A Complete 3D Inspection Solution

SPI Data Analysis, Paste Print Process Characterization

SMITA Guadalajara Chapter 2016

Ray Welch
October 6, 2016
SPI Data Analysis

Objectives of this Presentation

– Move beyond real-time paste print defect review at the SPI system
– Present some tools and techniques for detailed analysis of SPI data, to enable the *Characterization* and *Optimization* of the paste print process
– Share some example print process issues observed through SPI data analysis
– Present a data-driven approach for driving improvements in the print process to increase product yields and reduce rework / costs
SPI Data Analysis

Review Topics

- Why perform SPI data analysis?
- “Printing in the Dark”
- SPI Data Analysis Charts & Graphs
- Steps for Offline SPI Data Analysis
- Exporting SPI Data for Analysis in Excel and Minitab
- SPI Data Excel Pivot Tables
- SPI Data Analysis using Minitab
- Paste Print Process Characterization
- Print Performance Evaluation
Why perform SPI data analysis?

- Move beyond real-time paste print defect review at the SPI system
- *Characterize* the performance of the paste print process, assessing its *process capability* (i.e., its ability to meet the process requirements)
- Identify opportunities for process improvement and *optimization*
- *Validate* the print results after making process changes / improvements
- Evaluate different paste printing systems, materials, technologies, designs, tools, methods, ...
  - Screen Printer Platforms and Features
  - Stencil Technology, Foil Materials, Nano Coatings
  - Aperture Designs, Stencil Thickness / Steps, Aperture Area Ratio
  - Board Support Tooling / Clamping
  - Paste Selection, Powder Size / Type, Paste Handling Practices
- Drive improvements in the paste print process to increase product yields
“Printing in the Dark”
“Printing in the Dark”

- Performing the paste print process without the full and effective use of 3D solder paste inspection
- Generally results in:
  - A false (or unknown) sense of the true print performance
  - Unrecognized print process issues, including poor operator practices (misbehaviors) or subtle shifts / trends in the process
  - Inability to fully optimize the print process for each assembly
  - Increased time, cost and difficulty for identifying and addressing print process issues
  - Print process escapes, particularly random defects, resulting in...
  - Increased level and cost of rework, or potential customer escapes
- The following slides use Minitab run charts to present real-life examples, based on % Volume (Paste Transfer Efficiency) SPI results
SPI Data Analysis Charts & Graphs
Paste Transfer Efficiency (% Volume)

- Transfer Efficiency (% Volume) = Measured Paste Volume ÷ Stencil Aperture Volume * 100%
- Stencil paste release factors influence Transfer Efficiency
- TE is a key measure of printing performance

Type 3 Solder Paste Screened into an 11 mil Wide Aperture

100% Transfer Efficiency

~ 85% Transfer Efficiency

Stencil and solder paste spheres are to scale
Sample Means vs. Run Chart

- Some people may simply track and report the mean values of the print height, volume or Cpk, based on a limited sample of paste measurements.
- This often times results in a false sense of the actual print process performance.
- Plotting the individual data points about the means, using Run Charts, for a larger number of component sites and PCBs, provides a clearer view of the variation in the print process.
Run Charts - Time-based Analysis

- Run charts show *when* defects occurred, as well as their distribution and density
- Provides very helpful insight for identifying issues and possible causes
- This example shows the effects of a ramp-up in the print area temperature, with a degradation in the print results (upper chart)
- Histograms and process capability graphs do not provide such time-based analysis (lower graph)
Process Capability Graphs

- Provide an excellent graphical and statistical presentation of the data, relative to the spec limits & target
- The process capability indices (Cpk, Ppk, Z values, PPM) are only as accurate as the data is normally distributed
- Good Cpk/Ppk values (> 1.33, 4 Sigma) do not necessarily indicate that all is well (or in control)
- Run charts provide better visibility to more subtle issues (ex, clogged apertures or paste response-to-pause issues)
SPI Data Analysis
SPI Data Analysis

Steps for offline SPI data analysis

– Identify an PCB assembly and date range of interest
– Export the selected inspection results data from the SPI system
– Copy and paste the exported SPI results data into the “SPI Export Data Pivot Table Template” Excel file
– Refresh the pivot tables with the new SPI data
– Scan the pivot tables for Coefficient of Variation (CV) values ≥ 10% and Transfer Efficiency (TE) values < 60% or > 160%
– Identify the components of interest, including those considered challenging-to-print or having SMT yield issues
– Select and store the SPI data values for each component of interest in individual worksheets, in a separate Excel workbook (“Comp IDs” file)
– Open the “Comp IDs” file as a worksheet in Minitab
– Select the worksheet of interest in Minitab, then perform analysis using Run Charts and Process Capability Analysis
– Identify any issues, then develop and implement improvement activities
SPI Data Export > Pivot Tables > Minitab

