

# Optimizing Mill Effectiveness Through Statistical Process Control (SPC)

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## ABSTRACT

Statistical process control (SPC) is a powerful technique for improving customer satisfaction and mill productivity, while reducing product and process variability and waste. At its foundation, SPC identifies and controls meaningful variables, ensuring processes operate at their fullest potential *for the long term*.

In the 1980’s the U.S. paper industry attempted to adopt SPC, but most efforts quickly ceased. The industry was ill-prepared to sustain it, because there weren’t enough leaders committed to this approach to continuous improvement for the long term. Corporate leadership and unwavering commitment to leading the charge for the benefit of the customer is the most important element in establishing SPC in an organization. Early efforts lacked that dedication.

SPC identifies *special causes*, which are variations that happen on occasion and they are not often pursued or eliminated. When teams trained in SPC become highly skilled in identifying, statistically analyzing and eliminating sources of variation, they prove effective in getting to root cause and eliminating these special causes. By uncovering special causes at the outset of a process or test being tracked through control charts, the challenge of process optimization becomes clearer and simplified. The outcome is an increasingly consistent, high-quality product, which elevates customer satisfaction and loyalty.

The objective of this paper is to re-introduce SPC to a new generation of pulp and paper industry leaders, by highlighting its transformational benefits. Examples and tests will illustrate how this problem-solving method maximizes productivity by eliminating wasteful process variation. It also provides guidance in introducing SPC to an organization: setting realistic expectations, building the pioneering team, establishing systematic expansion, and maintaining momentum through visionary leadership.

**Keywords:** paperboard machine, cross-direction, CD, variability, scanner, basis weight, ply weight, analysis, profile

## INTRODUCTION

While statistical process control (SPC) has a long and continuous history in manufacturing worldwide, it never gained momentum in the U.S. pulp and paper sector. If you worked in our industry in the 1980’s, you may have been part of a flurry of classroom and on-the-job training, which taught the fundamentals of SPC. These efforts petered out within 18 months, with just a few mill efforts persisting, as they understood the benefits.

Commentary on the ineffective U.S. industrial efforts to integrate SPC into manufacturing practices suggested common themes:

1. Leadership at the top of organizations gave approval but did not *lead* it.
2. In a haste to “do something,” resources were tasked to their limits without of consideration of how to sustain it on the plant floor.
3. Competing priorities. The fundamental reason to implement SPC is to benefit the customer. This singular focus was lacking because of other competing business metric priorities, such as production and profit targets, etc.

This paper elevates the focus on SPC for the benefit of the pulp and paper industry. As proponents of this method, we will show how to implement SPC in a logical and industry-sensitive way. Also, we will demonstrate the benefits to stakeholders and offer suggestions to make SPC sustainable *for the long term*. What SPC can do to benefit this industry is nothing short of astounding.

## WHAT IS SPC?

SPC is a systematic method for identifying and tracking meaningful and actionable variation. When special variation is captured, response is quick to identify the problem and resolve it. This helps an operation attain optimal performance while delivering higher-quality products.

At the heart of SPC is the control chart developed by Walter Shewhart in the 1920's at Bell Labs [1] and popularized when used by Edwards Deming [2] throughout post-war Japan during the 1950s and 60s. The object of Deming's effort in Japan was intended to *singularly* benefit the manufacturer's customer [3, 4]. SPC reduces variation in products and highlights new opportunities to make products even more consistent, which elevates customer satisfaction and loyalty.

SPC also reduces the sources of costly manufacturing "reworks" and waste. Think of SPC as a method for "draining the swamp": when water is removed from a marshy area, the dangerous creatures that depended on the water (mosquitos, alligators, harmful bacteria, etc.) are removed. Without transformational, long-term solutions - diverting the murky water from the marshland - mills are forced to sell into the off-grade market or re-pulp at a significant loss or suffer the consequences of delivering low-quality product to customers.

### *Sources of variation*

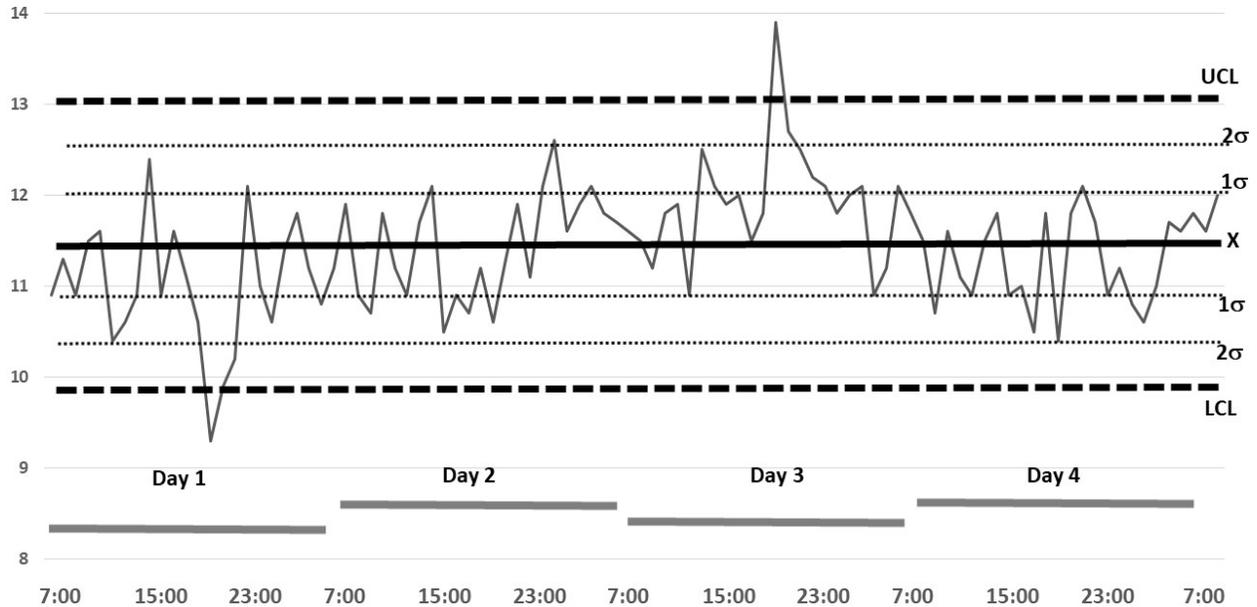
There are two statistically significant sources of process variation: *common cause* and *special cause variation*. *Common cause variation* is generally small and comes from many sources. Common cause variation represents a multitude of mostly continuous process variations such as: raw materials (pulp, voltage, steam pressure), control devices (inherent error in consistency regulators, pressure transmitters, etc.), and manufacturing methods (variation in interpreting SOPs, decision delays, etc.).

What is "special" about "special causes"? *Special cause variation* is infrequent and appears when an influence upstream causes strong disparity in the variable being charted. Think of ocean waves. They vary considerably, depending on ambient and climatic conditions. At their calmest, oceans may exhibit <1 ft. (30 cm) waves. However, in a severe storm, those waves could reach 40 ft. (~12 m). In our processes, four or five factors likely contribute to 30 of the 40 ft. waves in our processes. Examples might include: frequently sticking dilution valves, low or high consistency entering due to difficulties with thick stock dilution entering stock prep, or up-stream temperature shocks due to adding appreciable fresh water, etc. Because they are *large* and *not constant*, they are characterized as "special" causes on control charts. They tend to stand out and this enables the investigator to determine what factors aligned upstream to cause the special shift in the process.

When we substantially reduce the major sources of variation, we can recalculate and narrow the control limits, because the less apparent sources of special cause variation begin to appear. Previously, they were masked by the larger *common causes*.

The control chart helps distinguish between what is significant and what is not. The typical control chart of a process or product measurement is shown in Figure 1. Figure 1 tracks the permanganate number (P number) in a hardwood pulp mill. The chart was designed with the calculated limits shown after collecting enough measurements of the variable being tracked (min. 30 points) to represent its natural variability. Most processes follow a normal distribution or bell-shaped curve. A control chart is nothing more than a bell-shaped curve of data on its side. A value outside the bell curve or beyond the upper (3 sigma) limit, is a statistically significant event with a special cause, and the investigator can take action.

When a control chart is first designed with an initial dataset, the information is averaged, represented by the mean, “ $\bar{X}$ ” (termed an X-bar chart). In Figure 1, the mean (X) line is horizontally centered in the data. The first upper and lower lines are the 1σ (sigma) limits and represent about 68% of normally distributed data. The second line above and below the mean are the 2σ limits, representing about 95% of the operating range. The outermost limits are the 3σ limits, representing about 99.7% of the range.



**Figure 1:** Control chart of hardwood permanganate numbers showing the control and sigma limits

Figure 1 is an example of an “individuals” control chart. An “individuals”  $\bar{X}$  (referred to as X-bar) control chart means each data point represents an actual measurement of a P numbers test, not an average of several test measurements. The control limits were calculated using simple formula:

$$\bar{X} = \frac{\sum_{i=1}^n Xi}{n} \quad \text{Equation 1}$$

$$\bar{R} = \frac{\sum_{i=1}^n Ri}{n-1} \quad \text{Equation 2}$$

**For control chart for individual X values:**

$$UCL_X = \bar{X} + 2.66 \bar{R}$$

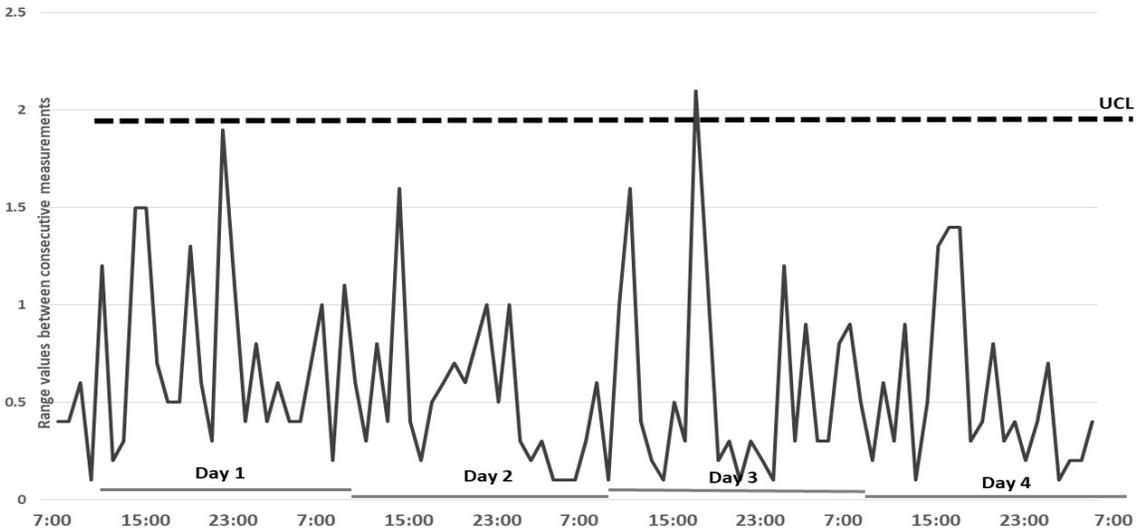
$$LCL_X = \bar{X} - 2.66 \bar{R}$$

**For control chart for running ranges:**

$$UCL_R = 3.27 \bar{R}$$

$$LCL_R = 0$$

The other chart, equally important to  $\bar{X}$  run charts, is a range chart. This chart detects rapid and unexpected differences from one data point to the next, based on historic data from the studied process. Figure 2 uses the same data in Figure 1 to examining the point-to-point change and the “range” between them (see equation 2) in an  $\bar{R}$  ( $R - \bar{\text{bar}}$  chart).

