

Pb-Free Implementation: Best Practices

by
Ronald C. Lasky, Ph.D., PE
Senior Technologist, Indium Corp
Visiting Professor, Dartmouth

Slide #0

Bottom Line Impact



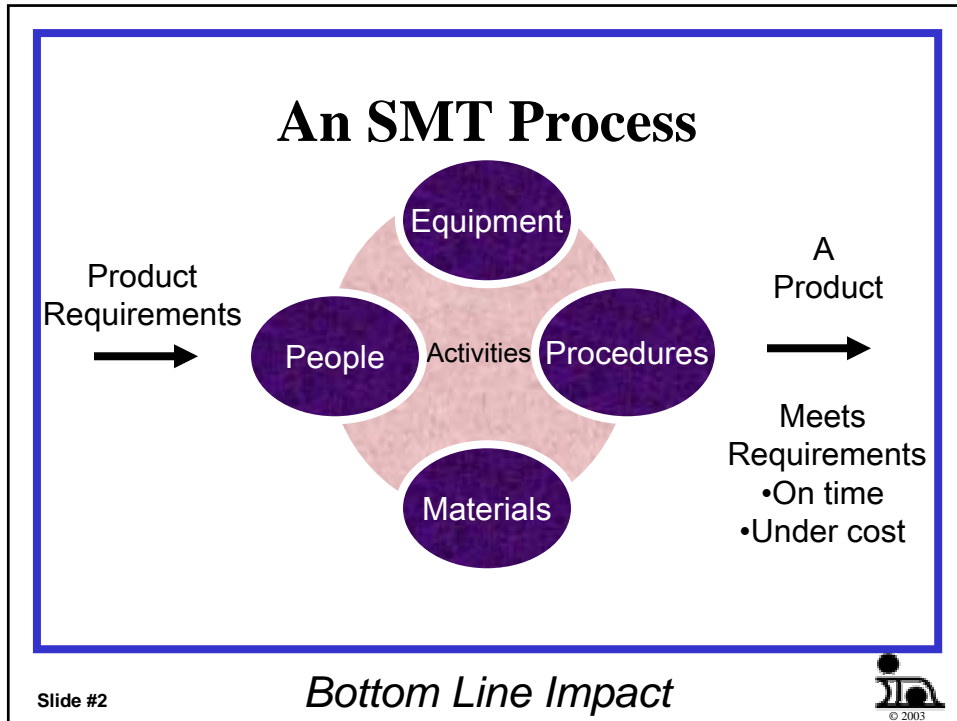
Pb-Free Best Practices


- **Assess Yourself**
 - Crucial with Pb-free
- **Throughput Maximization**
- **CIP**
- **Indium Process Software to Help**
- **Use the Right Tools**
 - Statistical Thinking
 - DOE
 - SPC

Slide #1

Bottom Line Impact





- ## Assessment Categories
- **DFM, Process and Equipment**
 - **Materials Supply and Validation**
 - **DOE, SPC, CIP**
 - **Training and Failure Analysis**
 - **Developed from pooled information from industry experts**
- Slide #3 *Bottom Line Impact*  © 2003

DFM, Process and Equipment

Ranking Key: 0 = strongly disagree or don't know , 3 = disagree, 5= neutral, 7 = agree, 10 = strongly agree

1	We have a documented and functioning DFM system that includes design ground rules (DGRs). Our entire organization is strongly committed to DFM. DFM is a way of life (this question counts 3 times):	10
2	Our DGRs are established by using designed experiments and statistical process control:	8
3	The process engineers know how to run all of the equipment:	3
4	The engineer(s) responsible for stencil printing knows how to design a stencil	9
5	The engineer(s) responsible for component placement knows how to balance and optimize the placement equipment. He assures that this operation is performed on all jobs:	9
6	The engineer in charge of the reflow process assures that the reflow profile matches the solder paste specification:	9
7	Our process engineers have a disciplined and proven strategy to improve productivity:	9
8	Our process engineers have a disciplined and proven strategy to improve quality:	9
9	Our process equipment is "qualified" with a test and evaluation procedure that is founded on DOE principles:	3
10	There is a process engineer or team of engineers responsible for implementing new processes and technology:	9
Total Score out of 120		98

Ratings:

World Class = > 95
 Above Average = 75 - 94
 Average = 55 - 74
 Below Average < 55

Your score places you as "World Class" in DFM, Process and Equipment for SMT assembly. Your clearly recognize the importance of these topics in your assembly processes. This score still offers some opportunity for improvement. Look at your results on each question and develop an action plan for improvement if appropriate.