(3) Minitab Run Charts & Process Capability Graphs

(2) SPI Data Excel Pivot Table Review

(1) SPI Results Exported
Exporting SPI Data for Analysis in Excel and Minitab
Export SPI Results to Excel

(1) Setup the SPI Results Export Format

(2) Export the SPI Results

(3) Copy and paste the SPI results into the pivot table Data Values worksheet
Right-click a cell in either pivot table, then click “Refresh” to update the Date Time and Pad ID pivot tables with the new SPI export data

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row Labels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(blank)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/1/2014 7:27</td>
<td>110.94</td>
<td>6052</td>
<td>5629</td>
<td>6572</td>
<td>258</td>
<td>4.26%</td>
<td>110.94%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 7:28</td>
<td>114.23</td>
<td>6231</td>
<td>6112</td>
<td>6561</td>
<td>225</td>
<td>3.54%</td>
<td>114.23%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 9:18</td>
<td>108.06</td>
<td>5894</td>
<td>5813</td>
<td>5975</td>
<td>81</td>
<td>1.37%</td>
<td>108.06%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 10:46</td>
<td>111.15</td>
<td>6064</td>
<td>5966</td>
<td>6161</td>
<td>98</td>
<td>1.61%</td>
<td>111.15%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 11:47</td>
<td>108.38</td>
<td>5912</td>
<td>5777</td>
<td>6046</td>
<td>135</td>
<td>2.28%</td>
<td>108.38%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 11:48</td>
<td>104.38</td>
<td>5693</td>
<td>5638</td>
<td>5748</td>
<td>55</td>
<td>0.97%</td>
<td>104.38%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 11:53</td>
<td>105.73</td>
<td>5767</td>
<td>5629</td>
<td>5905</td>
<td>138</td>
<td>2.39%</td>
<td>105.73%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 11:54</td>
<td>111.38</td>
<td>6076</td>
<td>5928</td>
<td>6223</td>
<td>148</td>
<td>2.43%</td>
<td>111.38%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 11:59</td>
<td>114.15</td>
<td>6217</td>
<td>6213</td>
<td>6240</td>
<td>14</td>
<td>0.22%</td>
<td>114.15%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 12:00</td>
<td>115.83</td>
<td>6319</td>
<td>6065</td>
<td>6572</td>
<td>254</td>
<td>4.01%</td>
<td>115.83%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 7:27</td>
<td>109.93</td>
<td>8794</td>
<td>8101</td>
<td>9324</td>
<td>335</td>
<td>3.81%</td>
<td>109.93%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 7:28</td>
<td>105.19</td>
<td>8415</td>
<td>8178</td>
<td>8651</td>
<td>237</td>
<td>2.81%</td>
<td>105.19%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 9:18</td>
<td>111.81</td>
<td>8944</td>
<td>8733</td>
<td>9155</td>
<td>211</td>
<td>2.36%</td>
<td>111.81%</td>
<td></td>
</tr>
<tr>
<td>1/27/2014 9:18</td>
<td>108.71</td>
<td>8697</td>
<td>8561</td>
<td>8832</td>
<td>136</td>
<td>1.56%</td>
<td>108.71%</td>
<td></td>
</tr>
</tbody>
</table>

- Clicking “Refresh” in either pivot table will update both tables.
- The tables will open with all fields expanded.
- Enter a descriptive name in the “DESCRIPTION” field for each pivot table.
- The fields may be collapsed for a quick review.
The **Date Time** pivot table presents the board-level results for each component reference designator (all pads for each CRD)

- Values are displayed for the Average of % Volume
- The Average, Min and Max are displayed for the Real Volume (cums)
- Standard Deviation and Coefficient of Variation are based on the Real Volume
- Transfer Efficiency is the Average of % Volume
- Each Date Time row represents Comp ID data for one board
SPI Data Pivot Table – Pad ID