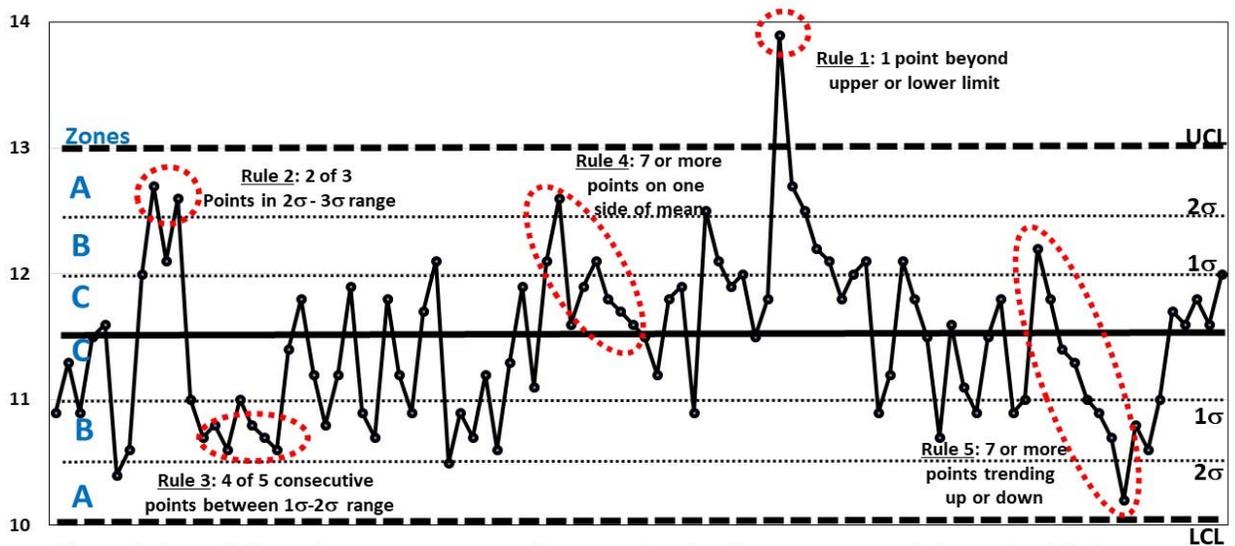


**Figure 2:** Range chart of Figure 1 permanganate numbers showing upper control limit (UCL)

Control charts are used to identify when a “special cause” has taken place. They are identified by using five basic rules for taking action [5]:

- Rule 1:** One value outside the  $3\sigma$  control limits
- Rule 2:** Two or more sequential values in between the  $2\sigma$  and  $3\sigma$  limits
- Rule 3:** 4 of 5 consecutive points between one and two sigma limits
- Rule 4:** Seven or more consecutive points on one or the other side of the mean
- Rule 5:** Seven consecutive points trending up or down

**Rule 5:** Seven consecutive points trending up or down



**Figure 3:** Control chart of permanganate number tests showing 5 common control chart rule violations

Examples of these rules are illustrated in Figure 3. While this is a brief overview of SPC, be assured the metrics and methodologies are well established, and the conclusions drawn have a robust statistical foundation.

### PAPER INDUSTRY IMPLEMENTATION STRATEGIES

The first step in integrating SPC methodology in a mill is creating a team of dedicated and vertically aligned employees, from mill operators to senior leadership. This team receives thorough training and preparation in SPC fundamentals.

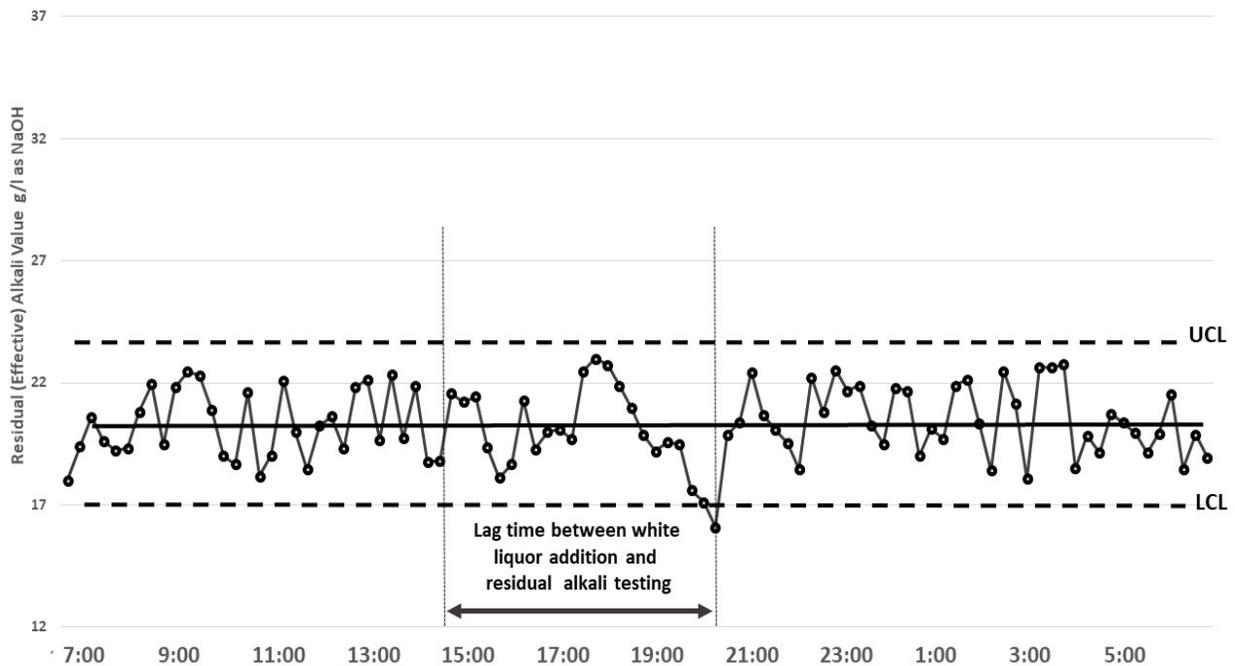
The initial project should study an area of the operation that *clearly benefits the customer*. The mill team might choose a process variable or test specification to follow. If a test specification is chosen, renewed training around that variable with the quality control testers should follow. This ensures all testers are getting the same results. It also increases understanding of the inherent variability in the test procedure. Start small, pick a variable that will be understood by the entire mill organization. [Note: There are suggestions for possible candidate variables to consideration later in the study.]

After solid success from a few projects, confidence using SPC will grow. Then this team will be prepared to train the next groups until SPC is integrated throughout the organization.

### USE OF CONTROL CHARTS

#### Tracking Variables

Using a pulp mill example, imagine tracking a residual alkali (EA) sensor following cooking in a continuous digester. This test is important to your customer: the bleach plant and/or the papermill. The frequency for the alkali analyzer provides a summary average of EA every five minutes.



**Figure 4:** Control chart of residual alkali 15-minute sensor summary (3 test values) from blow tank of Kamyr digester

Using historic data, a control chart is developed after accumulating 30+ test averages values (3, 5-minute tests / 15 minutes; i.e. 90, 5-minutes tests) Data for this process could look like the one used in Figure 5. Using each point as an average of three tests (n=3), the control chart is designed with appropriate limits using the formula:

**For control chart for sub-group=3 X values:**

**For control chart for sub-groups =3 running ranges:**

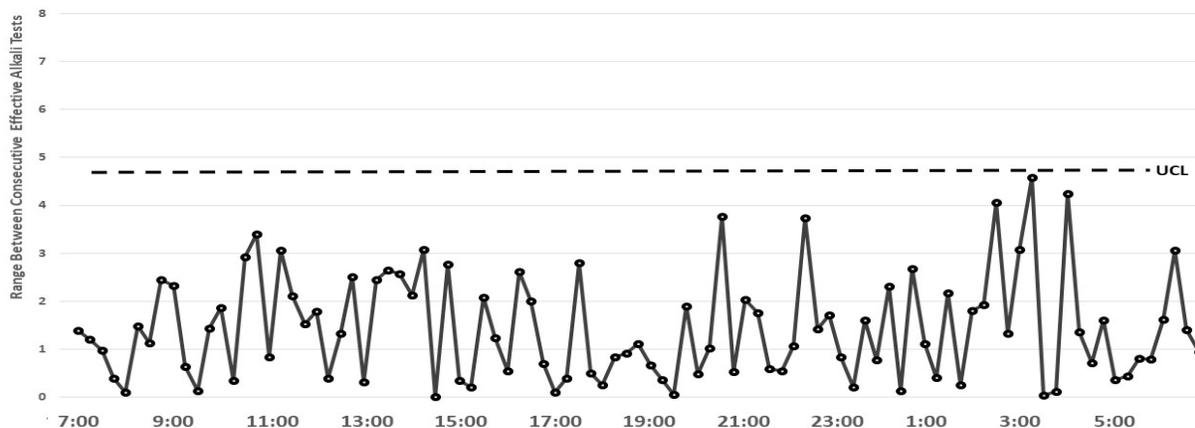
$$UCL_X = \bar{X} + A_2 \bar{R}, \text{ where } A_2 = 1.02$$

$$UCL_R = D_4 \bar{R}, \text{ where } D_4 = 2.57$$

$$LCL_X = \bar{X} - A_2 \bar{R}$$

$$LCL_R = D_3 \bar{R}, \text{ where } D_3 = 0$$

On Day 2 of SPC, the pulp mill operator observes that at 9:00 am (Figure 5) a point that clearly exceeds the  $3\sigma$  limits on the low side. In fact, during further inspection of the test pattern, it's clear that the EA value was heading downward over the past hour. The range chart (Figure 6) fails to show any out-of-control pattern due to the fact it was a “slow trend” out-of-control. The difference between adjacent points was not large enough to be flagged on the range chart.



