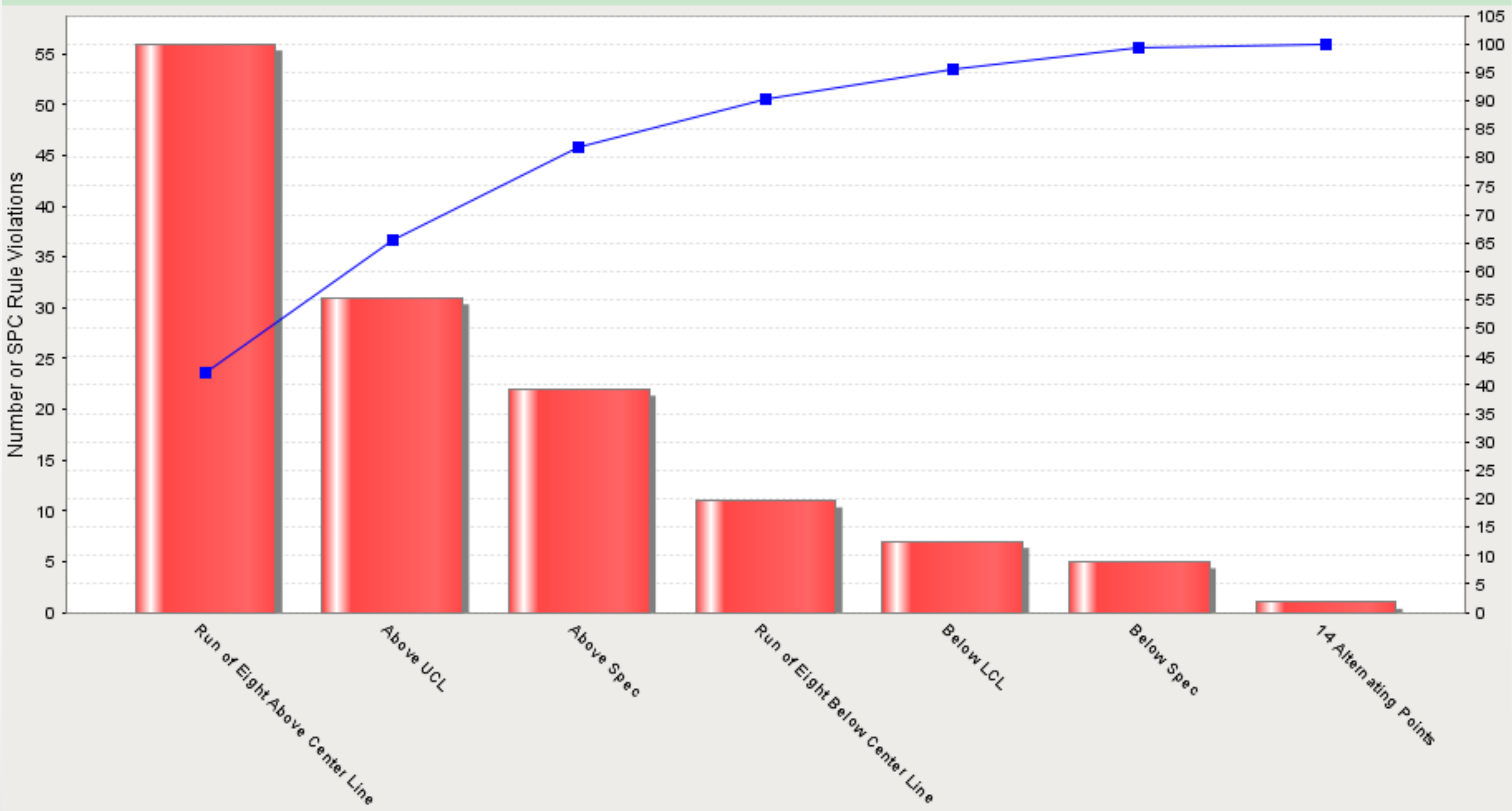
p-Charts

- Attribute data (go/no go) for varying sample sizes
- Monitors proportion defective
- Can be useful for micro or sensory results
  - Proportion of micro positive results in a week
  - Proportion of sensory panelists identifying a sample as not true to brand