The **Pad ID** pivot table presents the pad-level results for each component reference designator and Pad ID (for all boards inspected)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row Labels</td>
<td>Values</td>
<td>Average of % Volume</td>
<td>Average of Volume</td>
<td>Min of Volume</td>
<td>Max of Volume</td>
<td>StdDev of Volume</td>
<td>Coefficient of Variation</td>
</tr>
<tr>
<td>1c100</td>
<td>110.94</td>
<td>6052</td>
<td>5629</td>
<td>6572</td>
<td>258</td>
<td>4.26%</td>
<td>110.94%</td>
</tr>
<tr>
<td>1c107</td>
<td>108.77</td>
<td>5933</td>
<td>5629</td>
<td>6213</td>
<td>203</td>
<td>3.42%</td>
<td>108.77%</td>
</tr>
<tr>
<td>1c108</td>
<td>113.12</td>
<td>6171</td>
<td>5748</td>
<td>6572</td>
<td>252</td>
<td>4.08%</td>
<td>113.12%</td>
</tr>
<tr>
<td>7</td>
<td>108.24</td>
<td>8589</td>
<td>8101</td>
<td>9185</td>
<td>337</td>
<td>3.89%</td>
<td>108.24%</td>
</tr>
<tr>
<td>8</td>
<td>111.62</td>
<td>8929</td>
<td>8455</td>
<td>9324</td>
<td>274</td>
<td>3.07%</td>
<td>111.62%</td>
</tr>
<tr>
<td>9</td>
<td>113.13</td>
<td>8841</td>
<td>8211</td>
<td>9706</td>
<td>467</td>
<td>5.28%</td>
<td>113.13%</td>
</tr>
<tr>
<td>10</td>
<td>118.21</td>
<td>9238</td>
<td>8567</td>
<td>9706</td>
<td>311</td>
<td>3.36%</td>
<td>118.21%</td>
</tr>
<tr>
<td>11</td>
<td>108.05</td>
<td>8444</td>
<td>8211</td>
<td>8858</td>
<td>155</td>
<td>1.83%</td>
<td>108.05%</td>
</tr>
<tr>
<td>12</td>
<td>119.68</td>
<td>6528</td>
<td>6039</td>
<td>6916</td>
<td>239</td>
<td>3.66%</td>
<td>119.68%</td>
</tr>
<tr>
<td>13</td>
<td>122.32</td>
<td>6672</td>
<td>6094</td>
<td>6916</td>
<td>217</td>
<td>3.25%</td>
<td>122.32%</td>
</tr>
<tr>
<td>14</td>
<td>117.05</td>
<td>6385</td>
<td>6039</td>
<td>6622</td>
<td>161</td>
<td>2.53%</td>
<td>117.05%</td>
</tr>
<tr>
<td>15</td>
<td>119.17</td>
<td>2518</td>
<td>2361</td>
<td>2721</td>
<td>103</td>
<td>4.09%</td>
<td>119.17%</td>
</tr>
<tr>
<td>16</td>
<td>118.57</td>
<td>2506</td>
<td>2361</td>
<td>2654</td>
<td>105</td>
<td>4.19%</td>
<td>118.57%</td>
</tr>
<tr>
<td>17</td>
<td>119.77</td>
<td>2531</td>
<td>2411</td>
<td>2721</td>
<td>99</td>
<td>3.93%</td>
<td>119.77%</td>
</tr>
<tr>
<td>18</td>
<td>111.48</td>
<td>8711</td>
<td>8002</td>
<td>9349</td>
<td>362</td>
<td>4.16%</td>
<td>111.48%</td>
</tr>
<tr>
<td>19</td>
<td>113.78</td>
<td>8891</td>
<td>8185</td>
<td>9349</td>
<td>347</td>
<td>3.90%</td>
<td>113.78%</td>
</tr>
<tr>
<td>20</td>
<td>109.17</td>
<td>8531</td>
<td>8002</td>
<td>8907</td>
<td>278</td>
<td>3.25%</td>
<td>109.17%</td>
</tr>
<tr>
<td>21</td>
<td>113.13</td>
<td>12637</td>
<td>11639</td>
<td>13420</td>
<td>470</td>
<td>3.72%</td>
<td>113.13%</td>
</tr>
<tr>
<td>22</td>
<td>119.85</td>
<td>12678</td>
<td>11957</td>
<td>13420</td>
<td>468</td>
<td>3.72%</td>
<td>119.85%</td>
</tr>
<tr>
<td>23</td>
<td>113.86</td>
<td>6211</td>
<td>5672</td>
<td>6550</td>
<td>225</td>
<td>3.62%</td>
<td>113.86%</td>
</tr>
<tr>
<td>24</td>
<td>115.59</td>
<td>6305</td>
<td>5993</td>
<td>6509</td>
<td>224</td>
<td>3.66%</td>
<td>115.59%</td>
</tr>
<tr>
<td>25</td>
<td>112.13</td>
<td>6116</td>
<td>5672</td>
<td>6550</td>
<td>224</td>
<td>3.66%</td>
<td>112.13%</td>
</tr>
<tr>
<td>26</td>
<td>106.50</td>
<td>8520</td>
<td>8026</td>
<td>9050</td>
<td>299</td>
<td>3.51%</td>
<td>106.50%</td>
</tr>
<tr>
<td>27</td>
<td>104.72</td>
<td>8377</td>
<td>8026</td>
<td>8870</td>
<td>267</td>
<td>3.19%</td>
<td>104.72%</td>
</tr>
<tr>
<td>28</td>
<td>108.28</td>
<td>8662</td>
<td>8206</td>
<td>9050</td>
<td>258</td>
<td>2.98%</td>
<td>108.28%</td>
</tr>
</tbody>
</table>