**Figure 5:** Range chart of residual alkali values from Figure 4

What does the mill do now? An SPC teammate (perhaps the operator or a technical lead), who has familiarity with that part of the mill process is tasked to take the lead on investigation of the special cause of variability. By design, we “mirrored” the special cause investigation process strikingly similar to the safety investigation process already at use in the mill (the special cause investigations format was designed by the first SPC team earlier during training).

Because the SPC team had already strategized the variable to be tracked, the team knew the things to question when a low- or high-test result exceeded limits or violated one of the 5 Rules for Control Charts.

- What was the white liquor strength issue feeding the digester 5.7 hours before (lag time at this production rate pre-established)? Go to the DCS.
- Was it a sensor issue? Make a manual test to compare.
- Was it a chip quality issue, such as change of species or an older chip supply exposed to higher levels of biological activity consuming more alkali? Talk with the woodyard operator.
- Could the digester be running hotter, accelerating reaction rates? Check the DCS ... and so on.

Depending on this quick initial look, factors upstream of the blow tank could be studied that, most logically, would exhibit an impact on out-of-control events. Once upstream candidate causes are identified, the team could re-create this event in a limited way for a short time to compare these results with the process at a steady state. Working with operators, the team works to first define the root cause and then develop a strategy to soften or eliminate this as a future problem.

Once several sources of special cause variation are eliminated by the team, the mean ( $\bar{X}$ ), or average for the variable being tested, will shift to a mean having lesser variation. While analysis of variance [ANOVA] tests can be used to compare initial to current mean populations, it is usually a visual decision by the team to recalculate control limits based on the current diminished level of process or product variation.

Using Pareto's 80/20 Rule, experience suggests there are 4-to-5 special cause variables that, once identified, remove 60-80% of the variation. These initial investigations are essential to ongoing product quality. Customers will begin to see the benefits in product consistency... without a word being said.

## **HONEYMOON PERIOD WITH SPECIAL CAUSE VARIATION**

SPC purists demand that all product exhibiting special cause variation be reworked or discarded. In advance, we suggest (hesitantly) the mill commits to a "softer" approach. If the product exhibits special cause variation yet meets all customer specifications, we suggest that it be sold as "good" product. This assumes the investigation and resolution of the upstream special cause is completed in three to five working days. Again, the customer will shortly realize the benefit of a more consistent process while all the test specifications are in acceptable range.

The honeymoon ends when the average variation on a major test result, clearly defined as quality-improvement-meaningful to the customer, is reduced by 70%. The out-of-control points should be minimized and far less frequent. In the early phases of implementing SPC, the mill was given a "free-pass" on special cause variation. Now, tightening the reins on the mill's standards may be a challenging to personnel who have to manage SPC. Therefore, communication is critical at every step.

The biggest problem with the "honeymoon" period is that it condones the mill's acceptance with out-of-(statistical) control product. Up to this time, the effort had softer rules. Now it teeters on the edge, between future success or failure based upon the organization's response to when future special cause variations are observed. It is critical that the results of special cause investigations are met with an appropriate and meaningful response in order to create a sense of importance and urgency while maintaining process and management's integrity.

In many discrete parts of manufacturing (i.e. car parts, computer parts, etc.), the batch of parts is identified, pulled from the assembly and reworked (replaced as part of an assembly) or discarded. In a paper mill making product that is in specification but out-of-control, how do we create a sense of urgency without repulping the affected product? Product could be discounted to the customer, since they understand why we are doing it. This gives the SPC team the drive to pursue the "special cause," ultimately, going after the root issue. Creative solutions can be developed, but management's integrity around "penalty" standards is all-important to create the cultural change that instills this methodology as part of the mill's unwavering commitment to SPC.

## **KEY VARIABLE TO TRACK**

What consumers like about quality and what drives their purchasing decision is the consistency it affords them. From famous examples of hamburgers to automobiles to electronics, consistently setting and meeting expectations is critical. Can we wrap all of our forms of variability into one variable for the sake of our customer? We think so. Move forward to your paper mill (or final exit QC test, if you're a market pulp mill).

The dry end machine scanner creates an machine direction (MD) and cross direction (CD) statistic during the completion of each reel. This describes the variability found in each direction. This statistic can be outputted to a data historian. We've used this to quickly reduce reel variability.

In Figure 6, the dry end MD scanner data from a recycled mill was put into a control chart. We had suspicions that consistency swings from the stock prep area was a contributing cause in the mill's struggle with quality. The chosen summary statistic to track was the machine direction long-term statistic (MDL).

After the mill’s historian database captured the data, the scanner’s MD variation statistic was displayed on a meter-wide, red LED display in both the mill’s board machine room and stock prep area. We planned to capture the baseline data over a 10-day period to create the necessary base data for the control charts. For the first time ever, the stock prep crew could instantly and visually assess the short-term feedback from the machine’s dry-end scanner display and manage consistency and variability from stock prep.

When we accumulated enough base data and were ready to construct control charts, we saw a reduction in the MD scanner statistic by 45%. This reduction is seen in Figure 6. Since the mean values had shifted dramatically, it was necessary to collect more data to reflect the new reduction in variability, a small price to pay for major improvements in product quality. Once the new control limits were established, the mill went on to find further “special causes,” improving converting quality along the way.

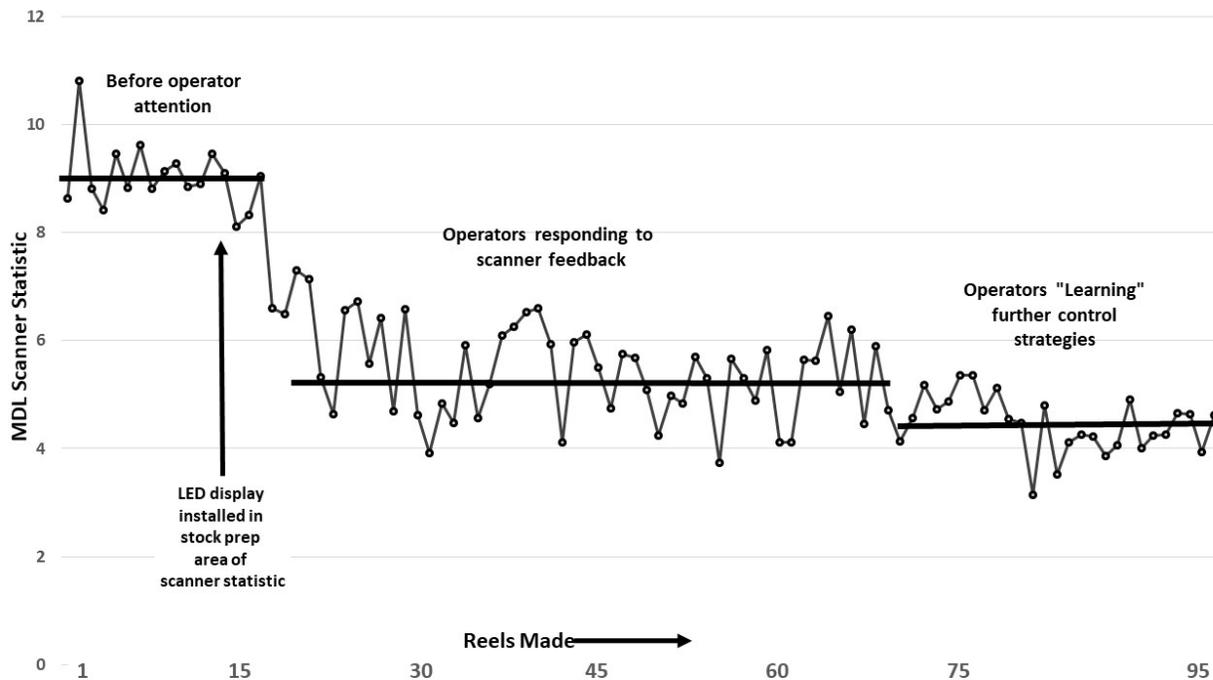


Figure 6: Control chart of dry-end scanner MD basis weight variability statistic for reels of paperboard

## LEADERSHIP – THE ESSENTIAL INGREDIENT

Japanese mavens of manufacturing quality were asked to comment on the early efforts of U.S. manufacturing firms to adopt the methodologies around SPC, lean manufacturing, etc. They responded that leadership drive to instill customer focus was lacking. At best, they considered our leadership “distracted” in our cultural attempt to “try” quality, while not subordinating competing forces, such as quarterly profits. Deming often quoted Ronald Moen who said “Beware of conference-room promises.” [6]

It is the personal, unwavering, long-term commitment of the leadership of the organization, including the board, that will guide the organization on a sustainable quality path – the journey never ends. Organizations must realize that a dramatic and sustained shift toward customer needs and welfare are above all else. Satisfying the customer is the business plan and all business activities rise to support it.

When an organization wants to use SPC to guide the quality of their customers’ products, they must:

1. Have organizational leadership at the highest level who fully understand, embrace and visibly support SPC initiatives. Their passion must be evident and unwavering.

2. Be driven by strength of leadership and clarity of message. Stick to the process when other competing and compelling issues arise.
3. Demonstrate a unique focus to SPC initiatives. While one might think the damage would be minimal, short-term focuses, such as mill site productivity and other such competing goals, must be subordinate to the support for and improvements shown by SPC.
4. Adjust staff compensation formulas to value full SPC implementation and organizational development.
5. Provide for ample staff training. It begins in small, targeted areas, where the most important variables being tracked are found.
6. Allow interest to grow by word of mouth and successful results.
7. Be quiet / no banners or claiming victory “parades”. Let your customer feedback, albeit delayed, be the wind in the sails of expanding SPC.