Out of Control

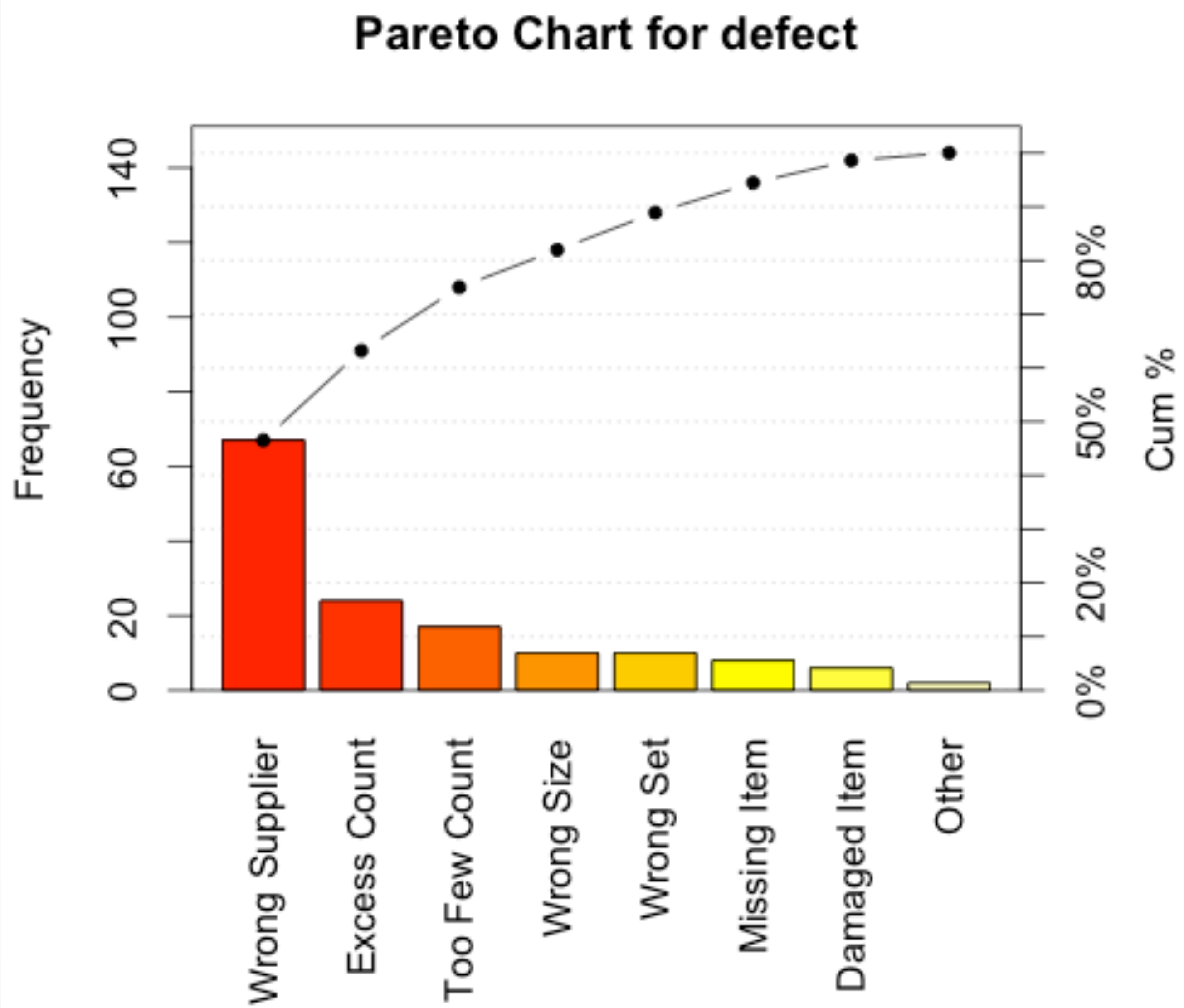
Now what?!?