Slide #4

Bottom Line Impact



Materials Supply and Validation

Ranking Key: 0 = strongly disagree or don't know , 3 = disagree, 5= neutral, 7 = agree, 10 = strongly agree

1	We evaluate our solder pastes and/or materials with a systematic evaluation procedure, such as "The 12 Board Paste Evaluator" (shown below) or DOE to assure its performance (this question counts 3 times):	0
2	My engineers have read and understand the solder paste and materials specs and assure they match our use conditions:	8
3	The response to pause of my solder paste is adequate for my applications:	5
4	The cost of my solder paste and/or materials is <u>not</u> the main criteria for its purchase:	7
5	The printed volume consistency of my solder paste is best of breed:	7
6	My materials supplier(s) understand(s) my process and business needs, we treat each other like partners:	4
7	Few, if any end of line defects can be traced to inadequacies of my solder paste and/or materials:	4
8	The type (i.e. 2, 3, 4, 5) of the solder paste we use matches the application requirement:	4
9	Our organization has a systematic method to assure that the materials/components for future jobs are being prepared while current jobs are being run:	6
10	Our organization has a systematic method to assure that we have an uninterrupted supply of materials from our vendors:	6
Total Score out of 120		51

Ratings:

World Class = > 95
 Above Average = 75 - 94
 Average = 55 - 74
 Below Average < 55

Your score places you below average among users of SMT materials. This position offers overwhelming opportunities for improvement. Look at your results on each question and develop an action plan for improvement. Your organization has an urgent need to recognize that evaluating your solder pastes and materials is a most important activity.

Slide #5

Bottom Line Impact



DOE, SPC, CIP

Ranking Key: 0 = strongly disagree or don't know , 3 = disagree, 5= neutral, 7 = agree, 10 = strongly agree

- | | | |
|-------------------------------|---|-----------|
| 1 | We have a continuous improvement plan that is effective, uses metrics, and is recognized as valuable by the entire organization (this question counts 3 times): | 3 |
| 2 | We measure our process uptime: | 8 |
| 3 | We measure our unscheduled downtime: | 2 |
| 4 | We measure our line efficiency: | 2 |
| 5 | We measure our work in process time: | 5 |
| 6 | We know our process's Cp and Cpk: | 9 |
| 7 | We have a statistical process control program and use the resulting data effectively to monitor and improve our processes: | 9 |
| 8 | Our process engineers use designed experiments to optimize our processes and evaluate equipment and materials: | 9 |
| 9 | Quality is everyone's job: | 8 |
| 10 | Productivity is everyone's job: | 8 |
| Total Score out of 120 | | 69 |

Ratings:
 World Class = > 95
 Above Average = 75 - 94
 Average = 55 - 74
 Below Average < 55

Your score places you as average in DOE, SPC and CIP for SMT assembly. This position offers significant opportunities for improvement. Look at your results on each question and develop an action plan for improvement. Having an effective CIP program is vital for success.

Slide #6

Bottom Line Impact



© 2003

Training and Failure Analysis

Ranking Key: 0 = strongly disagree or don't know , 3 = disagree, 5= neutral, 7 = agree, 10 = strongly agree

- | | | |
|-------------------------------|--|-----------|
| 1 | Our organization has a sophisticated training program for all levels of our staff (this question counts 3 times): | 9 |
| 2 | Our engineers understand the difference between common cause and special cause failures and use this knowledge in process troubleshooting: | 8 |
| 3 | Our engineers use sophisticated modeling tools, like StencilCoach, Reflow Coach and LineBalancer to help them model processes and perform "what if" analysis: | 5 |
| 4 | Management uses costing tools like ProfitPro to perform financial "what if" analysis, before making financial investments in equipment etc: | 3 |
| 5 | Our operators cannot change the process equipment's operating parameters: | 8 |
| 6 | Our engineers know and use analytical problem solving and brainstorming techniques to perform failure analysis: | 4 |
| 7 | There is a process line escalation policy that is understand by all (e.g. if the line is down and remains down this information gets escalated in a documented fashion): | 4 |
| 8 | Our process engineer's yearly performance review is related to process improvement goals: | 4 |
| 9 | We can perform failure analysis or vend this task out: | 6 |
| 10 | Our staff has all of the tools necessary to perform their jobs: | 6 |
| Total Score out of 120 | | 75 |