- Values are displayed for the Average of % Volume
- The Average, Min and Max are displayed for the Real Volume (cums)
- Standard Deviation and Coefficient of Variation are based on the Real Volume
- Transfer Efficiency is the Average of % Volume
The **Coefficient of Variation** for the average Real Volume (cu mils) values indicates the degree of paste transfer process variation.

\[
CV = \frac{\text{StdDevp of Volume}}{\text{Average of Volume (cu mils)}}
\]

- Desired CV < 10%
- CV cell conditional formatting:
  - No Fill  CV < 0.1
  - Blue    CV between 0.1 and 0.15
  - Red     CV > 0.15
The **Transfer Efficiency** is a key measure of printing performance, based on the paste transferred from the stencil to the PCB.

- TE = Measured Paste Volume ÷ Stencil Aperture Volume * 100%
- TE target is ~ 100%
- Typical acceptable average values range from ~ 90% to 120%
- TE cell conditional formatting:
  - No Fill  TE within 60% - 160%
  - Blue  TE < 60%
  - Red  TE > 160%
Coefficient of Variation and Transfer Efficiency Review
Coefficient of Variation Review

Scan the Date Time pivot table for CV values ≥ 10% at the **board level** (each Date Time row represents one board)

- Scan the Date Time pivot table for highlighted CV cells
- **Blue** is Marginal (CV between 10% - 15%)
- **Red** is Unacceptable (CV > 15%)
- Each Date Time row represents Comp ID data for one board
- Click Pad ID worksheet to review pad level data (next slide)
Coefficient of Variation Review

Scan the Pad ID pivot table for CV values ≥ 10% at the individual pad level (across all boards)

- Scan the Pad ID pivot table for highlighted CV cells
- **Blue** is Marginal (CV between 10% - 15%)
- **Red** is Unacceptable (CV > 15%)
- A component reference designator row represents data for that CRD across all boards
- A pad number row represents data for that particular pad across all boards
Transfer Efficiency Review

Scan the Date Time and Pad ID pivot tables are for highlighted Transfer Efficiency values (Blue, < 60% or Red, > 160%)

- Scan the Date Time and Pad ID pivot tables for highlighted TE cells
  - Blue is TE < 60%
  - Red is TE > 160%
  - TE target is ~ 100%

- Typical acceptable average values range from ~ 90% to 120%
- Also look for cells with wide variation, or unexpected values, while still within the 60% to 160% range
SPI Data Analysis using Minitab
SPI Data Formatted for Use in Minitab

Create a separate Excel workbook, with individual worksheets for each of the components of interest or specific component / aperture types

- Use the filter function in the pivot table data file to copy and paste selected data into individual worksheets in a new workbook
- Minitab analysis will be performed for the selected component data
- Do not import entire exported data file into Minitab!
SPI Data Opened in Minitab

Open the Excel workbook, with data for the individual components or specific component / aperture types, as a worksheet in Minitab.
Select the worksheet for the individual component or a specific component / aperture type to be analyzed

- For Excel files with multiple worksheets, display the Worksheets Folder, then select the worksheet to be used for the analysis
- Double-click the worksheet to set it as the “active” worksheet
- Perform analysis using each worksheet, as needed
Create a Run Chart for the SPI parameter of interest, typically % Volume, using Date Time to specify the Subgroup size.
Minitab Run Chart

The Run Chart provides a graphical view of the data, helping to identify patterns and any “special causes” in the print results, as well as when defects / issues occurred.
Minitab Capability Analysis

Select Capability Analysis in the Quality Tools menu, then select Normal.
Minitab Capability Analysis (Sigma Values)

Select the parameter of interest, use Date Time to specify the Subgroup size, enter the Lower and Upper Specs, then enter the Options.
Minitab Capability Analysis (Sigma Values)

Capability Analysis is used for process characterization & optimization

Z.Bench is the *Sigma Metric*

Cpk represents the process capability if the shift and drift between subgroups were eliminated