Pareto Chart



Pareto Chart – Collect

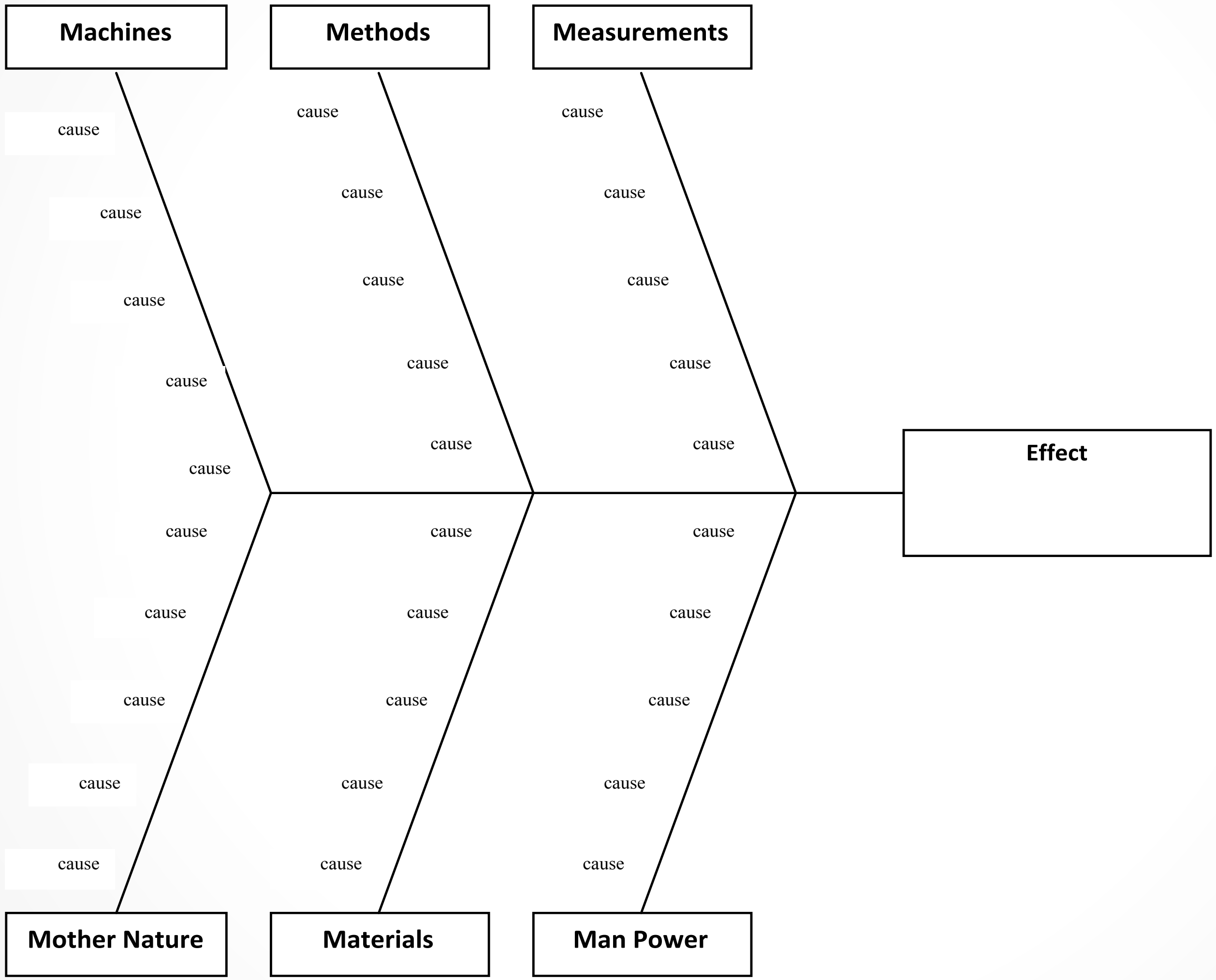
Error Type	Frequency	Percent	Cumulative %
Wrong Supplier	67	46.5	46.5
Excess Count	24	16.7	63.2
Too Few Count	17	11.8	75
Wrong Size	10	6.9	81.9
Wrong Sterile Instrument Set	10	6.9	88.8
Missing Item	8	5.6	94.4
Damaged Item	6	4.2	98.6
Other	2	1.4	100
TOTAL	**144**	**100**	


Pareto Chart for defect
Frequency
0
20
60
100
140
Cum %
0%
20%
50%
80%
Wrong Supplier
Excess Count
Too Few Count
Wrong Size
Wrong Set
Missing Item
Damaged Item
Other

