Training Workshop Covering All Components of a Manufacturing Process Control System (PCS)

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Agenda

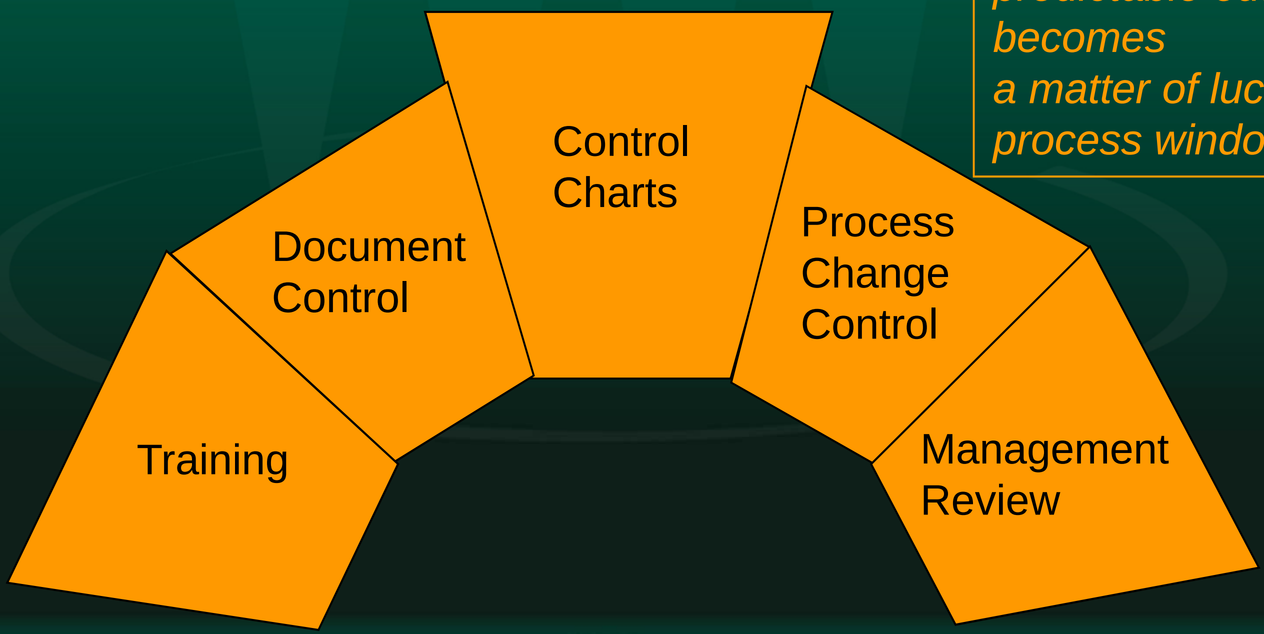
- **PCS Concepts and Methods**
  - Statistical Process Control (SPC)
  - Motivation for PCS
  - How is a Process Control System (PCS) different from SPC?
  - Statistics and Data Driven Methodology
  - How to Implement PCS (and how not to do it)
  - The PCS Team
- **Break (20 – 30 minutes)**
- **Examples: Control Charts and PCS in Action**
- **PCS Maturity Levels for your Organization**

From last year....

What is a Process Control System?

- **Control charts provide the caution light but...**
  - There are other critical components that the organization must have to make control charts fully effective
  - Any weakness in the other PCS components will eventually lead to process health issues

If any piece is missing, predictable output becomes a matter of luck when process windows are tight



Ground Rules

- **Ask lots of questions**
  - We need interaction for today to be successful
- **Give examples of issues you have where PCS might help**
  - Defect rates, visual inspections, manual processing, undetectable issues
- **Consider PCS concept as a *paradigm shift* for our industry**
  - It is a manufacturing methodology that enables high yield and quality
  - As I said last year, use of *PCS is critical to success*
- **Final note**
  - I'm not just pulling the stuff I'll cover from textbook or theory, I've lived this for 22 years at Intel

What is SPC?

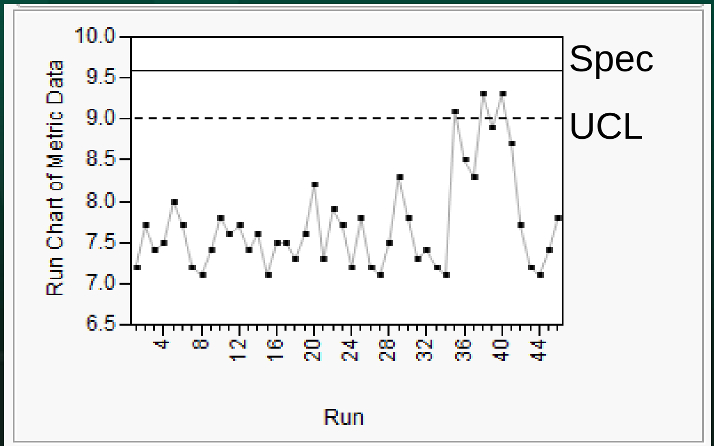
- **Leverages the power of statistics**
  - Data distribution and graphical tools
  - Sampling of processing data
  - How capable is my manufacturing process (Cpk)?
- **Leverages engineering skill and knowledge**
  - Provides extremely efficient tool for engineering to monitor manufacturing process steps
  - Quickly identifies if any processing steps are behaving abnormally

What is SPC? – cont'd

- **SPC is methodically monitoring the manufacturing process using statistics**
  - It is efficient and effective at reducing variation and identifying quality issues
- **SPC uses control limits (<u>not spec limits</u>) to identify if a process step is behaving abnormally**
- **Example**
  - All processing runs are in spec
  - No historical issues BUT...
  - Customer's <u>new product</u> has issues

  for processing runs with higher mean!

  ❖ Use of SPC



Motivation for PCS

- **Wafer test technology challenges continuing**
  - Shrinking pitch, increasing array size/probe count, current carrying requirements
- **Shrinking process window at test**
  - Performing test efficiently and producing correct results is very difficult
  - No longer have huge margins to allow test process to vary!
- **A robust process control system can be a matter of SURVIVAL!**
  - For a maturing industry, implementation of PCS is natural step of improvement
  - Within spec monitoring provides limited gains in quality and yield
  - 8 years go we needed PCS in sort
    - Every couple months the yield department would find something wrong with tool at sort
    - Control charts were put in place to detect issues, this was better but still too many issues
    - Simple SPC charts not enough, needed fab solution, entire system for good process control, i.e., a Process Control System

What is PCS?