## CONCLUSION

It is time for a new generation of paper industry leaders to harness the power of SPC. Its effectiveness for improving a mill’s product quality leads to a new customer experience due to the unique level of sheet quality. Embracing a comprehensive quality process like SPC requires extraordinary leadership to protect the implementation in its infancy and foster its progress for the long-term. SPC sparks employee engagement. They develop a higher level of process understanding and build life-long, critical problem-solving skills. Most gains in variability reduction are done without the need for capital funds, so they can be implemented quickly, with little cost.

Employing SPC generally takes a short time to see major reductions in special cause variability for both products and processes. Reductions in waste and the costs associated with them are the lasting benefit.

## ACKNOWLEDGMENT:

If anyone looks into the history of statistical process control (SPC), one sees the giant, W. Edwards Deming, a descendant of a Massachusetts’ pilgrim, who as a child developed deep rural Wyoming roots. He brought Walter Shewhart’s Bell Lab fundamental work on control charts, to life. His commitment, belief and persistence in a yet unrecognized data-driven process, even after massive rejection by American corporations in the late ‘40s, demonstrated his unwavering example of the “scrappy” leadership we should all emulate. To him, we doff our hats, in respect and admiration. Thank you, Dr. Deming!

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6. Deming, W. E., Quote attributed to Moen, R. “*Out of the Crisis*, MIT Center for Advanced Engineering Study (Press), Boston, Mass, USA (1986)

Gateway to  
the Future

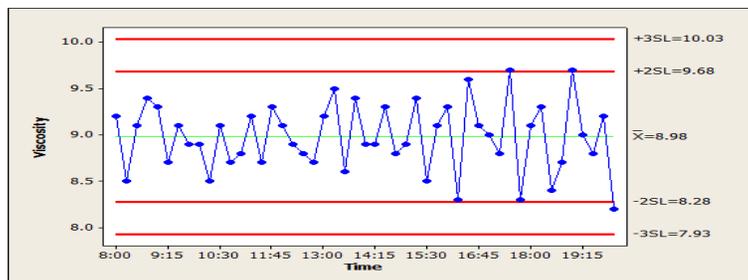
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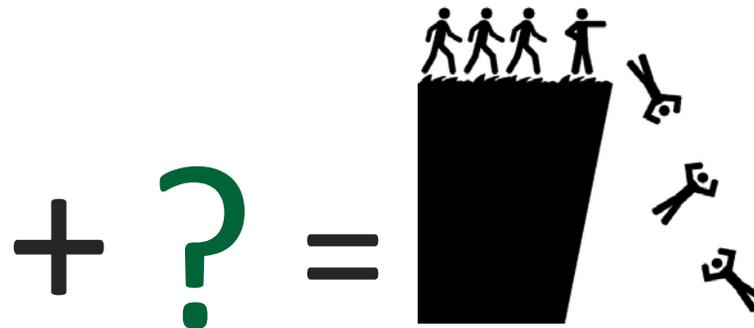


# History of SPC in the US

- Introduced in early 1980s
- Flurry of initial response
- Plans of how to manage SPC were not thought out
- Leadership had not counted the cost
- Rapid disengagement

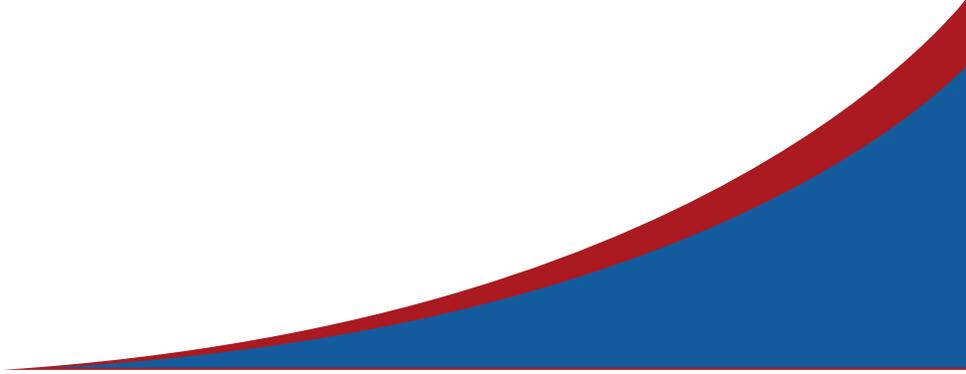


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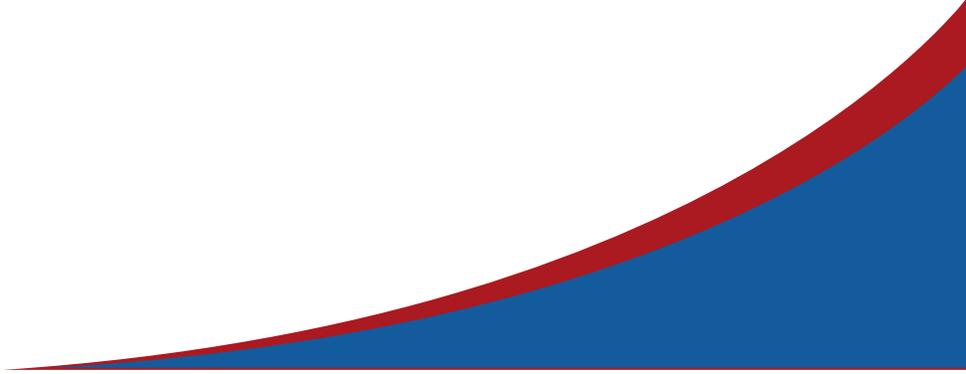
What is **Statistical Process Control (SPC)**?





## SPC

*A systematic method for identifying and eliminating meaningful and actionable variation*



# SPC Basics

## **Filter on variation**

- Important to customers
- We can effect and eradicate

## **Two kinds of process variability:**

- Common cause
- Special cause

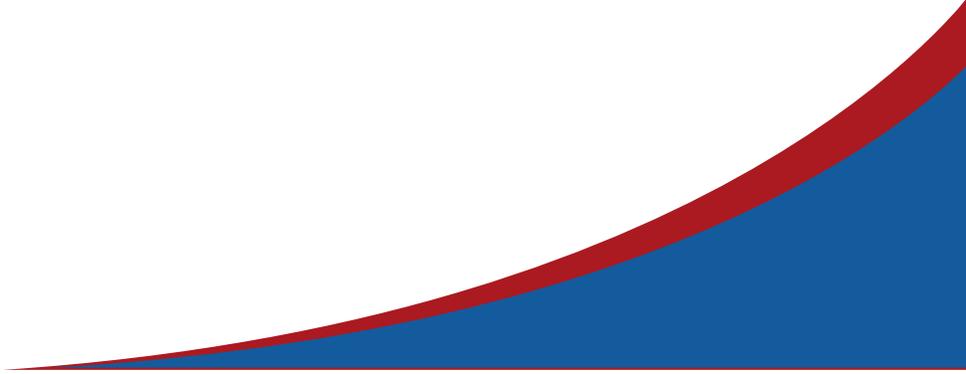
## **Data collection on few important process variables:**

- Control Chart
- Range Chart

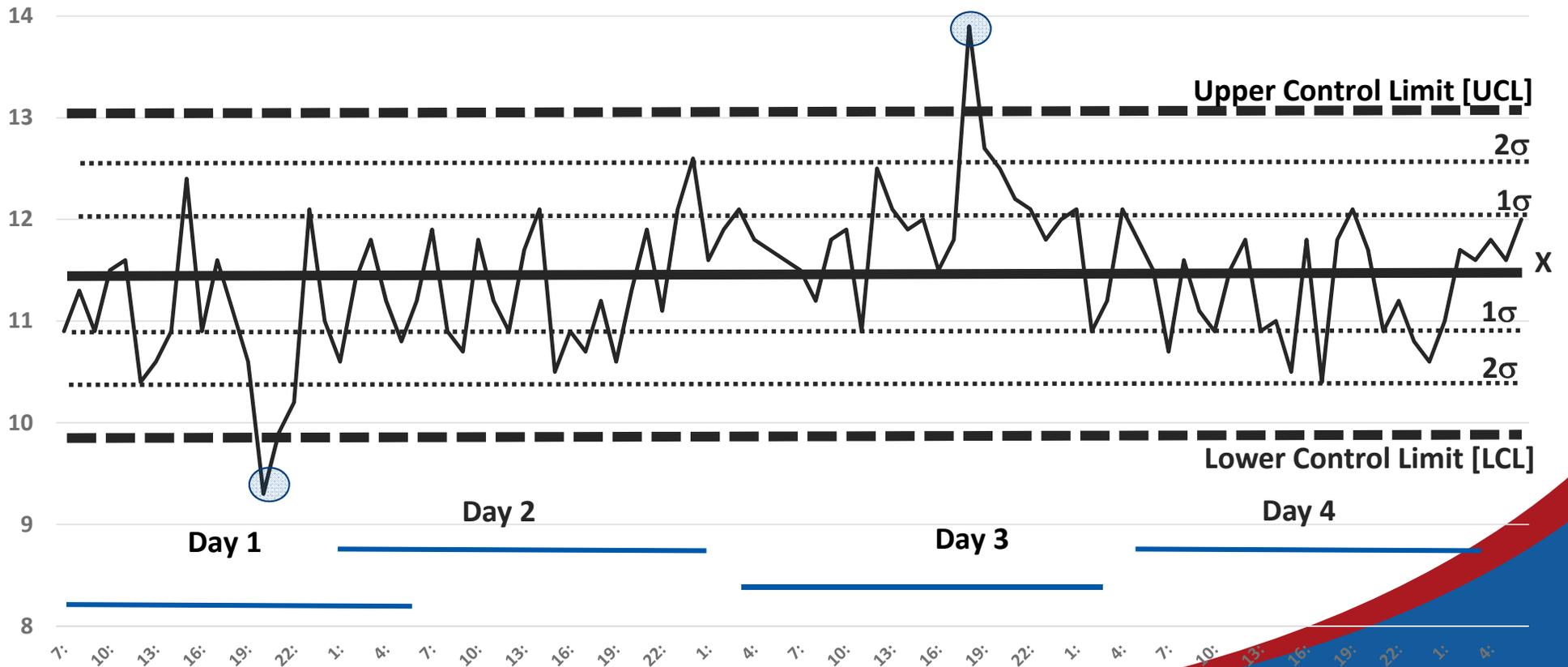
**Fundamentally sound approach – across many industries**



