Performance Analysis for Process Improvement

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Warning: This material may cause a paradigm shift. Should you not wish your paradigm shifted you may want to leave at this time.
Presentation Outline

- Introduction
- Sampling
- Process Performance Measures
- Process Performance Analysis
- Example
Quality Goals

- The elimination of nonconformance
- The minimization of variation around appropriate targets
Quality Goal Questions

- How well are these quality goals being realized?
- What must be done to improve?
Traditional Approach

- Establish statistical control of a process
- Determine the underlying process distribution
- Conduct a Process Capability Analysis
Scenario #1

- A Plastic Lid Manufacturer
  - 40 molding machines
  - 54 Tools per molder
  - Tools are replaced every few weeks
  - Tool-to-Tool Differences found
  - Differences from Raw Material batches
  - Variation from maintenance cycles, startup periods, and operator adjustments
Scenario #2

◆ A Metal Crown Company
  – Eight Presses
  – Each Press Contains 22 dies
  – Differences exist die-to-die and press-to-press
  – The process exhibits tool wear
  – Slight fluctuations are observed with lot-to-lot changes in steel
Scenario #3

- An Aluminum Can Manufacturer
  - Two Lines in One plant
  - Each Line contains 16 stations
  - Station-to-station differences are found
  - This process also undergoes tool wear
  - Perfect through-time stability (or control) is not observed in many of the stations
Conclusions

- Traditional capability methods are inadequate in these situations.
- Without statistical control, capability assessment cannot be made.
- The number of process streams yields a nightmare to mathematically model.
- Practitioners still need a means of assessing their process.
Performance Measures

- In recent years “Process Performance Measures” have gained popularity

<table>
<thead>
<tr>
<th>Capability</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cpk</td>
<td>Ppk</td>
</tr>
<tr>
<td>Cp</td>
<td>Pp</td>
</tr>
<tr>
<td>Cpm</td>
<td>Ppm</td>
</tr>
</tbody>
</table>
Process Performance Measures Differ from Capability Measures

- Statistical control not required for analysis
- Common and special causes may both be present
- Do not consider distributional shape
- Measure past performance only
- Do not predict the future
Process Performance Measures

- Assess total observed variation produced during a particular time period
- Can be used as validation measures for process improvement
Process Performance Analysis

- Uses Process Performance Measures, descriptive measures, and graphical techniques to study processes
With Process Performance Analysis

- Assess processes before statistical control is achieved
- Determine sources of process loss
- Make comparisons among characteristics, products, plants, and suppliers
- Determine control and improvement priorities
- Assess results of process improvement efforts
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Sampling

- Measure total outgoing variation as sent to the customer
Total Outgoing Variation

- Variation inherent to the process
- Variation from sources such as:
  - differences from lot-to-lot,
  - tool-to-tool,
  - line-to-line,
  - shift-to-shift,
  - setup-to-setup,
  - day-to-day,
  - and throughout maintenance cycles.
Sampling

- Generally done at end-of-line
- May be done upstream if characteristic formation is complete and will not change
- Should be done after sorting
Stratification

- Used for process diagnosis
- Stratifications may include:
  - Lines
  - Tools
  - Stations
  - Cavities
  - or Other
Sample Frequency

- Samples taken periodically within defined time periods
Sampling Amount

- Long periods are preferred
- Minimum one month, preferably, three months worth of data
- 1,000 is a desired minimum
- 10,000 or more may provide better analysis
Measurement System Analysis

- Measurement system analysis should be conducted prior to data collection
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Process Performance Measures

- Ppm
- Ppk
- Pp
- Pp(process stream)
- Cp(potential)
Ppm

◆ Assessing overall performance

\[ P_{pm} = \frac{USL - LSL}{6\sqrt{\frac{\sum (X-T)^2}{n-1}}} = \frac{USL - LSL}{6\sqrt{s^2 + \frac{n}{n-1}(\bar{X}-T)^2}} \]
Ppm will improve as:

- Process brought into better control
- Differences in tooling, setup, operators, machines, and material are reduced
- Process brought on target
- Inherent process variation reduced
Assessing overall performance without targets

\[ P_{pk} = \min \left( \frac{USL - \bar{X}}{3s}, \frac{\bar{X} - LSL}{3s} \right) \]
 Assessing performance as if process was on target

\[ Pp = \frac{USL - LSL}{6 \times s} \]
% Off-Target

A further diagnostic measure

\[
\text{% Off-Target} = \left| \frac{\bar{X} - T}{\text{USL} - \text{LSL}} \right| \times 100\%
\]
Pp (process stream)

- Assessing performance without process stream differences

\[ Pp \text{ (process stream)} = \frac{(USL - LSL)}{6 \, s \text{ within stream}} \]
% Process Stream Difference

◆ A further diagnostic measure

\[
\% \text{ Process Stream Difference} = \left( \frac{\bar{X}_{\text{max stream}} - \bar{X}_{\text{min stream}}}{\text{USL} - \text{LSL}} \right) \times 100\%
\]
Cp (potential)

Assessing Potential Performance

\[ Cp(\text{potential}) = \frac{USL - LSL}{6 \sigma_{\text{potential}}} \]
Potential Standard Deviation

- Short-term capability studies
- Estimated using average or median dispersion statistics
A further check