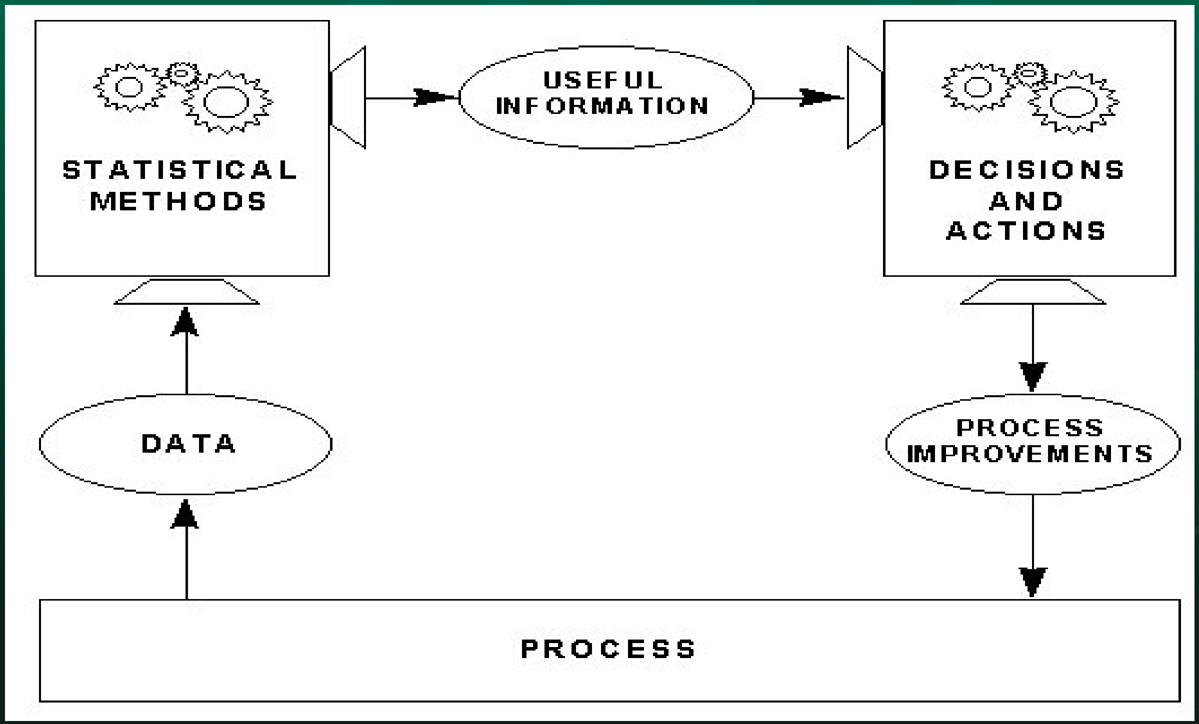
- **SPC is at the core of PCS**
- **PCS additionally provides a system that drastically reduces people and procedural variation and provides a solid foundation for SPC effectiveness**
- **How does it do this?**
  - Training system
  - Document control system
  - Process change control system
- **How does it drive continuous improvement (CIP)?**
  - Begins with rigorous focus on SPC monitoring
  - Involves all levels of organization
    - Technician and operator input
    - Engineer response to SPC signals, fixing root cause, making improvements
    - Managers review PCS data, provide clear direction and prioritization

Why use Statistics and Data Driven Decision Making?

- **“In God we trust. All others bring data.”**
  - – W. Edwards Deming (1900-1993)

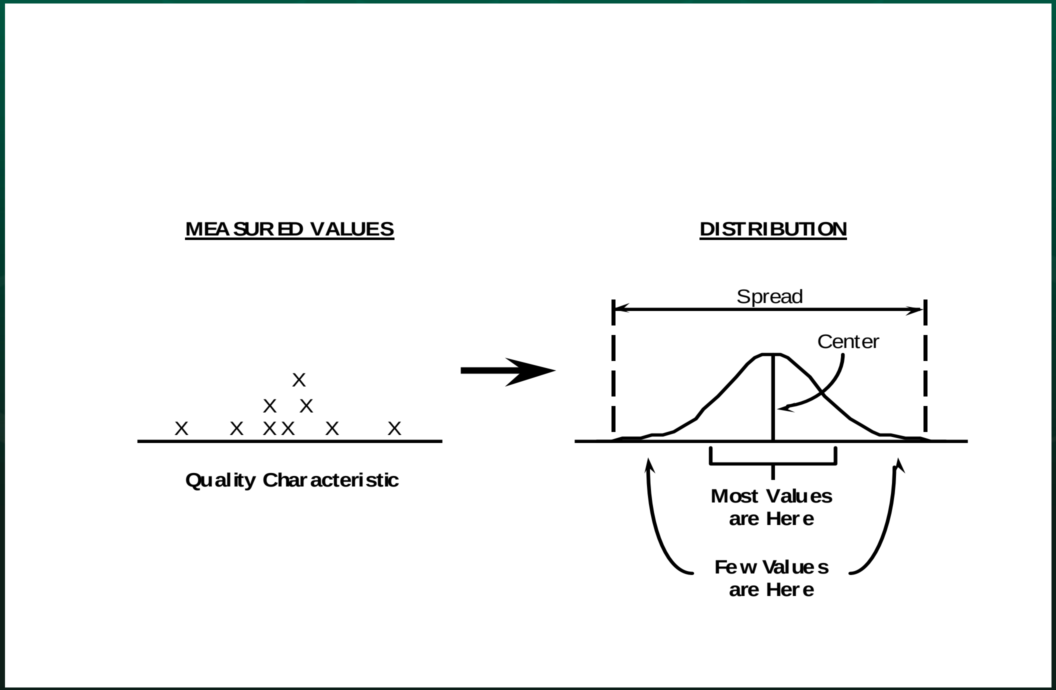
Data Driven Decision Making

- **We use statistics to learn about a process or piece of equipment and make decisions**
  - Is this technology better than that one?
  - Is a process step behaving as we expect?
  - Is the second metrology tool producing equivalent results to the first one?
  - Is the manufacturing process stable and capable?



Visualizing Data : Distributions

- Distributions are fundamental to most statistical analyses
- They are also very useful to quickly understand the structure of a dataset

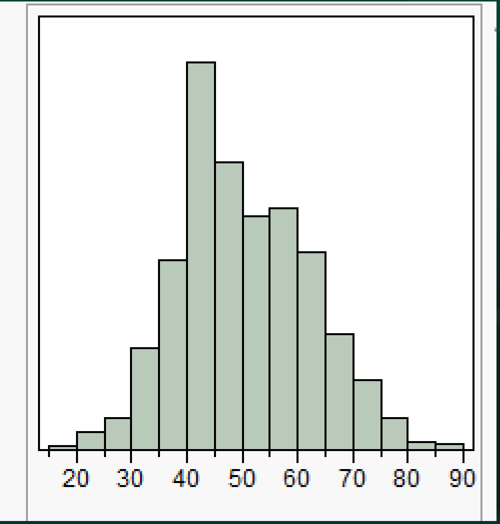


Distributions – cont'd

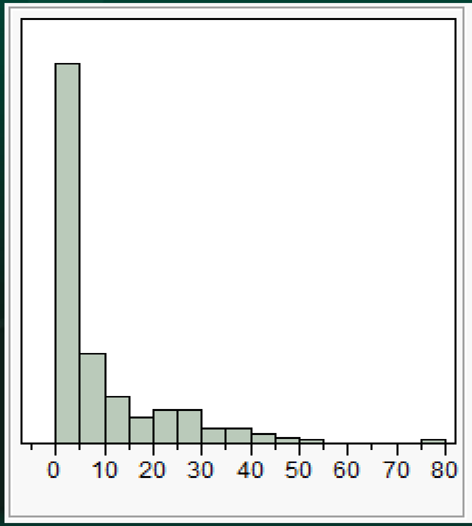
- **A distribution is described by its shape, center, spread**
  - Shape is determined by:
    - Symmetry
    - Modality
    - Outliers
  - Common measures of center:
    - Mean
    - Median
  - Common measures of spread:
    - Range, Interquartile Range (IQR)
    - Standard Deviation, Variance