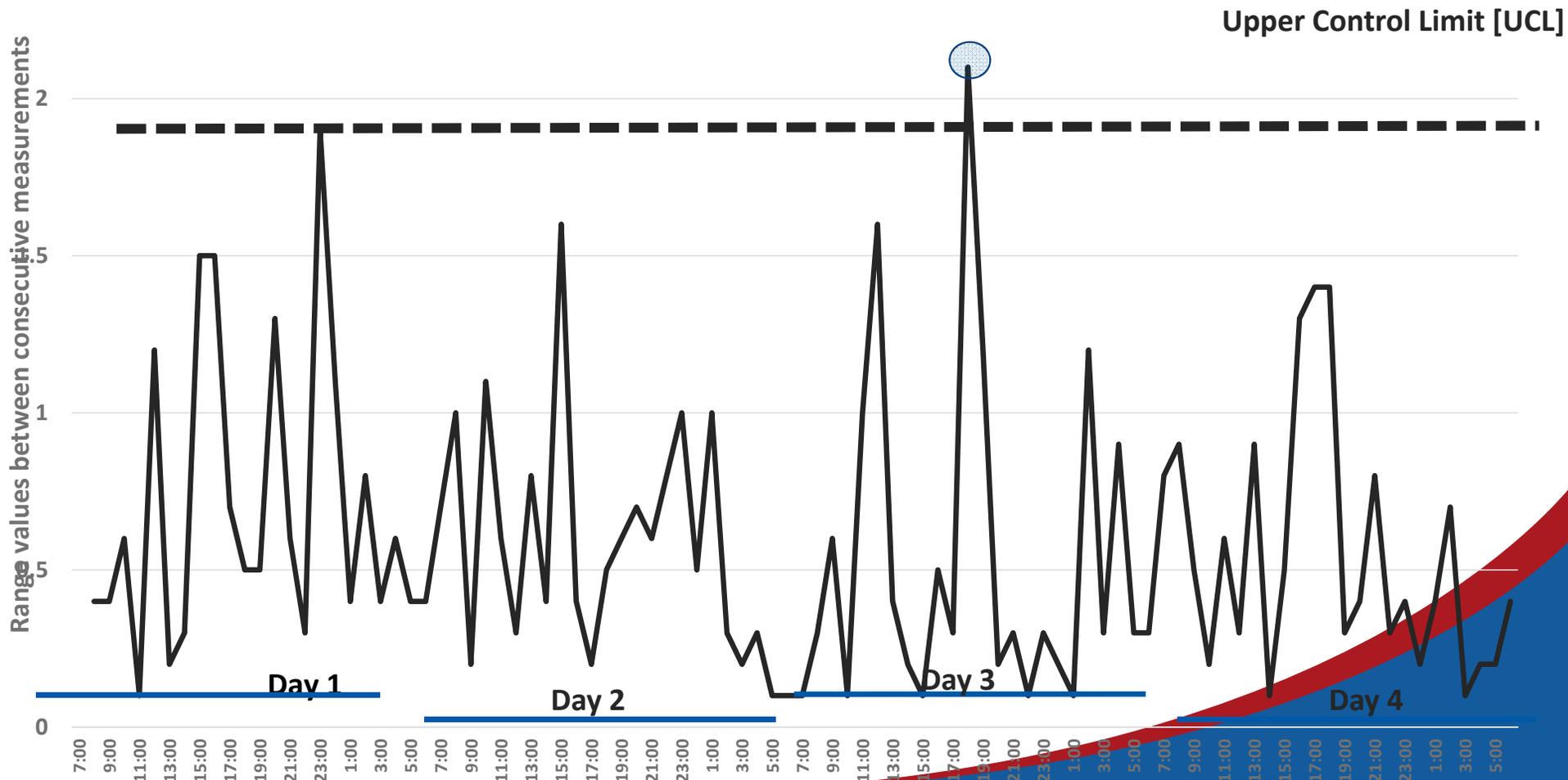
# Tools Used in SPC



# Typical Statistical Process Control Chart for Individuals

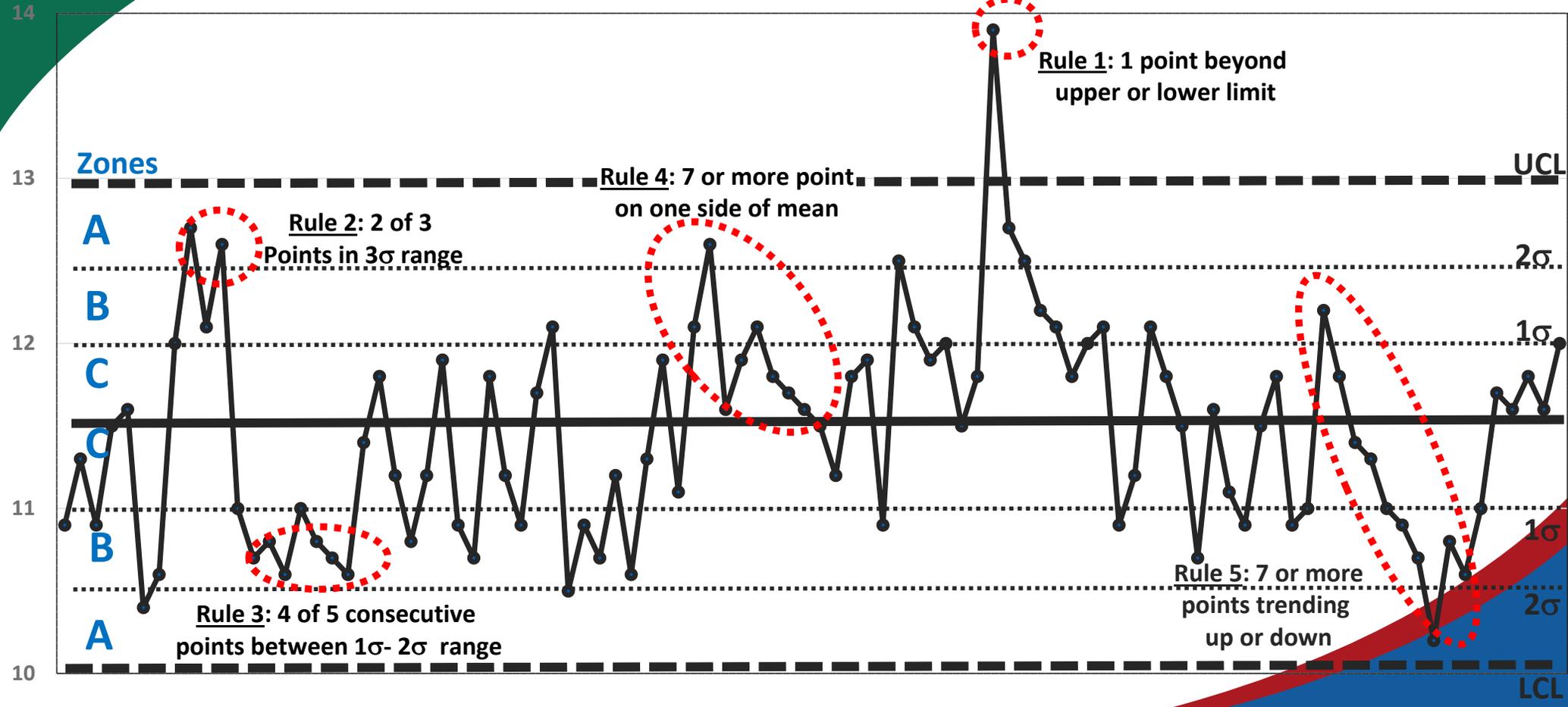


# Typical Statistical Process Range Chart for Individuals



# When is Your Process Out of Control? - 5 Common Rules -

14



Zones

A

B

C

C

B

A

Rule 2: 2 of 3  
Points in  $3\sigma$  range

Rule 4: 7 or more point  
on one side of mean

Rule 1: 1 point beyond  
upper or lower limit

Rule 3: 4 of 5 consecutive  
points between  $1\sigma$ - $2\sigma$  range

Rule 5: 7 or more  
points trending  
up or down

UCL

$2\sigma$

$1\sigma$