Ppk includes the variation between subgroups, and therefore is more appropriate for SPI data analysis

\[
Ppk = \min \left\{ \frac{USL - \mu}{3\sigma} ; \frac{\mu - LSL}{3\sigma} \right\}
\]

Only as accurate as the data is normally distributed
Paste Print Process Characterization
Print Process Characterization

Plan / Collect / Analyze

- Identify PCB assemblies for characterizing the paste print process
  - High runner or focus products, challenging-to-print boards, …
  - Assemblies experiencing paste-related SMT defects or yield issues
  - Use historical / recent SPI data, or collect new data
- Export SPI data into Excel, then analyze for Coefficient of Variation (CV) values ≥ 10% and Transfer Efficiency (TE) values < 60% or > 160%
- Create Run Charts for components of interest, or are challenging-to-print
  - Perform graphical analysis of the print process variation
  - Identify any patterns and “special cause” process variation, then determine the associated root causes and corrective actions
- Perform Capability Analysis to assess the “natural” process variation
- Identify any opportunities process improvement / optimization
- Develop and execute plan for addressing the necessary improvements
- Validate the results after making process changes / improvements
Print Process Characterization

Scan the pivot tables for Coefficient of Variation values > 10% and Transfer Efficiency values < 60% or > 160% to identify any print issues, and the components of interest for more detailed analysis.
Run Charts - Time-based Analysis

- Run charts show *when* defects occurred, as well as their distribution and density
- Provides very helpful insight for identifying issues and possible causes
- This example shows the effects of a ramp-up in the print area temperature, with a degradation in the print results (upper chart)
- Histograms and process capability graphs do not provide such time-based analysis (lower graph)
Print Process Characterization

Process Capability Graphs

- Provide an excellent graphical and statistical presentation of the data, relative to the spec limits & target
- The process capability indices (Cpk, Ppk, Z values, PPM) are only as accurate as the data is normally distributed
- Good Cpk/Ppk values (> 1.33, 4 Sigma) do not necessarily indicate that all is well (or in control)
- Run charts provide better visibility to more subtle issues (ex, clogged apertures or paste response-to-pause issues)
Print Process Characterization

Screen Printer and Printing Practices

- Identification of issues with the current screen printer and printing practices, followed by validation of process improvements with a new printer and implementation of printing process best practices.

### Screen Printer A + Current Printing Practices

**Run Chart of % Volume - U910 (0.5 mm BGA, AR=0.75)**

- Number of runs about median: 51
- Expected number of runs: 75.0
- Longest run about median: 25
- Approx P-Value for Clustering: 0.000
- Approx P-Value for Mixtures: 1.000
- Number of runs up or down: 100
- Expected number of runs up or down: 94.3
- Longest run up or down: 3
- Approx P-Value for Trends: 0.072
- Approx P-Value for Oscillation: 0.128

### Screen Printer B + Printing Best Practices

**Run Chart of % Volume - U910 (0.5 mm BGA, AR=0.75)**

- Number of runs about median: 60
- Expected number of runs: 51.0
- Longest run about median: 5
- Approx P-Value for Clustering: 0.985
- Approx P-Value for Mixtures: 0.035
- Number of runs up or down: 68
- Expected number of runs up or down: 66.3
- Longest run up or down: 3
- Approx P-Value for Trends: 0.355
- Approx P-Value for Oscillation: 0.345
Print Process Characterization

Stencil Design Aperture Area Ratios

- Identification of paste release issues due to low area ratio stencil design (< 0.66 AR), with validation of new stencil design (0.75 AR)

5 mil stencil (Area Ratio = 0.60)

4 mil stencil (Area Ratio = 0.75)
Squeegee Blades

- Identification of issues related to old / worn squeegee blades, with validation of print process improvement after blade replacement
Operator Practices

- Identification of operator issues related to long pauses between prints, without kneading the paste prior to resuming printing

![Run Chart of % Volume - Paste Print Response to Pause](chart.png)

- Printing resumed without kneading

<table>
<thead>
<tr>
<th>Sample</th>
<th>Number of runs about median: 15</th>
<th>Expected number of runs: 15.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Longest run about median: 5</td>
<td>Expected number of runs: 19.0</td>
</tr>
<tr>
<td></td>
<td>Approx P-Value for Clustering: 0.427</td>
<td>Longest run or down: 5</td>
</tr>
<tr>
<td></td>
<td>Approx P-Value for Trends: 0.181</td>
<td>Approx P-Value for Oscillation: 0.819</td>
</tr>
</tbody>
</table>
• Run Chart showing the recurrence of pads with no solder for a particular BGA location
• Also reflects a large paste print variation for this BGA
• Such issues are very difficult to identify and monitor, without use of inline or 100% SPI
• SPI sampling is not effective for capturing random defects, may result in print escapes
• Example of vastly different SPI results between the front and rear print strokes
• Poor printer setup probably caused this issue, but worse…
• The problem went unchecked for much of the build, then was finally corrected
• Periodic operator monitoring / coaching is required
• A key objective is to identify and understand any process variation due to “special causes”, then work to eliminate the sources of variation