Distribution Shape : Symmetry

- **Symmetric**
  - Portions above and below the center are roughly mirror images
  - Examples:
    - Heights of females
    - Measurement errors
    - Average daily temperatures

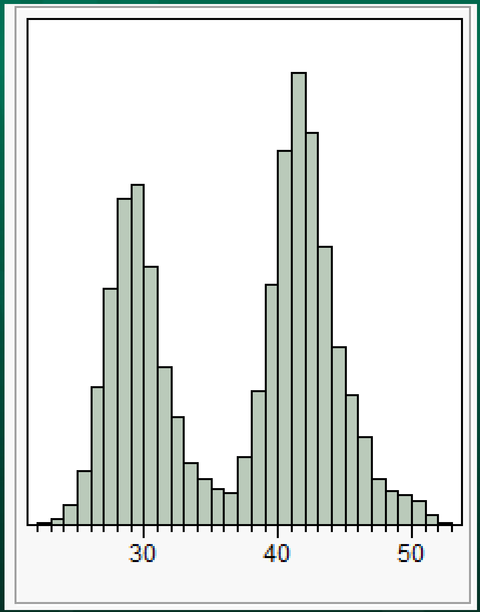


- **Skewed**
  - Skewed left - long tail to the left.
  - Skewed right - long tail to the right.
  - Examples
    - Total daily rainfall (right)
    - Annual salaries (right)



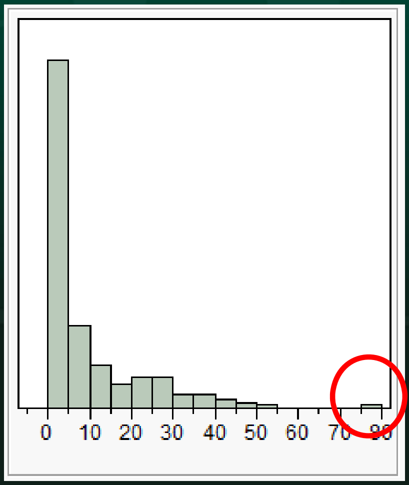
Distribution Shape - Modality

- **Modality**
  - Mode: Most frequent value
  - Modality: Number of peaks in a dataset
    - Bi-Modal – Two peaks
    - Tri-Modal – Three peaks
    - Multi-Modal – Many peaks
  - Usually the result of the combination of multiple groups of data
  - Examples :
    - Heights of American and Japanese males (bimodal)
    - Length measurements from 3 machines that have not been calibrated and matched



Distribution Shape - Outliers

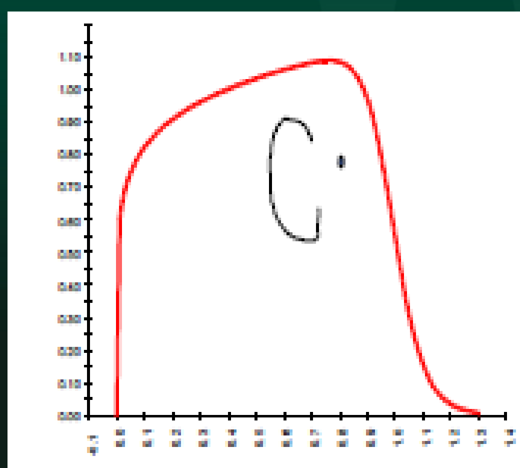
- **Outliers are observations that fall outside the rest of the distribution**
- **Outliers are usually the result of special causes**
  - Do not simply delete and ignore outliers!
  - Their cause needs to be identified and understood.
  - Analysis should be done with and without outliers to understand their effect.

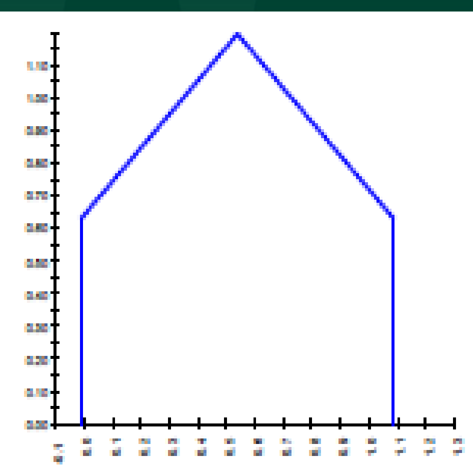


Graphical Representation of Data

- **"You can tell a lot just by looking at it"**
  - Yogi Berra

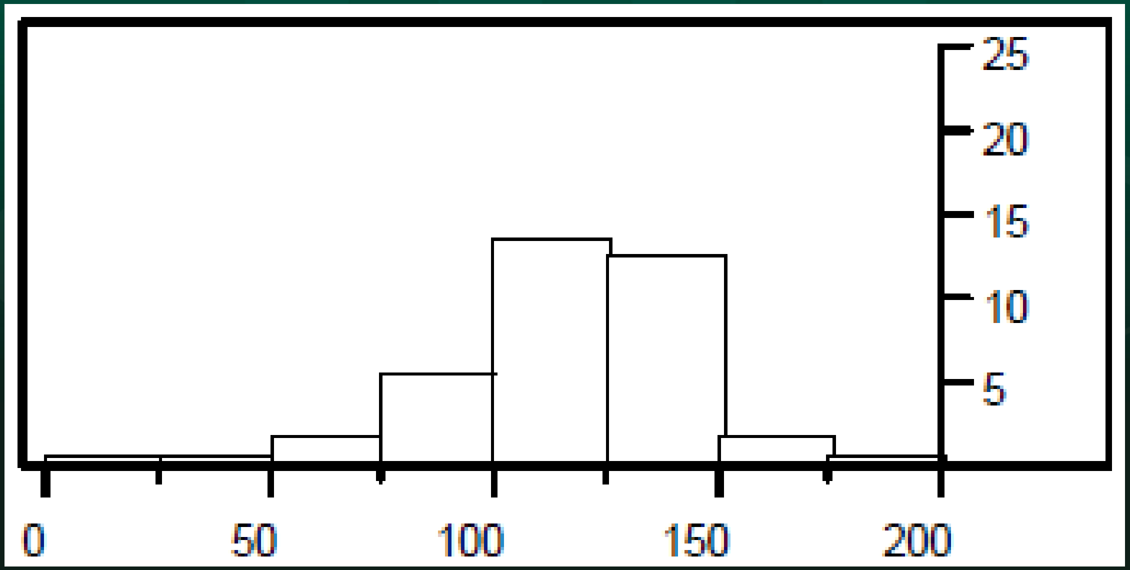
avg	= 0.5387	avg	= 0.5387
stdev	= 0.2907	stdev	= 0.2906
skewness	= 0.0000	skewness	= 0.0000
kurtosis	= 2.0000	kurtosis	= 2.0000