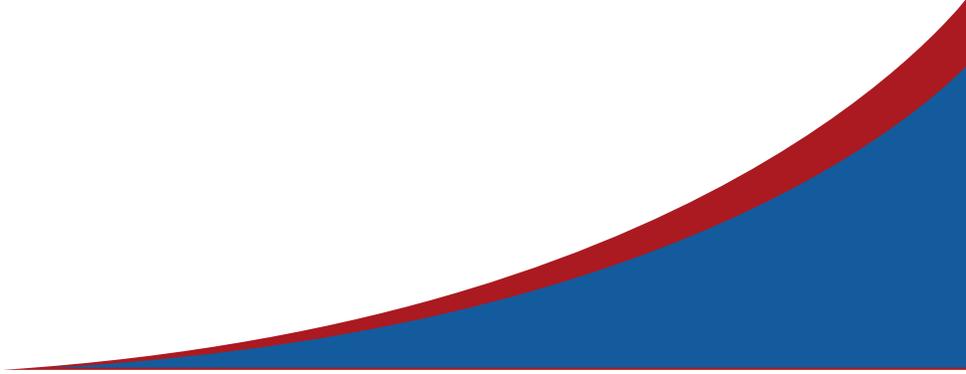
$1\sigma$

$2\sigma$

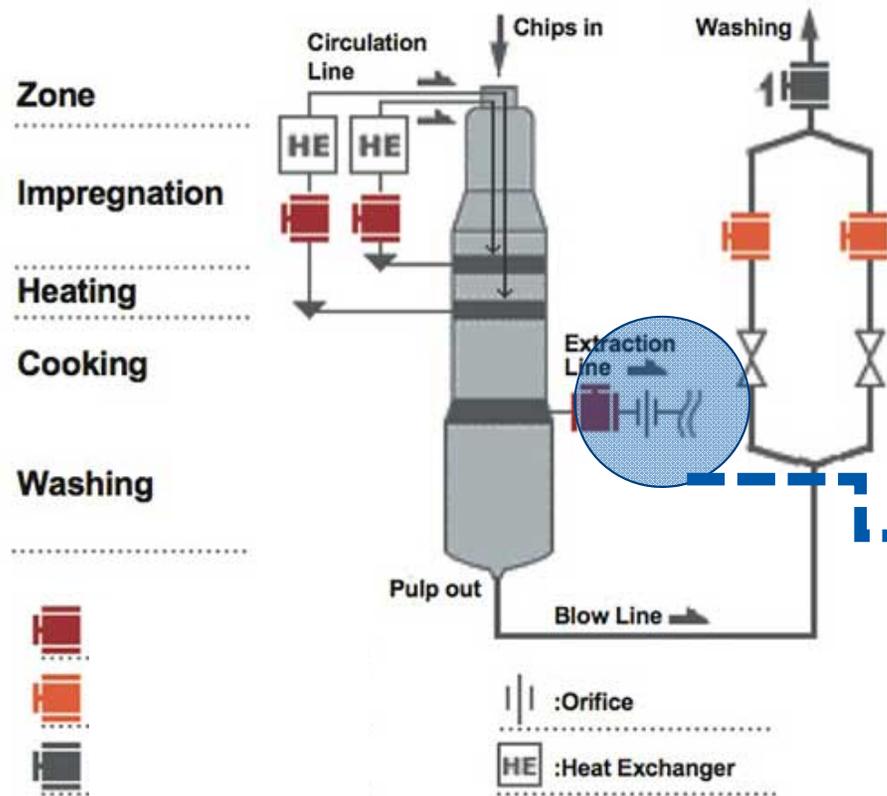
LCL



# Applying SPC in Processes



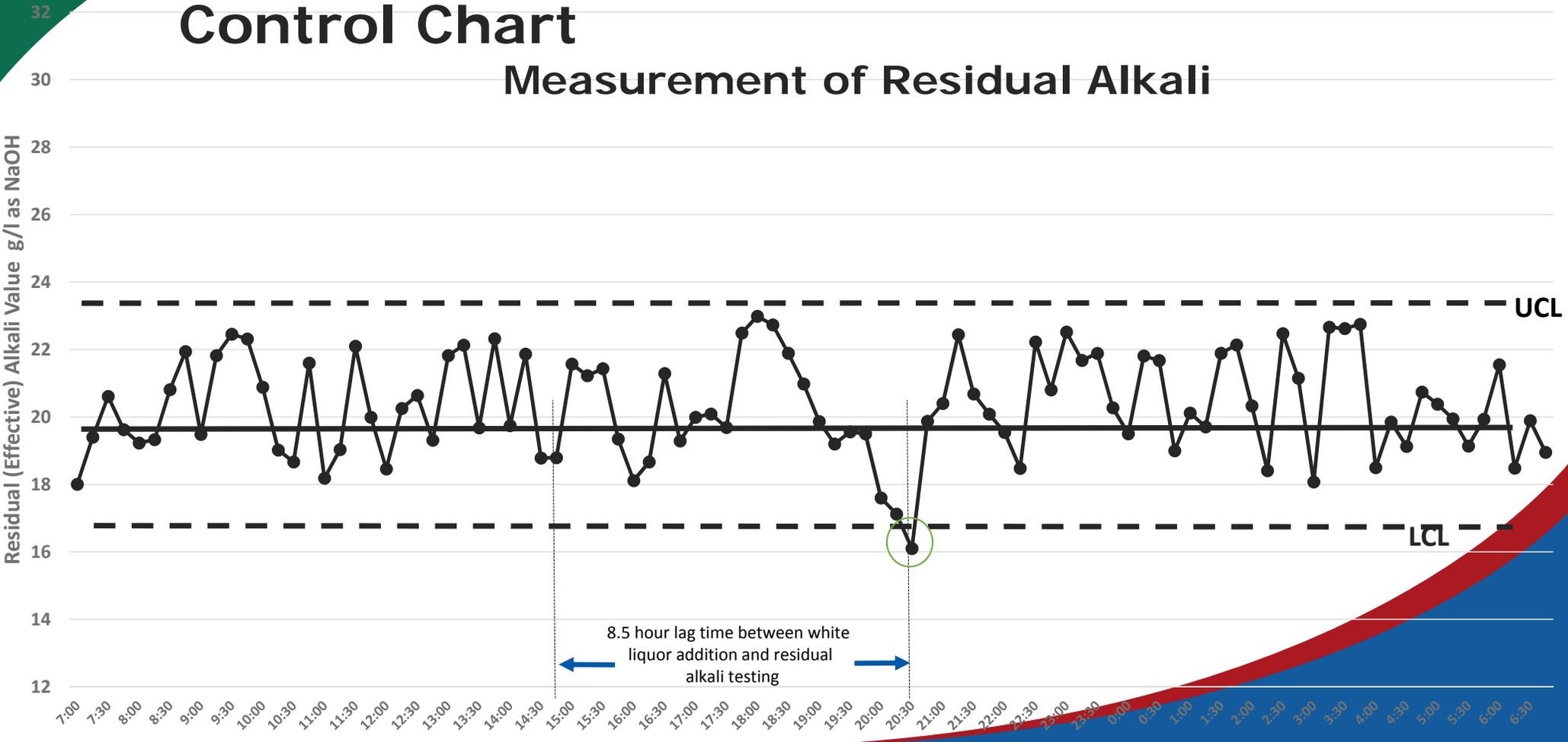
# Example: Continuous Digester Residual Effective Alkali Strength



- Auto sampled at exit of cooking zone
- Stream Sampling Rate:  
Each 5 minutes
- Display Composite Rate:  
Each 15 minutes, n = 3

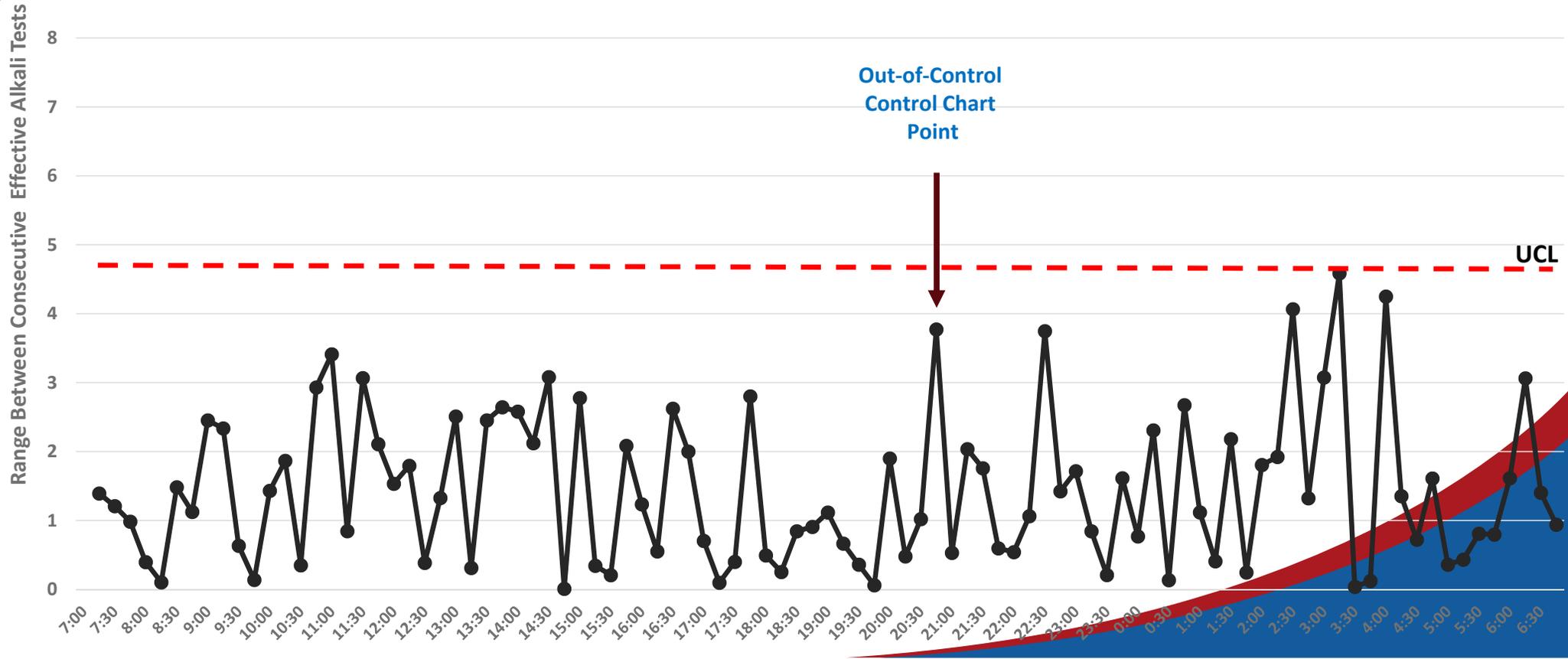
# Responding to a Special Cause Event on Control Chart

## Measurement of Residual Alkali



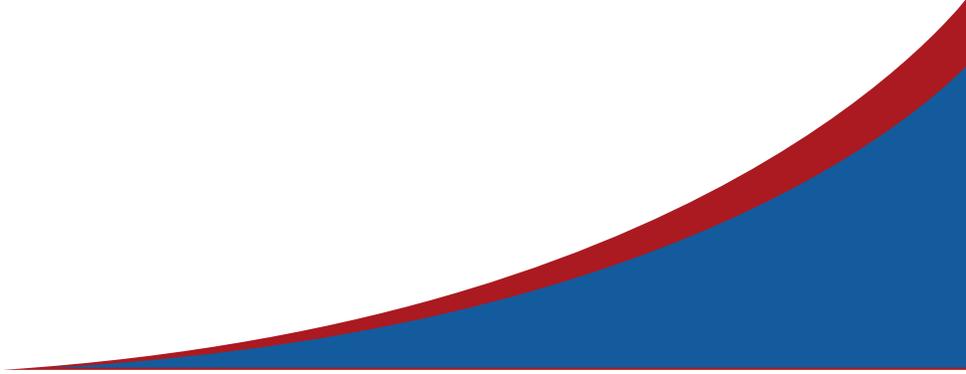
# No Out-of-Control found in a Range Chart of Same Process

