Using Statistical Process Control (SPC) for improved Utility Management

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Hach Company

Manage and Transform *data into information* to gain efficiencies
Data, Data Everywhere

• We track enormous amounts of data about our systems
  – Lab for regulatory and to check process
  – Online / SCADA for real time control
  – Operator observations and tests

• Since we have collected all this data – How can we use it to:
  - To Save Money
  - Improve Water Quality
Use SPC as part of Continuous Improvement

What is Statistical Process Control (SPC)?

A method of quality control which uses statistical methods. SPC is applied in order to monitor and control a process. Monitoring and controlling the process ensures that it operates at its full potential thus eliminating waste.
Utilize SPC Principles as part of Plan-Do-Check-Act

Use Statistical Process Control (SPC) Techniques to better understand your systems.

The goal of SPC is to identify when we need to look deeper into a situation or is this just “noise”.

- With properly set control limits, we can identify when the process has shifted or become unstable. With this knowledge, we can then study that particular situation (known as a “special cause”), identify root cause, and come up with a plan to minimize or eliminate these occurrences.

- Walter Shewhart (founder of statistical quality control) found that control limits placed at three standard deviations from the mean in either direction provide an economical tradeoff between the risk of reacting to a false signal and the risk of not reacting to a true signal – regardless the shape of the underlying process distribution.
Some Examples on How to Use SPC

• If the process has a normal distribution, 99.7% of the population is captured by the curve at three standard deviations from the mean. Stated another way, there is only a 0.3% chance of finding a value beyond 3 standard deviations. Therefore, a measurement value beyond 3 standard deviations indicates that the process has either shifted or become unstable (more variability).

• Examples of parameters to look at using SPC:
  • Effluent Quality Parameters – BOD, TSS, etc..
  • Finished Water Quality Parameters – Turbidity, Cl₂, etc…
  • Wastewater Process Parameters – MLSS, SRT, F/M
  • Variance between Process and Lab Results
  • Benchmarks - Total Operating Cost/Treated Water, BOD Removed / KWH used

• ….?????
Creating a control chart

Control limits are defined as follows:

• Upper Control Limit (UCL) – Average + 3 * Standard Deviation
• Upper Warning Limit (UWL) – Average + 2 * Standard Deviation
• QC Mean – Average
• Lower Warning Limit (UWL) – Average - 2 * Standard Deviation
• Lower Control Limit (LCL) – Average - 3 * Standard Deviation

Your initial QC Limits should be calculated
• From data when the process was running well
• Contains 20 or more data points
• Takes into account seasonal changes to process
How to calculate Standard Deviation

1. Calculate the Average of historical data
2. Find the difference of each value from the average
3. Calculate the Variance – The average of the squared differences
4. Take the Square Root of the Variance

- Usually 68% of samples will fall inside one standard deviation from the mean
- 95% fall within two standard deviation from the mean
- 99.7% fall within three standard deviation from the mean

- Software packages such as Excel (STDEV function), Hach WIMS, etc… make the calculation easy.
Lab - Calculate the Standard Deviation

<table>
<thead>
<tr>
<th>Date</th>
<th>Effluent TSS (mg/L)</th>
<th>Difference Value - Avg</th>
<th>Variance Difference ( ^2 )</th>
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<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>-12</td>
<td>144</td>
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<tr>
<td>2</td>
<td>25</td>
<td>-11</td>
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<td>3</td>
<td>28</td>
<td>-8</td>
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<td>4</td>
<td>41</td>
<td>5</td>
<td>25</td>
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<td>5</td>
<td>42</td>
<td>6</td>
<td>36</td>
</tr>
<tr>
<td>6</td>
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<td>7</td>
<td>50</td>
<td>14</td>
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<td>39</td>
<td>3</td>
<td>9</td>
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<td>9</td>
<td>40</td>
<td>4</td>
<td>16</td>
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<tr>
<td>10</td>
<td>31</td>
<td>-5</td>
<td>25</td>
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</table>

**SUM** 360

**AVERAGE** 36

Average Variance: 65.2

Standard Deviation (Square Root of Variance): 8.074651695
### Lab - Calculate Control Limits

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AVERAGE</strong></td>
<td>36</td>
</tr>
<tr>
<td><strong>Average Variance</strong></td>
<td>65.2</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>8.074651695</td>
</tr>
<tr>
<td><strong>UCL</strong></td>
<td>Avg + 3 SD</td>
</tr>
<tr>
<td><strong>UWL</strong></td>
<td>Avg + 2 SD</td>
</tr>
<tr>
<td><strong>LWL</strong></td>
<td>Avg -2 SD</td>
</tr>
<tr>
<td><strong>LCL</strong></td>
<td>Avg -3 SD</td>
</tr>
<tr>
<td><strong>Value</strong></td>
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</tr>
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<td><strong>60.22395509</strong></td>
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<tr>
<td><strong>52.14930339</strong></td>
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<td><strong>19.85069661</strong></td>
<td></td>
</tr>
<tr>
<td><strong>11.77604491</strong></td>
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</table>
Creating a control chart

Plot the Control limits and the Average
Creating a control chart

Plot new data sets on the chart
Interpreting SPC control charts

- All points above or below the Upper and Lower Control Limit
- 2 Consecutive points are above or below the Warning Limits
- 7 Consecutive points are on one side of the mean
- 5 Consecutive points are sloping in one direction

The following rules are derived from the “Western Electric Rules” - “The Western Electric Rules were codified by a specially-appointed committee of the manufacturing division of the Western Electric Company and appeared in the first edition of its Statistical Quality Control Handbook in 1956.[2] Their purpose was to ensure that line workers and engineers interpret control charts in a uniform way” - Wikipedia
SPC Charts

- All points above or below the Upper and Lower Control Limit:
SPC Charts

• 2 Consecutive points are above or below the Warning Limits
SPC Charts

- 7 Consecutive points are on one side of the mean
SPC Charts

• 5 Consecutive points are sloping in one direction
What samples indicate “Special Cause”
What samples indicate “Special Cause”

Point above UCL of 60

2 Points in a row below the LWL
What do we do with a “Special Cause”

It means that this is not normal. Therefore we should look into the root cause. It is a call to action.