Graphical Tools: Histogram

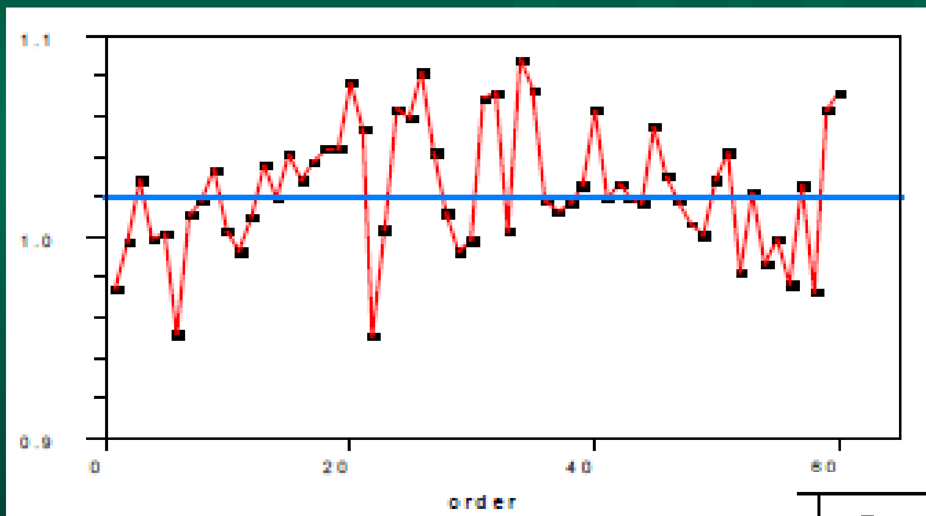
- Most common and simple tool for data representation
- Effective for identifying center, spread, and shape of distribution
- Less effective for comparing multiple distributions



Graphical Tools: Trend Plots

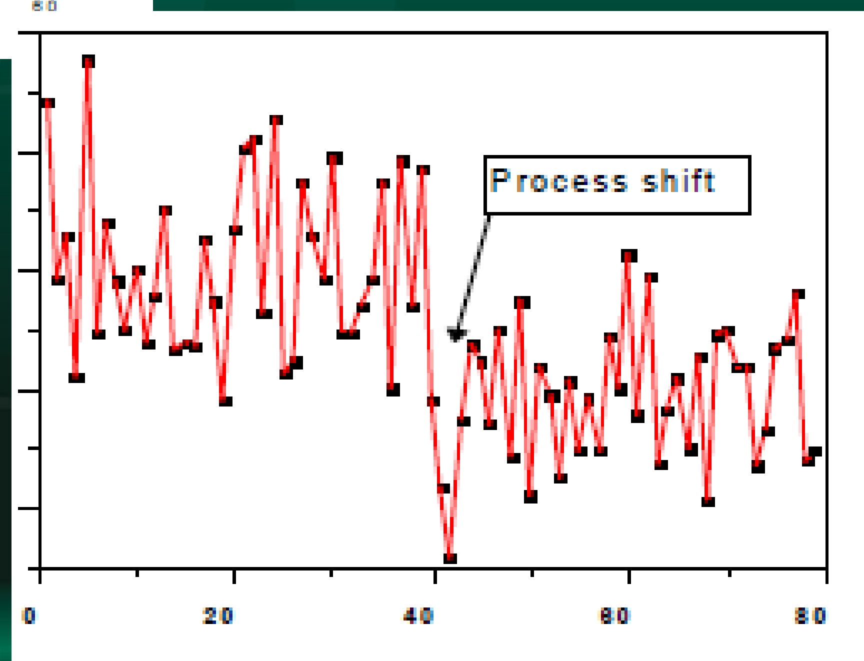
- **Used to determine stability of a distribution over time.**
  - Can identify shifts in the data and detect subtle trends.
  - Distribution of interest on Y axis, time on X axis.
- **A stable process has mean and standard deviation consistent over a period of time.**
- **An extension of the Trend Plot is the Control Chart**
  - The basis for Statistical Process Control

Graphical Tools: Trend Plots



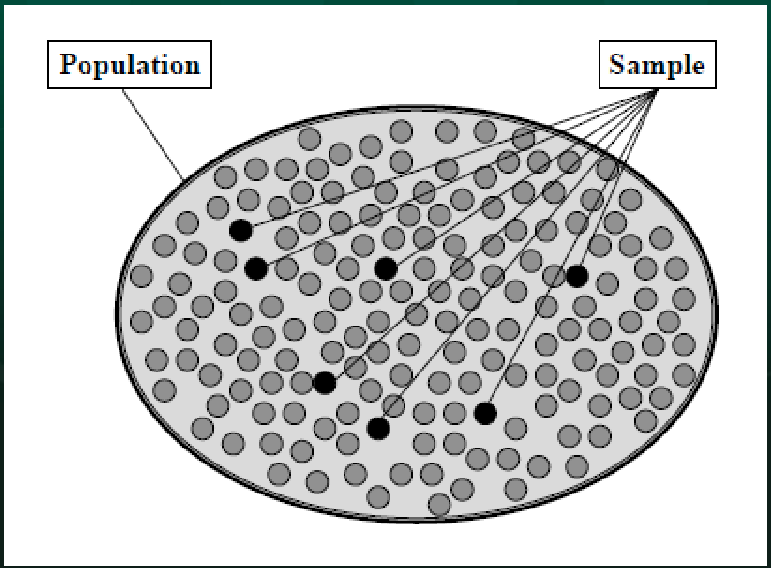
Is this process stable?

Precise timing of process shift identified



Sampling

- **Population: Consists of ALL measurements for a specific group.**
- **Sample: A representative subset of a population.**
- **Sampling is a more cost effective and efficient way of measuring an entire population, and *nearly* as accurate.**



Population vs. Sample

Population	Sample
The entire population of the United States of America (census)	A marketing study of 1000 Americans for a certain test product
Every single Canadian Goose	A sample of 200 Canadian Geese being tracked in a migration study
Planarity and orientation of every single probe within a probe card array.	Measurements of the planarity and orientation of a smaller subset of the probes used to estimate the overall probe card health

Good Sampling

- **Sampling is an effective way of measuring a very large population**
- **Sample must be indicative of overall population**
  - 1st understand variation of population, i.e., distribution
  - Ensure sampling captures variation like for a non-normal distribution
- **Additionally use randomization and a large enough sample**

Sample Size

- **Logically, the larger the sample size, the closer the results will be to the population.**
- **Solid estimates can be obtained with sample sizes of around 20 to 30.**
- **Sampling should be based on measurement level with highest level of variability.**
  - Ex: Variability likely larger from one probe card to another rather than within a single probe card. Better to sample more cards and fewer probes within card.

Sample Size

Detectable Difference	Minimal Sample Size
0.35 standard deviations	109
0.5 standard deviations	54
0.75 standard deviations	26
1.0 standard deviations	16
1.5 standard deviations	8
2.0 standard deviations	6
Gross Reality Check (GRC)	5 or less

Note: numbers are taken from a larger sample size table for a 1 sample hypothesis test assuming alpha and beta values of 0.05.

Sampling Wrap-up

- Populations contain every possible set of the data in question, but is often very difficult or impossible to completely measure.
- Sampling is an effective way to measure part of a distribution which will represent the population.
- Some of the mistakes made in sampling include not randomizing, using an insufficient sample size, or pulling non-representative samples.