Measurement of Residual Alkali





# **SPC Implementation**



# Where to begin SPC?

## At the Mill:

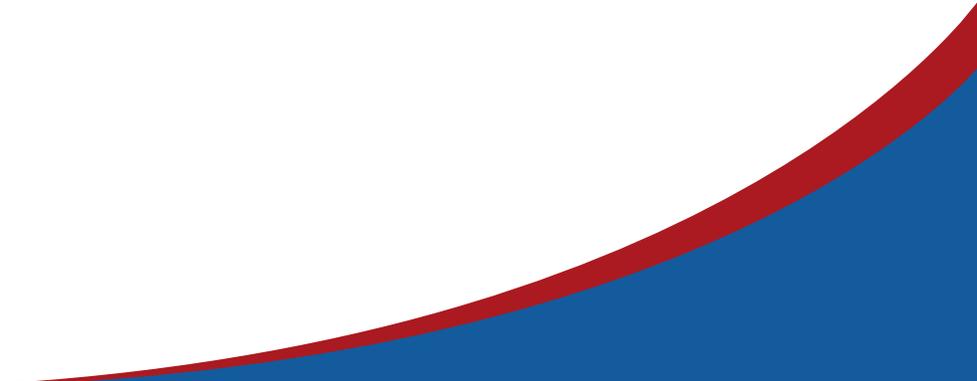
1. Start small with a vertical team
2. Provide training for full team
3. Model “out-of-control” event investigations after safety approach

**Choose customer-centric candidate variable to track**



# Phase In SPC Consequences

## **Suspend strict SPC protocol for out-of-control events**

- Spec vs. rule driven
  - Response to statistical process excursion
  - Cut over to full implementation
- 

# Candidate Mill Variable for Consideration

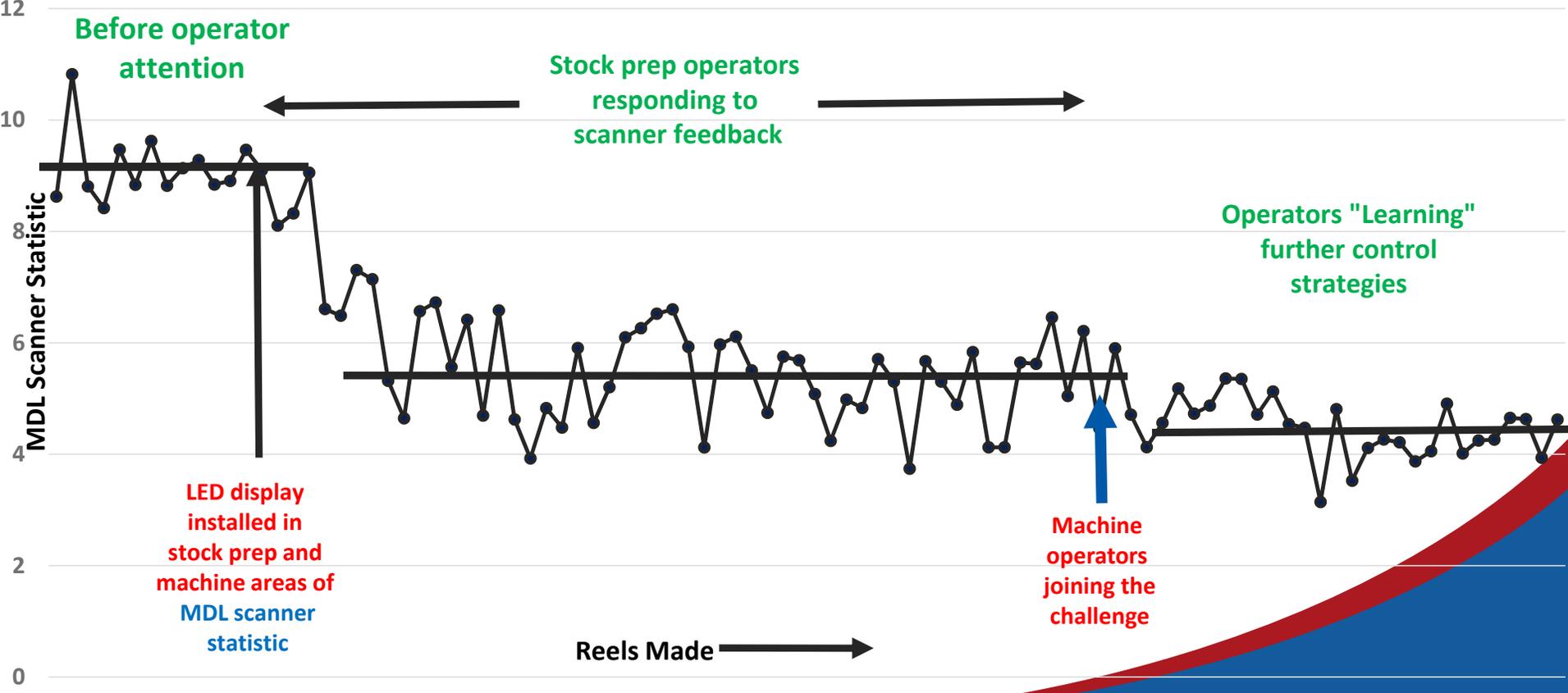
**SPC starts with the customer!**

## *Recommendation:*

**Consider machine-direction, dry-end scanner statistics (MDL)**

- Basis weight variability has the greatest impact on product quality
- MDL is process-comprehensive measurement for each reel

# Recycled Mill Example Using MDL Scanner Statistic



Before operator attention

Stock prep operators responding to scanner feedback

Operators "Learning" further control strategies

LED display installed in stock prep and machine areas of MDL scanner statistic

Machine operators joining the challenge

Reels Made

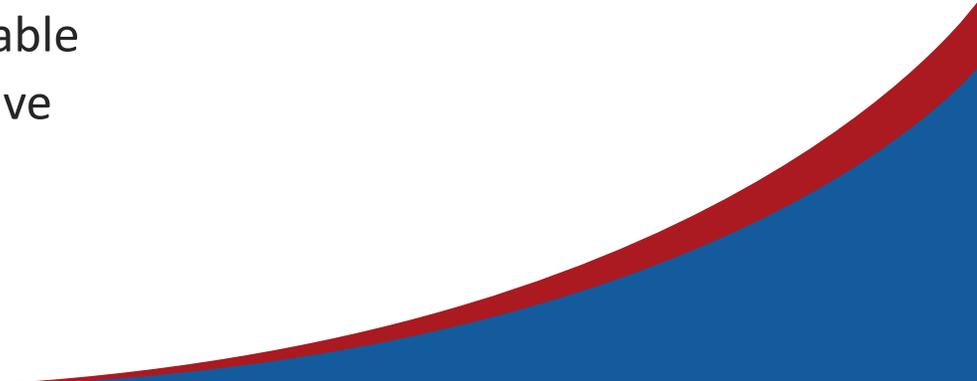
# The Essential Ingredient → LEADERSHIP

- **Driven by senior leadership**
  - Responsible for the “system”
  - The “system” is redesigned to serve the customer
  - Believers in the process - Continually focused and involved
  - Defend against competing priorities
  