- Observed Nonconforming Rates

\[
\text{Nonconforming Proportion (ppm)} = 1,000,000 \times \frac{\text{Total Nonconforming}}{\text{Total Items}}
\]
Attributes Data

- Similar sampling may be done for attributes
- Nonconforming rate used to evaluate attribute performance
Presentation Outline

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- Example
Stacked Bar Charts

The following Relation holds:

\[ P_{pm} \leq P_{p} \leq P_{p(\text{process stream})} \leq C_{p(\text{potential})} \]
Stacked Bar Charts

\[ C_p \text{(potential)} - P_p \text{(process Stream)} \]

\[ P_p \text{(process stream)} - P_p \]

\[ P_p - P_{pm} \]

\[ P_{pm} \]
Stacked Bar Charts

Process Performance Analysis

Performance

Cp (potential)
Pp (process stream)
Pp
Ppm
Cannot Compare Areas of the Stacked Components
Variance Components

- Total variance about target, $\tau^2$, can be decomposed
- May be done with simple formulas

$$\tau^2 = \sigma^2_{\text{potential}} + \sigma^2_{\text{off-target}} + \sigma^2_{\text{process stream}} + \sigma^2_{\text{time}}$$
Presentation Outline

◆ Introduction
◆ Sampling
◆ Process Performance Measures
◆ Process Performance Analysis
◆ Example
Case Study
Aluminum Lids - Height

- Aluminum Lids are produced on a Press with 22 Stations
- Each day, Lids from each Station are sampled and Lid Height measured
- Each sample contains a single Lid from each station
- Data collected over Three-month period
- Specifications are 98 ± 5
Box Plot of Each Station
Control Chart from Station #1

Height Station 1

Individual Values

96.0 96.5 97.0 97.5 98.0 98.5 99.0 99.5 100.0 100.5

Moving Range

0.0 0.5 1.0 1.5 2.0

Point Number

1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133

UCL=99.15  CL=98.368  LCL=97.57

UCL=0.972  CL=0.297  LCL=0.000
Control Chart from Station #5

Height Station 5

Individual Values

Moving Range

Point Number

UCL=101.053
CL=100.356
LCL=99.659

UCL=0.856
CL=0.262
LCL=0.000
Run Chart Station #1 with Specs

Height Station 1

LSL=93.00  
USL=103.00  
Target=98.00

Point Number

Values

104.0
103.0
102.0
101.0
100.0
99.0
98.0
97.0
96.0
95.0
94.0
93.0
92.0

1  7  13  19  25  31  37  43  49  55  61  67  73  79  85  91  97  103  109  115  121  127  133
Run Chart Station #5 with Specs

Height Station 5

- LSL = 93.00
- Target = 98.00
- USL = 103.00

Values vs. Point Number
### Descriptive Statistics

<table>
<thead>
<tr>
<th>Station</th>
<th>n</th>
<th>mean</th>
<th>s</th>
<th>s (MMR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>134</td>
<td>98.37</td>
<td>0.63</td>
<td>0.26</td>
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<td>22</td>
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<td>101.06</td>
<td>0.49</td>
<td>0.27</td>
</tr>
</tbody>
</table>

**SQRT (MSW)**

(Std Dev Within) = 0.58

**AVG Std (MMR)**

(Std Dev from Median MR) = 0.23
## Descriptive Statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
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<tbody>
<tr>
<td>n</td>
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<tr>
<td>Mean</td>
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<td>Std. Dev</td>
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<td>Q3</td>
<td>101.14</td>
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<tr>
<td>High</td>
<td>102.94</td>
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</table>
Performance Measures

%Off Target = 24.82%
Max Station Mean = 102.21
Min Station Mean = 98.37
%Process Stream Loss = 38.42%

Ppk = 0.858
Ppm = 0.625
Pp = 1.703
Pp(Stream) = 2.862
Cp(pot) = 7.212

n = 2948
Total Out = 0 (0 ppm)
Process Performance Analysis

Performance

Height1

Cp(potential)
Pp(stream)
Pp
Ppm
Process Performance Analysis

Performance

- Height
- Target
- Stream
- Target+ Stream
- Time (Control)

Opportunity
Ppm
Variance Components

Process Performance Analysis
Variance Components

Target Loss (86.52%)

- Time (Control) (4.07%)
- Process (0.70%)
- Process Stream (8.71%)
Conclusions for Example

- Biggest opportunity: getting the individual tools on target
- Improving through-time stability (control) will have minimal effect in this example
Summary Results of Selected Cases

Process Performance Analysis

Performance

Legend:
- Ppm
- Pp
- Pp(stream)
- Cp(potential)
Summary Results of Selected Cases

Process Performance Analysis
Variance Components

- **Potential**
- **Target Loss**
- **Process Stream**
- **Time (control)**

Variance %

0  10  20  30  40  50  60  70  80  90  100

<table>
<thead>
<tr>
<th></th>
<th>Potential</th>
<th>Target Loss</th>
<th>Process Stream</th>
<th>Time (control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
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<td>5</td>
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Conclusions

◆ Process Performance Analysis provides an effective means of describing performance of complex processes not in a state of control
◆ PPA is an effective means of showing effects of process control and improvement efforts
◆ PPA helps the practitioner determine how they are doing, what processes need work and which one do not
◆ PPA gives you another way of looking at your processes
The End