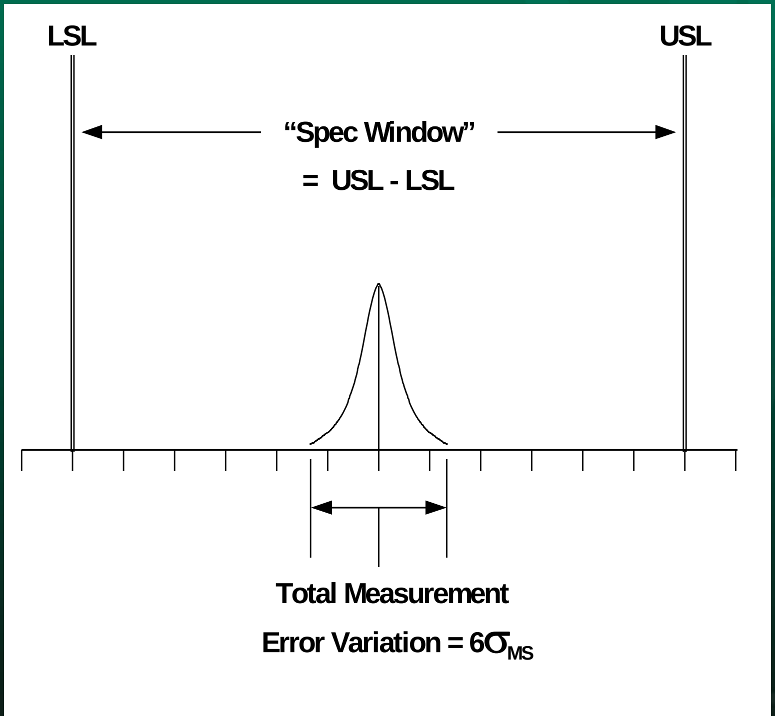
Capability (Cpk)

- The capability of a *manufacturing process* is its ability to meet specifications.

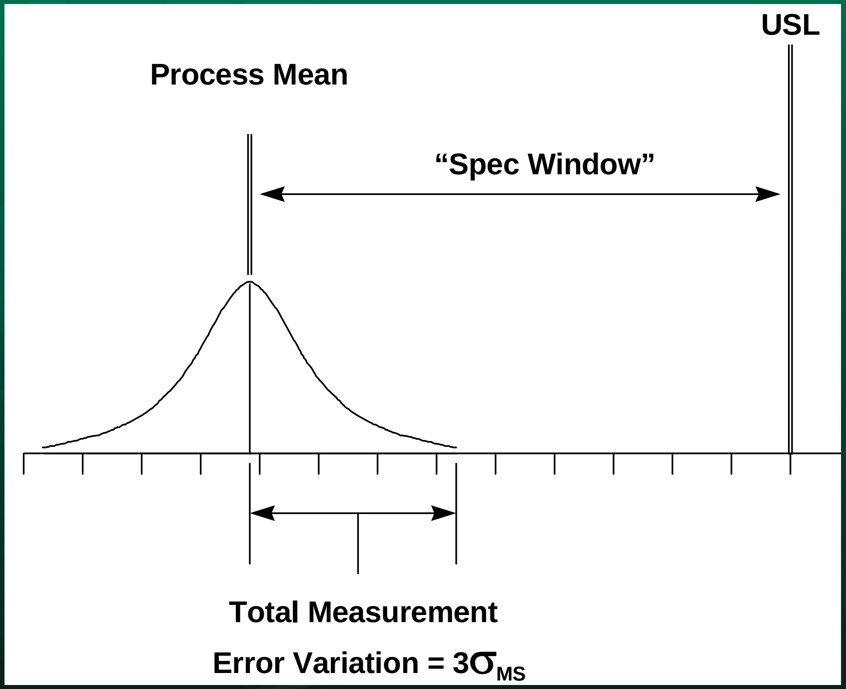
- In contrast, the capability of a *measurement system* is the amount of the spec window that is lost to measurement variation.

Capability (Cpk)

Two-Sided Specs



Single-Sided Spec



CPK – An Example

- Data in this example is a comparison of 3 different technologies (using made up data) comparing the CPK of probe marks.
- CPK is a measure of how close a distribution is to violating a spec limit. In this case, how close the probe marks are to the edge of the pad.
- CPK value of less than 1.0 is considered to indicate low level of quality. CPK value above 1.3 is an indication of higher quality.

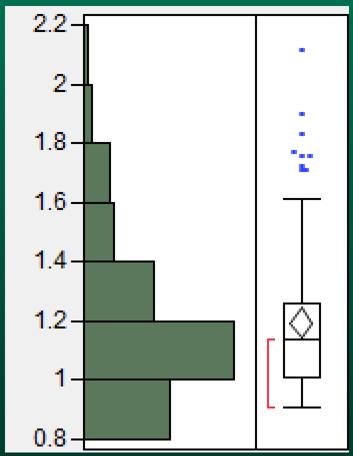
CPK – An Example

Summary data

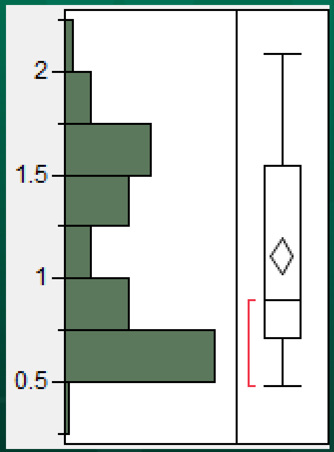
Technology	Mean	SD
A	1.19	0.26
B	1.11	0.44
C	1.55	0.32