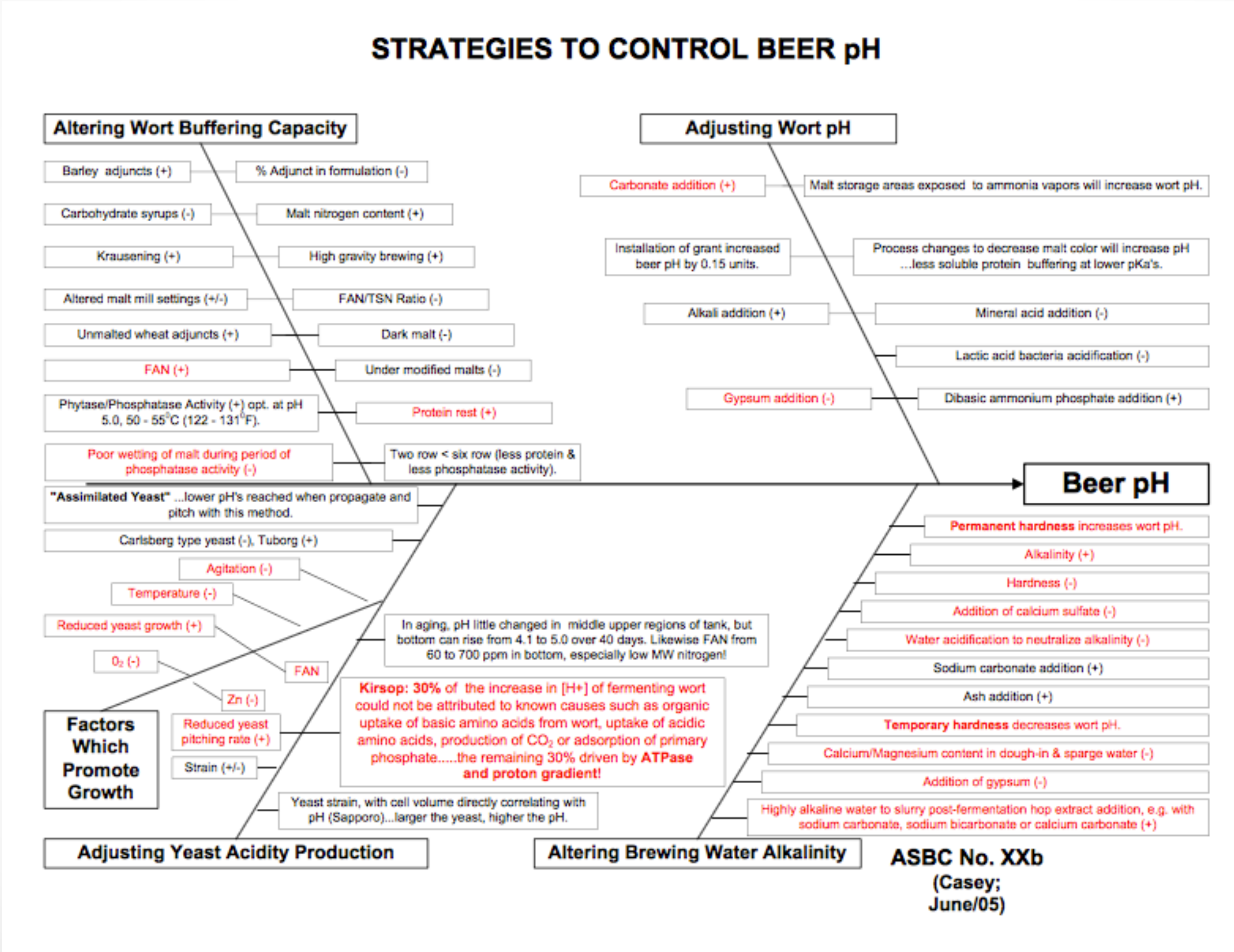
Pareto Chart

- Pareto charts are very helpful in identifying where to focus energy to address out-of-control condition and/or drive improvement when using attribute data
- Examples of Pareto charts would include number of micro positive results by area of process or number of no go's on sensory panel by flavor defect identification

Cause and Effect Diagrams



ASBC Fishbone Diagrams



NBB Brewmaster Ready

- Validate method and measurement with Measurement System Analysis/Gage R&R
- Select appropriate control chart and plot at least 25 points
- Validate data – remove errors (e.g., fat finger data or wrong brand)
- Document out-of-control action plan (living document)

Just Do It

- People are resistant to change/change is hard
- There are many, many formats, details and rules that can be debated
- There are many things that are measured
- Pick a few critical parameters on which you would want to take action
- Start charting – formats and rules will evolve and improve over time and more measurements will be identified

SPC II

- Process Capability Analysis
  - Spec Limits vs. Control Limits

- Gage R&R Analysis

  (partition measurement variability)
  - Instrument– Repeatability
  - Measurement Process – Reproducibility

Thank you!