- **Humility**

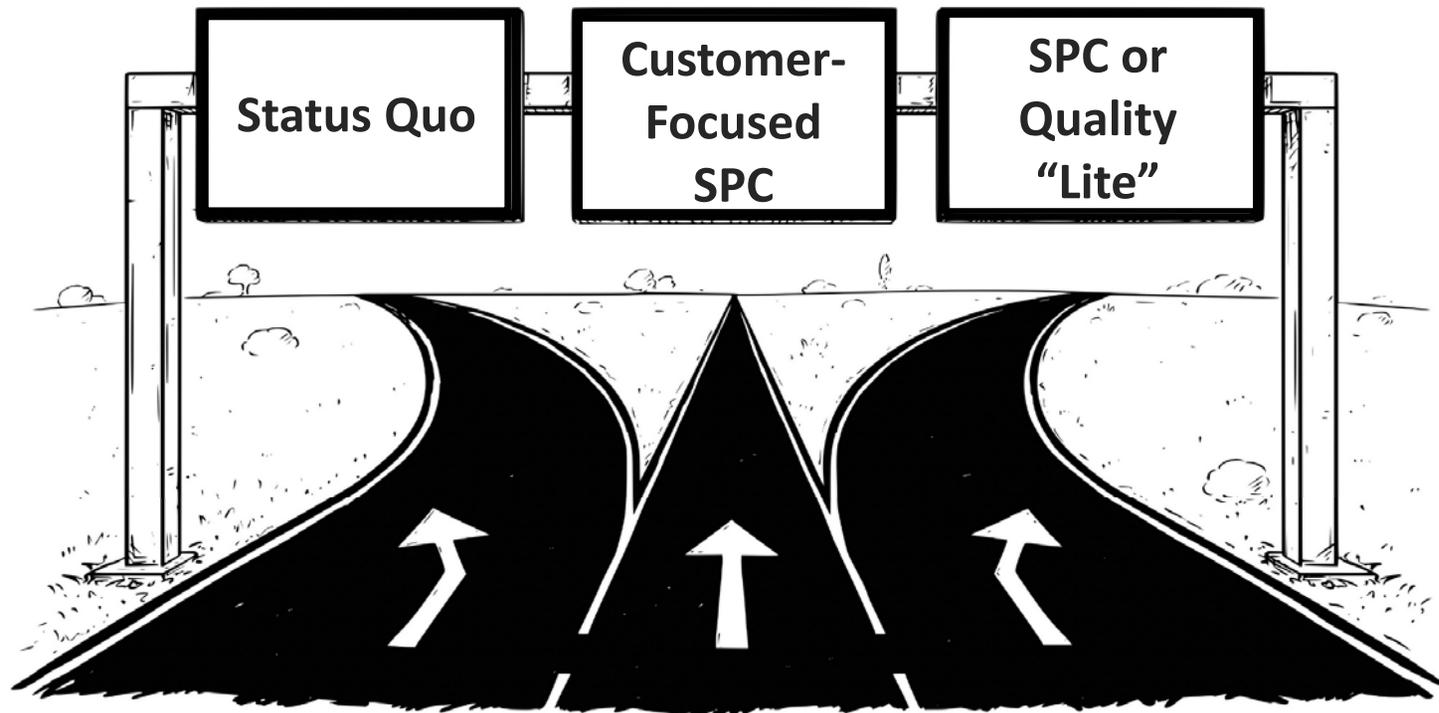




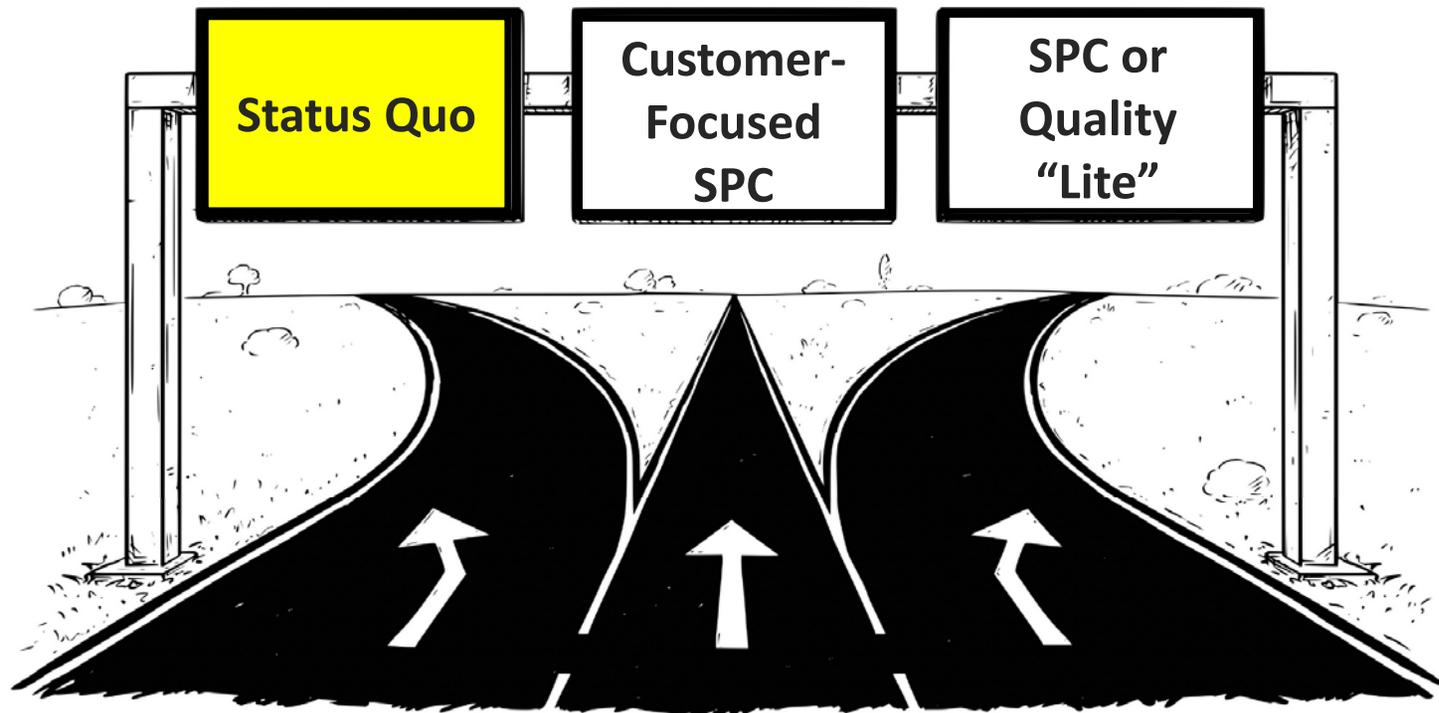
## Change is inevitable

- ❖ Our industry's reaction in 1980 has no bearings on our actions today
  - ❖ We are now competing on a world stage where we can no longer write the playbook
  - ❖ Those that continuously reduce their product's variability will win
    - Customer loyalty – make them successful
    - Ridding of “waste” – become more profitable
    - Run more stable – become more productive
- 

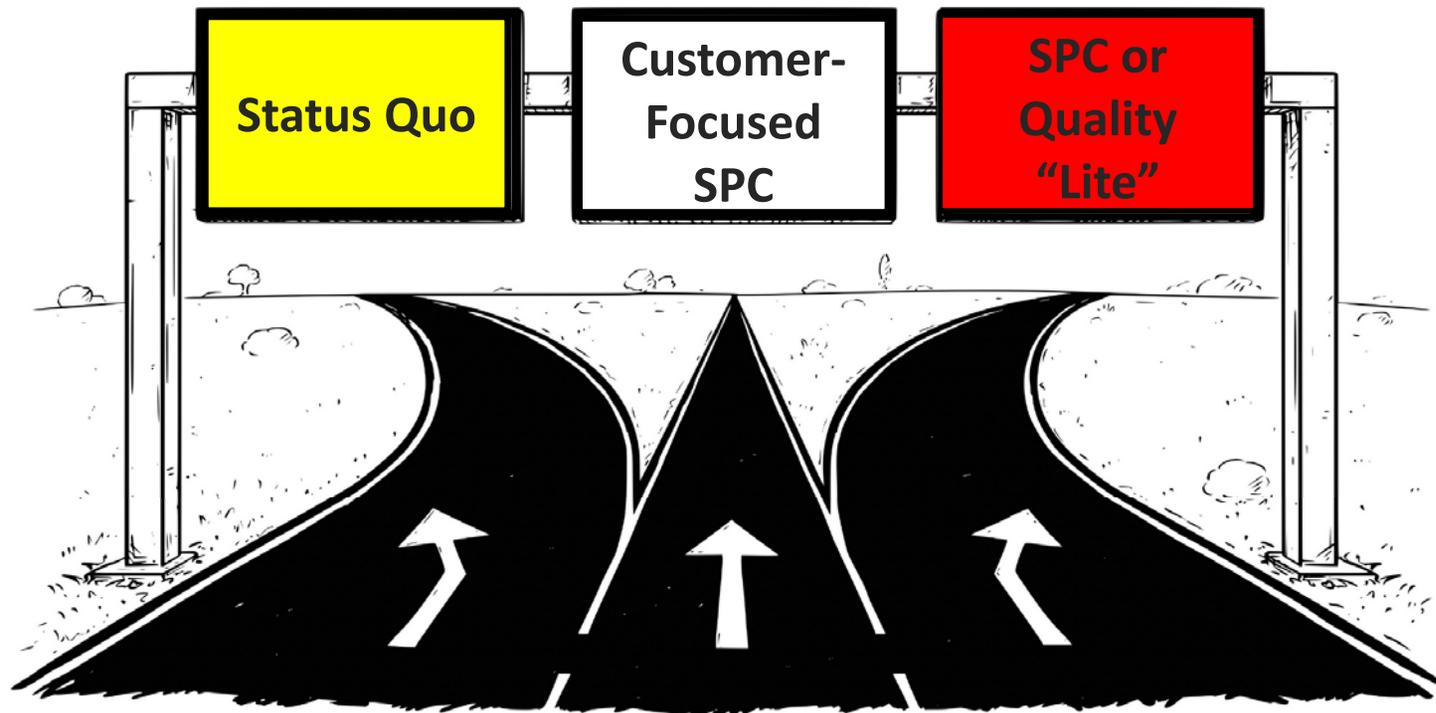
The road to the future lays before us...  
and splits into three paths



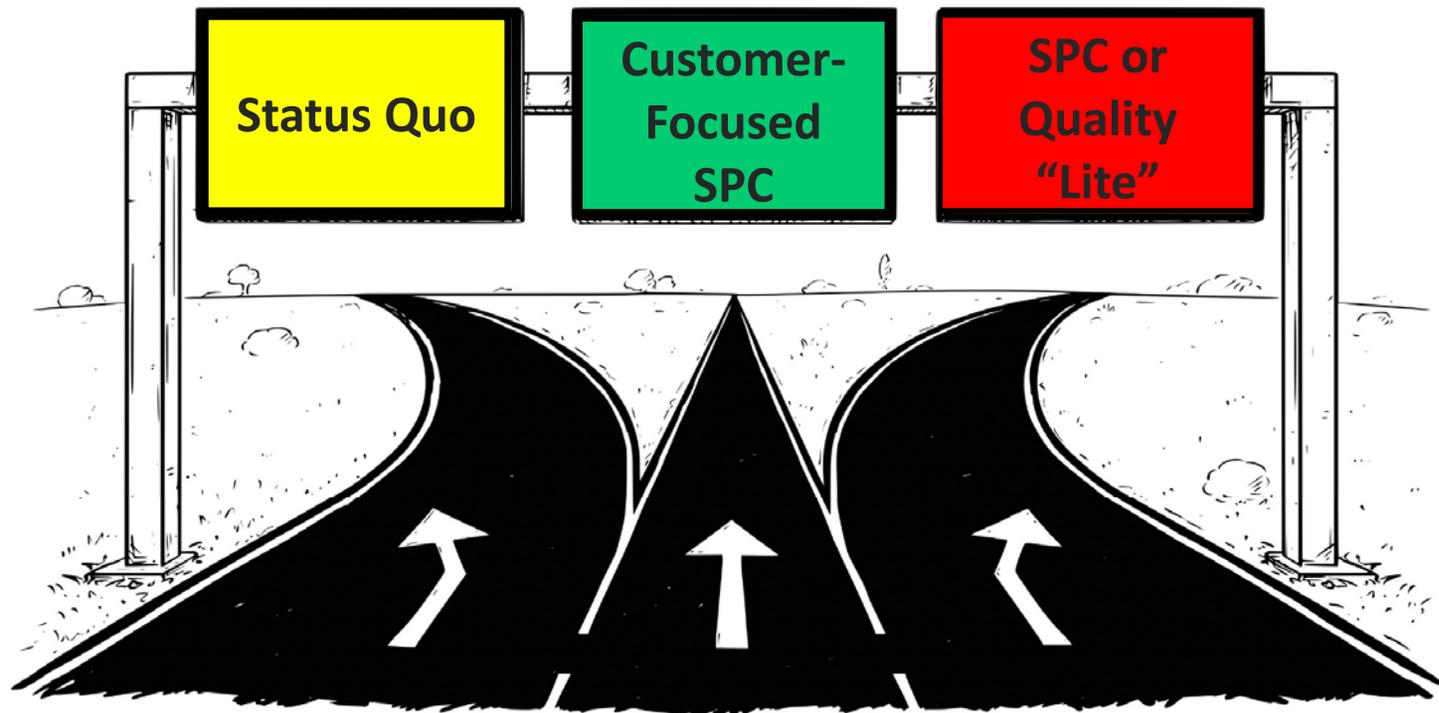
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## **Journey Down the Center Path – embracing SPC as a customer-driven process**

- ✓ Cultural change will be hard and demanding
- ✓ The activities of most people in the organization will change
- ✓ Leadership will continue to hone the “system” and operations will make the “system” fit the needs of the customer
- ✓ A never-ending profitable and productive effort



## The Road our Industry must take lays before us

- **We must become far-more customer-centric**
  - **Leadership at all levels must embrace the process**
  - **We must trust the process, keeping true to our path**
- 

Gateway to  
the Future

Our “Gateway to the Future” is SPC

Are YOU going to be part of it?



# Questions or Comments?

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