• Special causes must be addressed, or its SPI data removed, to assess the natural, “common cause” process variation
SPI Tolerance Setting

- **Characterizing** the print process assists in:
  - Validating that the process is running at/near the expected or required “target” and process capability, then…
  - Validating / setting the SPI inspection tolerances, with the process stable and free of any “special causes”

- The SPI tolerances should be set for **where** the process should be running, not where it just **happens to be** running (which may be poorly)
Print Process Characterization

- Sound stencil design and proper technology selection, with area ratios ≥ 0.66
- Proper paste handling and screen printing practices
- Robust and repeatable screen printer capability
- Secure and precise board support / clamping
- Process characterization / optimization using SPI
- Are each required to achieve Six Sigma print processes

Overall Z.Bench represents the process capability Sigma value.
Print Performance Evaluation
Print Process Test Vehicle

A standard test vehicle may be used to characterize and optimize the current screen printers, operator practices and overall print process, as well as evaluate / compare new or different:

- Screen Printer Platforms and Features
- Stencil Technology, Foil Materials, Nano Coatings
- Aperture Designs, Stencil Thickness / Steps, Aperture Area Ratio
- Board Support Tooling / Clamping
- Paste Selection, Powder Size / Type, Paste Handling Practices
Print Process Test Vehicle

- Evaluation test vehicle, with difficult-to-impossible to print apertures (2.4 to 0.25 area ratios with a 4 mil stencil)
- Used to characterize the print process, with a focus on insufficient solder errors (% Volume)
- 16,630 total pads: 4,542 apertures have area ratios < 0.50, 10,268 apertures have area ratios < 0.63

Dark blue indicates pads with insufficient solder (TE ≤ 60%)
Print Process Test Vehicle (8x10”)

![Print Process Test Vehicle Diagram](image-url)
Example Test Vehicle Results

- Use of a standard test vehicle provides a quick visual reference via the SPI defect map, as well as comparison to previous evaluation results and benchmark data.

- Upper image represents benchmark results for a best-in-class printer, with ~3200 insufficient solder SPI errors, using a 4 mil LC FG stencil and type 4 paste.

- Lower image is for a printer with ~5700 insufficient solder SPI errors, using the same 4 mil LC FG stencil and type 4 paste.

- Note the density, distribution and symmetry of the SPI errors across the PCBs.
Example Test Vehicle Results

• The density of the SPI defects provides a quick visual reference in comparison to known nominal results for a particular printer, paste, stencil or setup

• Upper image represents print start-up without first performing a paste kneading cycle (~5800 SPI errors)

• Lower image represents an extreme print condition, possibly poor paste condition or printer setup / operation (~8700 SPI errors)

• Nominal SPI error counts will vary based on the paste, stencil and test vehicle PCB fab
## Print Performance Evaluation

Test vehicle pivot table review of critical area ratios (0.50 - 0.69)