CPK – An Example

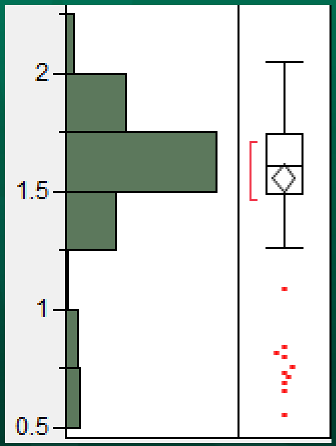
Histograms



A is skewed



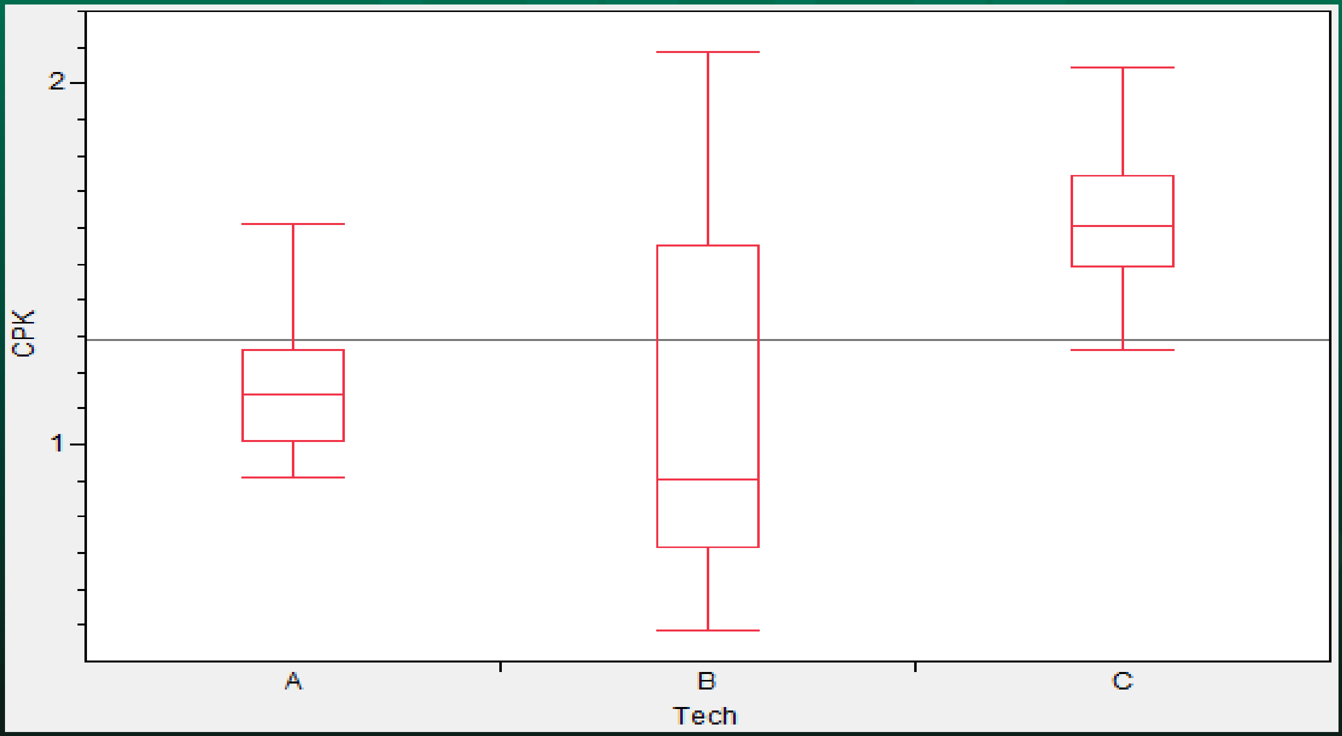
B is bi-modal



C has outliers

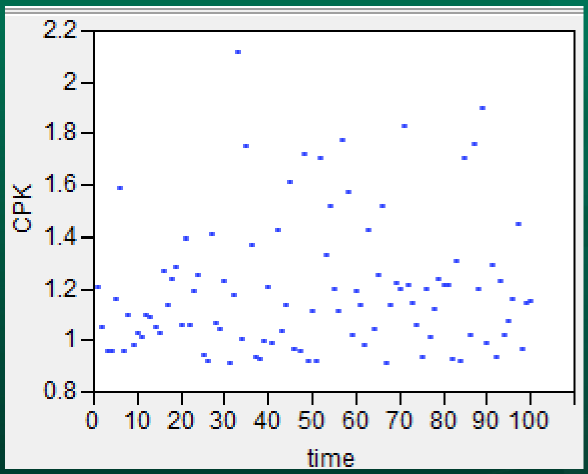
CPK – An Example

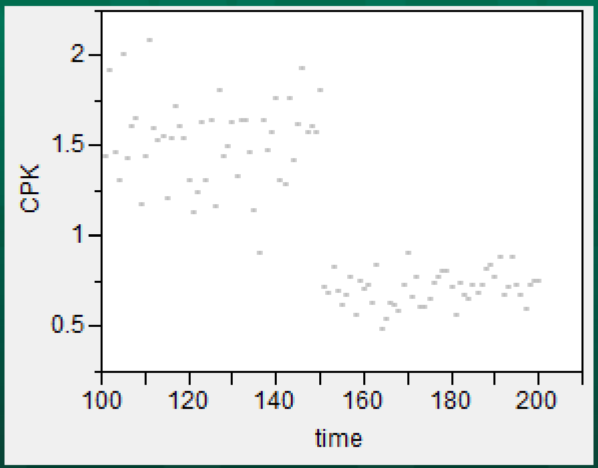
Box Plot Comparison

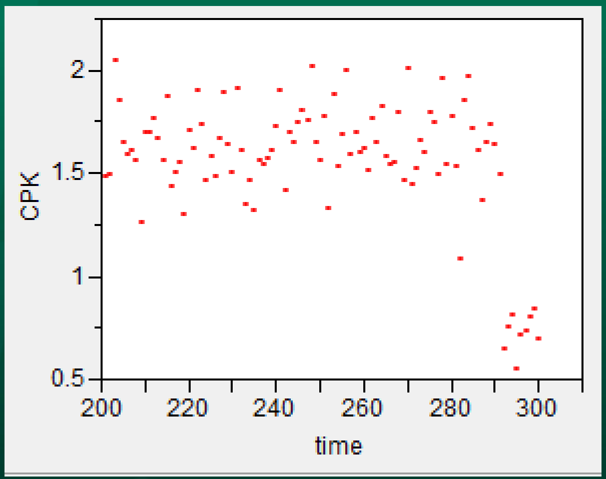


CPK – An Example

Trend Plots







Relatively constant trend over time for A

Clear shift seen with B. This information can be used to determine why the sift happened

Timing of outliers can be seen with trend plots

Graphics Wrap-up

- Use histogram to get first idea of distribution shape, center, and spread.
- Prob plots and box plots can be used to compare multiple distributions at once.
- Once items of interest are identified within a distribution, look at trend plots to determine specific trends, shifts, or spikes in data.
- Always ask "What question are we asking the data?"

How Not To Implement PCS

- **Give someone task of creating control charts with little knowledge of how specific process steps behave**
  - i.e., hiring a statistician to create SPC charts, put in place, then tell process engineers to start using
- **Good control charts require careful thought and creative solutions (metrology, sampling, statistics, control limits) to be effective**
  - It is rarely cookie cutter
  - Can't simply use textbook methods, e.g., using 3 sigma for control limit calculation, charts for mean and standard deviation, many times NOT effective

How To Implement PCS

1. **a) Identify PCS champion (overall leader) with experience to drive the effort**
   - Someone with SPC and process control experience
   - Often this is a process engineer with experience and SPC expertise
   - Someone that can push through roadblocks and drive solutions with competing priorities

b) Expect process engineers to establish control charts, rigorously respond to OOCs and drive process improvement

Upfront realize

- Not simply making 3 sigma control charts on measured parameters
  - Have to figure out which are the most critical parameters
  - Identify where gaps or improvements are needed in monitoring
- Defect monitoring requires special focus, i.e., understanding of what defects might matter and solutions in how to monitor
  - Analytical technique and metrology, i.e., how to "identify and count defects"

How to Implement PCS – cont'd

2. **Identify control parameters (most important of these will be called "Key Parameters" -- Cpk will be watched closely for these)**
   – Some identified parameters might need metrology improvement
   – Control charts for all control parameters
3. **If Cpk < 1.3, immediately start driving improvement. Sometimes requires better understanding of process step spec limits**

How to Implement PCS – cont'd

4. **Continue implementing and improving effectiveness of control charts**
   – Improve limits, targets, sampling, metrology
5. **Responding to signals detected with control charts**
   – Initially will require prioritization of large number of signals