Brainstorm and look at data. Potentially plot TSS vs key parameters (Influent Values, SRT, F/M, MLSS…).
Other SPC Charts

Histogram - Creates a picture of the data distribution
  • Normally distributed data should create a “Bell Curve”
  • Allows you to see outliers that may skew your averages

Individuals and Moving Range (I-MR) chart
  • Shows variability between one data point and the next

Correlation
  • Scatter plot with best fit line (or curve) used for prediction
Histogram
A Histogram shows the frequency of certain values or categories in a bar chart.
An individuals and moving range (I-MR) chart is a pair of control charts used to determine if a process is stable and predictable.

It creates a picture of how the system changes over time.

The individual (I) chart displays individual measurements.

The moving range (MR) chart shows variability between one data point and the next.
Correlation chart

Plots pairs of points and draws the best fit line thru the points.

Here we see that as rainfall increases so does our flow. The equation for the line is shown and can be used for prediction:

\[ Y = 0.4 \times \text{Rainfall} + 2.77 \]

Therefore if you expect one inch of rain your predicted flow is.

3.17 \((0.4 \times 1 \times 2.77)\)
Case Study
Western Berks Water Authority
Optimization for Chemical Treatment/Costs
### Chemical Cost Per Day

**01/01/13**

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Dose</th>
<th>Daily (lbs)</th>
<th>Bid Price</th>
<th>Unit</th>
<th>Total</th>
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<tbody>
<tr>
<td>KMnO₄</td>
<td>0.25</td>
<td>7.27</td>
<td>$204.00</td>
<td>cwt</td>
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<tr>
<td>CO₂</td>
<td>0.00</td>
<td>0.00</td>
<td>$344.40</td>
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<td>Activated Carbon</td>
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<td>Coagulant</td>
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<td>Fluoride</td>
<td>0.60</td>
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<td>Chlorine</td>
<td>8.59</td>
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<td>KOH</td>
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<td>0.00</td>
<td>$39.74</td>
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<tr>
<td>Phosphate</td>
<td>2.90</td>
<td>84.36</td>
<td>$5.67</td>
<td>gal</td>
<td>7.33 gals</td>
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<tr>
<td>Ammonium Sulfate</td>
<td>4.16</td>
<td>120.96</td>
<td>$45.00</td>
<td>cwt</td>
<td>$54.43</td>
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**Raw Flow (GPM)**  2,310.8  
**BW Recycle Flow (GPM)**  111.4  
**Plant Flow (GPM)**  2,422.2  
**Plant Flow MGD**  3.49  

**24 Hour Total**  $525.89  
**Minute Total**  $0.37  
**Hour Total**  $21.91  
**Shift Total**  $175.30  

<table>
<thead>
<tr>
<th>Operators</th>
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<th>3rd</th>
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<tr>
<td>MM</td>
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<td></td>
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<tr>
<td>MR</td>
<td></td>
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</table>

**Cost per 1000 Gal**  $0.15

**Amm suff. 1:1**  
**Gallons/Hr**  5.04  
**Gallons/Day**  120.96  
**water lbs/gal**  8.34
Chemical Cost per Day

Chemical costs go up every summer. Why?

Is it just the way it is?

What is driving the cost?
Chemical Cost per Day

Plotted each chemical vs CCPD and found Coag is driving the cost.
Raw water turb – there are times that the turb spike caused cost spike but the key learning here is that cost spiked without Turb increase. So WHY?? We graphed around 3 years everything that we test for in Raw Water vs Cost (Turb, DO, Mn, Fe, pH, Temp, ORP, Alage)
Discovered Manganese was the key driver for costs. Discussed why with committee:

“In past, one time overfeed of Potassium permanganate (KMno4) caused operators to be fearful of overfeeding. We did not feed enough to remove (oxidize) the Mn. The Mn would cause the Turb to creep up at Post DAF (pre filter), so the operators added more Coag which had no effect on the Mn. There is the waste.”
Chemical Cost per Day

Total Chemical Cost per Day vs Raw Manganese

CCPD Total Chem Cost Daily

Date (1/1/2011 to 8/31/2013)

Raw Manganese (Daily Avg)
Chemical Cost per Day

Graph showing the chemical cost per KGAL from June 1, 2014, to August 31, 2014. The graph includes data points for each day, with trends indicating fluctuations in cost throughout the period.
Conclusion

SPC has helped WBWA:

- Transition to a QA/QC mindset
- Collect and analyze data instrumental in meeting optimization goals
- Install internal controls for chemical inventory
- Standardize plant operations
- Optimize the treatment process by continuously calculating CCPD
Questions?

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