<table>
<thead>
<tr>
<th>Row Labels</th>
<th>Average of % Volume</th>
<th>Average of Volume</th>
<th>Min of Volume</th>
<th>Max of Volume</th>
<th>StdDevp of Volume</th>
<th>Coefficient of Variation</th>
<th>Transfer Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR050-RD-NSMD</td>
<td>64.61</td>
<td>129</td>
<td>10</td>
<td>215</td>
<td>42</td>
<td>32.52%</td>
<td>64.61%</td>
</tr>
<tr>
<td>AR050-RD-SMD</td>
<td>59.17</td>
<td>118</td>
<td>38</td>
<td>191</td>
<td>32</td>
<td>26.79%</td>
<td>59.17%</td>
</tr>
<tr>
<td>AR050-SQ-NSMD</td>
<td>76.15</td>
<td>192</td>
<td>67</td>
<td>248</td>
<td>27</td>
<td>14.22%</td>
<td>76.15%</td>
</tr>
<tr>
<td>AR050-SQ-SMD</td>
<td>64.81</td>
<td>163</td>
<td>102</td>
<td>230</td>
<td>20</td>
<td>12.53%</td>
<td>64.81%</td>
</tr>
<tr>
<td>AR056-RD-NSMD</td>
<td>79.97</td>
<td>203</td>
<td>92</td>
<td>246</td>
<td>23</td>
<td>11.36%</td>
<td>79.97%</td>
</tr>
<tr>
<td>AR056-RD-SMD</td>
<td>68.94</td>
<td>175</td>
<td>115</td>
<td>244</td>
<td>22</td>
<td>12.41%</td>
<td>68.94%</td>
</tr>
<tr>
<td>AR056-SQ-NSMD</td>
<td>80.03</td>
<td>257</td>
<td>207</td>
<td>312</td>
<td>20</td>
<td>7.75%</td>
<td>80.03%</td>
</tr>
<tr>
<td>AR056-SQ-SMD</td>
<td>69.27</td>
<td>223</td>
<td>172</td>
<td>299</td>
<td>22</td>
<td>9.86%</td>
<td>69.27%</td>
</tr>
<tr>
<td>AR063-RD-NSMD</td>
<td>88.60</td>
<td>280</td>
<td>232</td>
<td>329</td>
<td>20</td>
<td>7.15%</td>
<td>88.60%</td>
</tr>
<tr>
<td>AR063-RD-SMD</td>
<td>74.48</td>
<td>235</td>
<td>168</td>
<td>310</td>
<td>25</td>
<td>10.64%</td>
<td>74.48%</td>
</tr>
<tr>
<td>AR063-SQ-NSMD</td>
<td>87.26</td>
<td>352</td>
<td>308</td>
<td>398</td>
<td>21</td>
<td>5.93%</td>
<td>87.26%</td>
</tr>
<tr>
<td>AR063-SQ-SMD</td>
<td>73.19</td>
<td>295</td>
<td>232</td>
<td>373</td>
<td>24</td>
<td>8.03%</td>
<td>73.19%</td>
</tr>
<tr>
<td>AR069-RD-NSMD</td>
<td>93.58</td>
<td>352</td>
<td>289</td>
<td>424</td>
<td>23</td>
<td>6.64%</td>
<td>93.58%</td>
</tr>
<tr>
<td>AR069-RD-SMD</td>
<td>83.57</td>
<td>314</td>
<td>256</td>
<td>418</td>
<td>30</td>
<td>9.64%</td>
<td>83.57%</td>
</tr>
<tr>
<td>AR069-SQ-NSMD</td>
<td>90.43</td>
<td>436</td>
<td>352</td>
<td>498</td>
<td>25</td>
<td>5.85%</td>
<td>90.43%</td>
</tr>
<tr>
<td>AR069-SQ-SMD</td>
<td>79.29</td>
<td>382</td>
<td>316</td>
<td>472</td>
<td>29</td>
<td>7.49%</td>
<td>79.29%</td>
</tr>
</tbody>
</table>
Print Performance Evaluation

Example Test Vehicle Results

- Paste transfer efficiency (% Volume) is analyzed in Minitab for select apertures (ex. various 0201 aperture designs)

- Minitab run charts and process capability graphs provide an excellent graphical view of the print process

- The use of SPI is an absolute must for characterizing the print process and assessing process capability
### Print Performance Evaluation

Test vehicle used to evaluate three different screen printers

<table>
<thead>
<tr>
<th>Category / Apertures</th>
<th>Printer A</th>
<th>Printer B</th>
<th>Printer C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side B Median Errors / Warnings</td>
<td>4067 / 4272</td>
<td>5609 / 2159</td>
<td>3847 / 5740</td>
</tr>
<tr>
<td>Side B Print Pattern (2-up panel)</td>
<td>Symmetrical</td>
<td>Asymmetrical</td>
<td>Symmetrical</td>
</tr>
<tr>
<td>AR 0.69-SQ-NSMD</td>
<td>1.91 Ppk</td>
<td>1.22 Ppk</td>
<td>1.43 Ppk</td>
</tr>
<tr>
<td>AR 0.75-SQ-NSMD</td>
<td>2.12 Ppk</td>
<td>1.31 Ppk</td>
<td>1.51 Ppk</td>
</tr>
<tr>
<td>BGA 0.5 mm NSMD (0.75 AR)</td>
<td>2.35 Ppk</td>
<td>0.83 Ppk</td>
<td>2.24 Ppk</td>
</tr>
<tr>
<td>BGA 0.75 mm NSMD (0.94 AR)</td>
<td>2.60 Ppk</td>
<td>1.32 Ppk</td>
<td>3.02 Ppk</td>
</tr>
<tr>
<td>BGA 256 1.0 mm (1.06 AR)</td>
<td>4.27 Ppk</td>
<td>2.08 Ppk</td>
<td>3.85 Ppk</td>
</tr>
<tr>
<td>QFN32 0.5 mm (1.0 AR)</td>
<td>2.49 Ppk</td>
<td>2.04 Ppk</td>
<td>2.80 Ppk</td>
</tr>
<tr>
<td>0201s (0.81 - 0.94 AR)</td>
<td>2.32 Ppk</td>
<td>1.82 Ppk</td>
<td>2.18 Ppk</td>
</tr>
<tr>
<td>X-Offset (+/- 2.5 mil spec limits)</td>
<td>3.91 Ppk</td>
<td>3.70 Ppk</td>
<td>1.73 Ppk (1)</td>
</tr>
<tr>
<td>Y-Offset (+/- 2.5 mil spec limits)</td>
<td>2.98 Ppk</td>
<td>2.96 Ppk</td>
<td>2.44 Ppk</td>
</tr>
</tbody>
</table>