Steps above are the PCS cornerstone

– ***The other PCS components are just as critical as SPC***

Components of Complete PCS

PCS is... A system for process control that removes people and procedural variation and drives continuous improvement, i.e., better yield and quality

1. **Rigorous SPC**
   – Cornerstone of PCS
2. **Training System**
   – Controlled documentation on how to perform process steps (aka Specs)
   – Specs must be very clear and followed absolutely
   – Controlled training checklists to ensure proficiency
   – Technician/operator certification, including tracking for recertification

Components of Complete PCS

3. **Document Change Control**
   - Specs, training checklists, design rules
4. **Process Change Control**
   - Fixed set of 3-4 people that approve process changes for entire process, should include statistical expertise
     - Review and approve qualification plans before data collection
     - Standardized change control template to ensure consistent expectations

Components of Complete PCS

5. **Meeting structure/Management Support**
   - Weekly control chart, Cpk review in appropriate forum
   - Monthly manager review of Key Parameter control charts and Cpks
   - CIP teams for highest risk/lowest Cpk processing steps
     - Never stop driving continuous improvement
     - Continually leverage PCS to improve manufacturing
       - Solid process health
       - Drive quality indicators to exceed competitors
       - PCS reduces risk of cost reduction
         - » Watch control charts very closely when implementing cost reduction process changes to ensure no quality impact
         - » Use process change control methodology for approval of process changes related to cost reduction

Components of Complete PCS

6. Automation/data tracking

- Use of database for process data
  - Low volume: Data entry can be manual to database
  - High volume: Likely need automatic data loading to database
  - Database should link process runs to lot identification and processing tool
- Control charts: Simple scripts to update each process run data are best but can be done manually by technician/operator
- Engineering analysis of process step data
  - Database of process data is essential
  - Need software tool with statistical methods built-in that enable efficient analysis in minimal time

PCS Maturity Levels

Maturity Level	Attributes
World-class PCS (exemplary)	Clear and consistent demonstration of PCS use, identifying issues and effectively controlling process Excursion root cause is quickly identified, existing PCS leveraged for quick resolution Customer detection of process issues is rare Exhibit continuous improvement All members of manufacturing team aware of PCS/quality
Complete PCS in Place (meeting expectations)	Rigorous SPC data and trend review for all critical steps (KPPs) by individual owner and weeky forum PCS summary reports weekly, management review Document and process change control used rigourslу Technician response to OOCs, training certifications Use of multiple PCS tools (fishbone, tracking sheets, pareto, improvement trends)
SPC Implemented (not meeting expectations)	Control charts used to control the process Key process parameters identified (KPPs) Management expects response and continuous process improvement
Outgoing Quality Monitors Only (not meeting expectations)	Limited process step monitoring with control charts Monitors for outgoing quality in place
Very Limited Monitoring (poor process monitoring)	No process step monitoring with control charts Limited monitors for outgoing quality in place

PCS Team Members

- **Technicians and Operators**
  - Understand PCS concept, respond to control charts and always follow specs
  - Have a forum for communicating improvement ideas
- **Process Engineers**
  - Own PCS in their area
  - Drive continuous improvement in their area
  - Present control charts regularly to appropriate review forum

PCS Team Members – cont'd

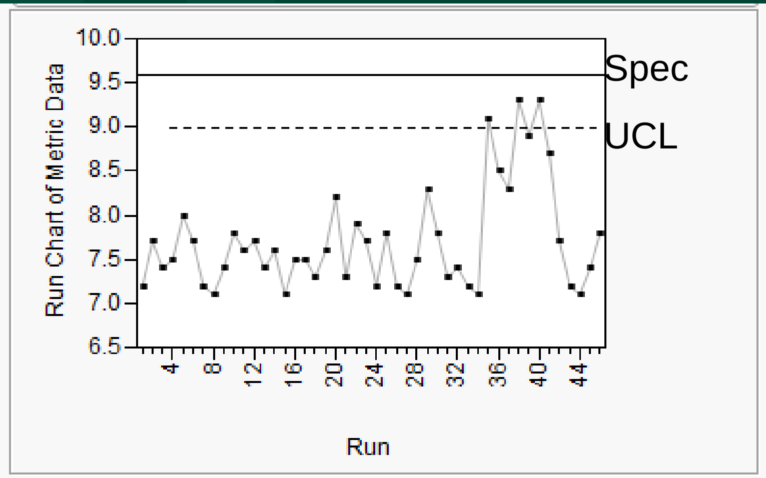
- **Management Commitment to PCS**
  - Communicate PCS as a top priority
    - And "walks the talk", i.e., demonstrates this in actions
  - Monthly manager review of Key Parameter control charts and Cpk
    - The best managers always seem to keep on eye on the most critical control charts

Examples: Issue 1

- **SPC is using control limits (<u>not spec limits</u>) to identify if a process step is behaving abnormally**
- **In this example**
  - All processing runs are in spec (resistance, force, length, defect count)
  - No historical issues BUT...

    Customer's <u>new product</u> has issues

    for these processing runs!
  - <u>Problem fixed or intermittent?</u>



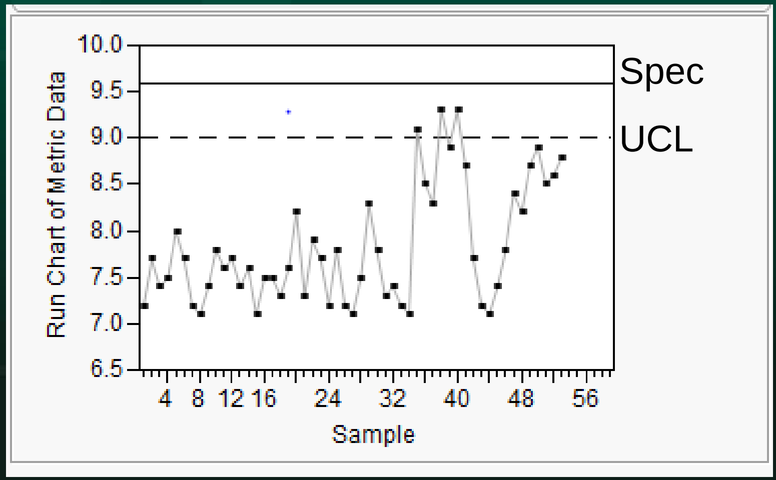
- **Rigorous SPC provides...**
  - Opportunity to identify root cause
  - Prevent future occurrence
  - ❖ PCS Reviews
  - ❖ Meeting Structure/Management Support

Issue 2 Example

- **Was process issue fixed or intermittent?**
- **Two problems with the control chart**
  - No target line
  - UCL might be too loose
- **Possible causes**
  - Process tools running differently
  - Difference in manufacturing personnel
    - Using different setup techniques
    - Different manual techniques