> 1.33 Cpk / Ppk = “Capable Process”, 2.0 Cpk / Ppk = “Six Sigma Process”

(1) Due to residual offset values from earlier work
Print Performance Evaluation

Print Parameter Optimization

- Optimization of paste print separation speed / distance, using a standard screen printing process test vehicle
Print Performance Evaluation

Solder Paste Evaluation

• Evaluation of print performance (transfer efficiency) for different solder pastes, using a standard screen printing process test vehicle.

[Graph showing Solder Paste Transfer Efficiency for Square NSMD Apertures - LC PhD EP NC 4 mil Stencil]
Print Performance Evaluation

PCB Pad Design Comparison

- Comparison of paste transfer efficiency of NSMD vs. SMD pad designs, printed using square apertures on a 4 mil stencil
Print Performance Evaluation

Stencil Foil Material Evaluation

- Evaluation of three different stencil foil materials, using a standard screen printing process test vehicle.
## Stencil Foil Material Evaluation

Test vehicle used to evaluate three different stencil foil materials

<table>
<thead>
<tr>
<th>Category / Apertures</th>
<th>Foil A</th>
<th>Foil B</th>
<th>Foil C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side B Median Insufficient Errors</td>
<td>4227</td>
<td>4293</td>
<td>4494</td>
</tr>
<tr>
<td>AR 0.63-SQ-NSMD</td>
<td>~ 1.70 Ppk</td>
<td>~ 1.75 Ppk</td>
<td>~ 1.62 Ppk</td>
</tr>
<tr>
<td>AR 0.69-SQ-NSMD</td>
<td>~ 1.84 Ppk</td>
<td>~ 1.91 Ppk</td>
<td>~ 1.78 Ppk</td>
</tr>
<tr>
<td>AR 0.75-SQ-NSMD</td>
<td>~ 2.15 Ppk</td>
<td>~ 2.25 Ppk</td>
<td>~ 2.00 Ppk</td>
</tr>
<tr>
<td>AR 0.81-SQ-NSMD</td>
<td>2.64 Ppk</td>
<td>2.45 Ppk</td>
<td>2.35 Ppk</td>
</tr>
<tr>
<td>BGA 0.45 mm NSMD (0.63 AR)</td>
<td>1.59 Ppk</td>
<td>1.45 Ppk</td>
<td>1.46 Ppk</td>
</tr>
<tr>
<td>BGA 0.5 mm NSMD (0.75 AR)</td>
<td>2.04 Ppk</td>
<td>1.98 Ppk</td>
<td>~ 1.89 Ppk</td>
</tr>
<tr>
<td>BGA 0.75 mm NSMD (0.94 AR)</td>
<td>~ 2.20 Ppk</td>
<td>2.38 Ppk</td>
<td>2.46 Ppk</td>
</tr>
<tr>
<td>BGA 256 1.0 mm (1.06 AR)</td>
<td>~ 2.05 Ppk</td>
<td>~ 2.44 Ppk</td>
<td>2.92 Ppk</td>
</tr>
<tr>
<td>QFN32 0.5 mm (1.0 AR)</td>
<td>~ 2.08 Ppk</td>
<td>~ 2.02 Ppk</td>
<td>~ 1.85 Ppk</td>
</tr>
<tr>
<td>0201s (0.81 - 0.94 AR)</td>
<td>1.44 Ppk</td>
<td>1.36 Ppk</td>
<td>1.53 Ppk</td>
</tr>
<tr>
<td>01005s (8x10 mils, 0.56 AR)</td>
<td>&lt; 0.41 Ppk</td>
<td>&lt; 0.47 Ppk</td>
<td>&lt; 0.45 Ppk</td>
</tr>
</tbody>
</table>

> 1.33 Cpk / Ppk = “Capable Process”, 2.0 Cpk / Ppk = “Six Sigma Process”