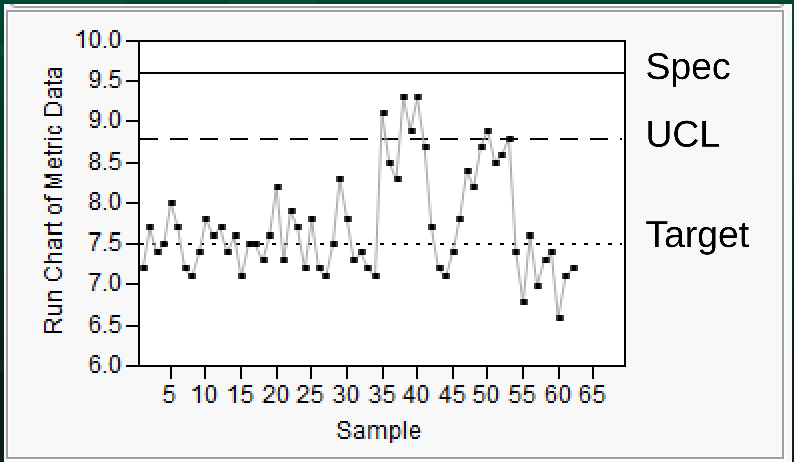
❖ Training System

❖ Document Control System



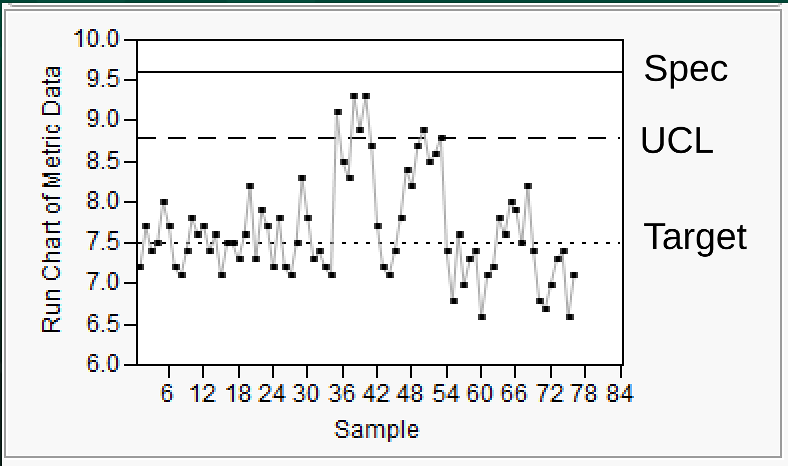
Issue 3 Example

- **Assume two issues identified**
  - Tools not calibrated
  - Weekend shift procedural slightly different from weekday
- **From previous learning**
  - Reduced UCL slightly
  - Added a target line
- **What is wrong with the process now?**
- **What are possible causes?**
  - Calibration adjustments caused shift
    - Other possible root causes?



Issue 4 Example

- **What is wrong with the process in this chart?**
  - Sawtooth pattern
- **Is something missing in control chart?**
  - Answers?
- **Just because no spec on lower side doesn't mean it is okay to let the process run differently than historical baseline**
  - You are giving your customer something different than before
  - This could be benign or it could lead to an issue at customer (I don't advise finding out the hard way)



❖ Rigorous SPC

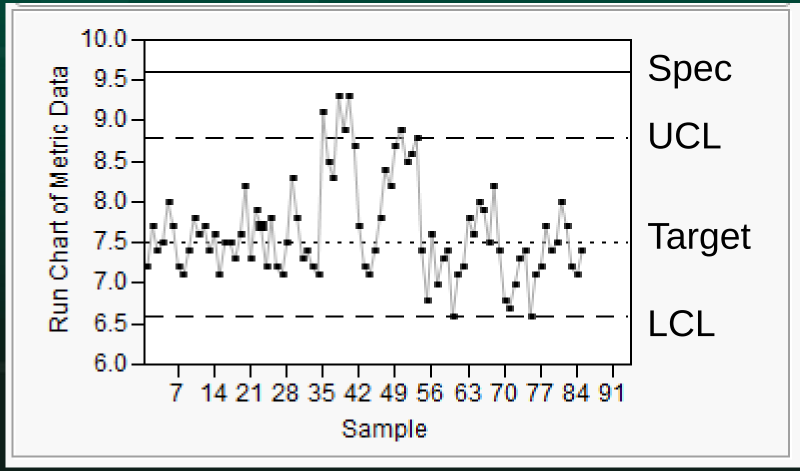
Issue 5 Example

- **Process is now running on target**
- **Process change made to change the calibration procedure**
  - Quality engineer sees issues related to this step
  - Process mean chart looks good
- **A miss in process change control**
  - Process change data did not include within run variation

❖ **Process Change**

Control System

– statistical expertise

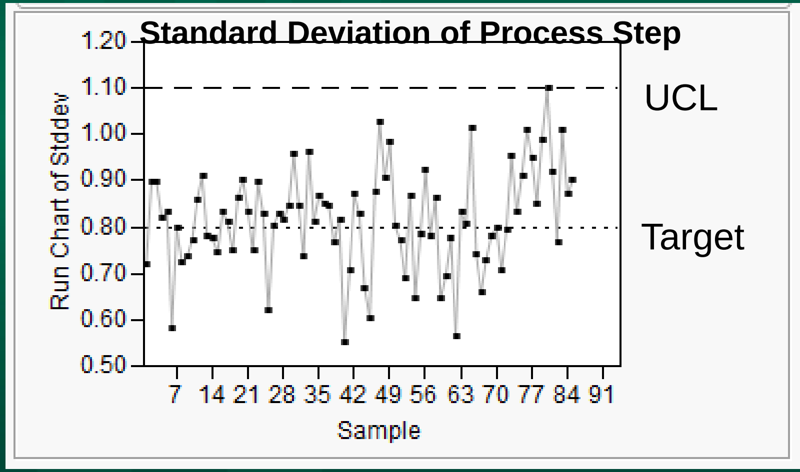


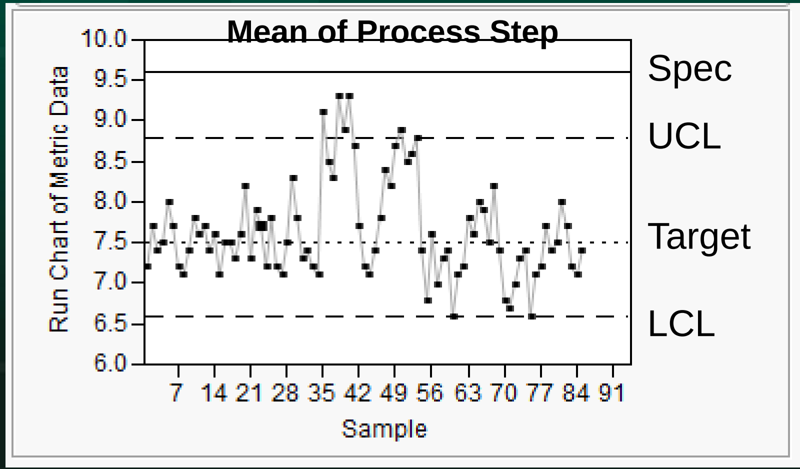
Issue 5 – cont'd

- **A miss in process change control**
  - Very subtle signal in standard deviation control chart
  - Process engineer should have familiarity to detect variation increase

❖ **Rigorous SPC**

❖ **Process Change Control System**





Going Forward

As our industry matures PCS will improve chance of success ☺

- **What are the biggest barriers for implementing at your company?**
- **Next year at SWTW bring back a success story**

I am confident you will find success using PCS