Ratings:
 World Class = > 95
 Above Average = 75 - 94
 Average = 55 - 74
 Below Average < 55

Your score places you as above average in Training and Failure Analysis for SMT assembly. This score still offers considerable opportunity for improvement. Look at your results on each question and develop an action plan for improvement, if appropriate.

Slide #7

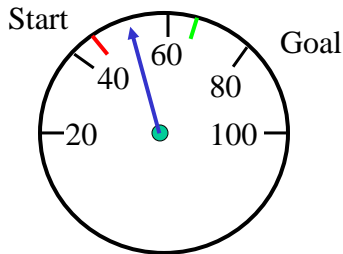
Bottom Line Impact



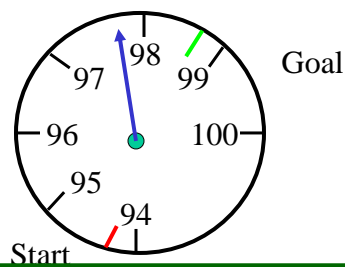
© 2003

Line Level Metrics

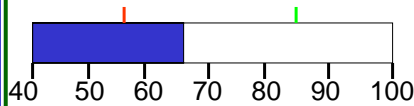
Line Efficiency (%)



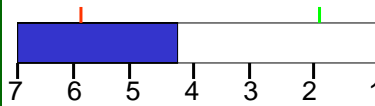
First Pass Yield (%)



Line Uptime (%)



WIP (hrs)



Slide #8

Bottom Line Impact



But No Matter What You do, Have a CIP

- **Assess yourself** ←
- **Establish/Measure Metrics**
 - Paste Volume
 - Productivity Metrics
 - Pareto Defects
- **Monitor Success/Develop Action Plan**
- **Fix the Problems**

Slide #9

Bottom Line Impact



Software Tools to Help

- In addition to AuditCoach™
- Stencil Coach™
 - Helps design stencils including PIP
- WaveCoach™
- LineSimulator™
 - Simulates entire line, much easier than Arena®
- ReflowCoach™

Slide #10

Bottom Line Impact



Stencil Design: StencilCoach™

Aspect Ratio

Aperture Width > 4-5 particle diameters
Aspect Ratio = $W/t > 1.5$

Area Ratio

$A_{\text{opening}} = \pi D^2/4$
 $A_{\text{wall}} = \pi Dt \Rightarrow$
 $ArR = D/4t$

Circular Aperture Diameter > 8 particle diameters
 $ArR = D/4t > 0.66$

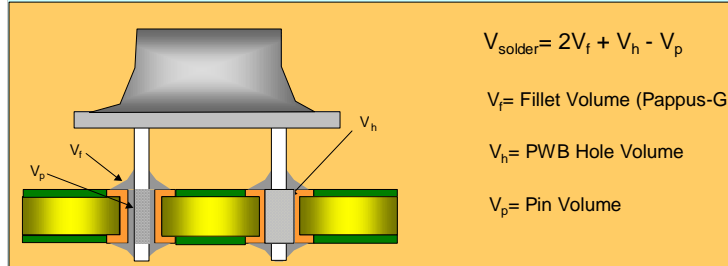
Calculations		Recommendations:		PW=1-3x P/2	W = PW - 2 to 3	AR= W/h > 1.5				
Rectangular Apertures		Pitch (P - mils)	Pad Width (PW - mils)	PW OK?	Aperture (W - mils)	W OK?	Stencil Thickness (t - mils)	Aspect Ratio (AR)	AR OK?	Solder Paste Type
50	25	TRUE	23	TRUE	6	TRUE	3.833	TRUE	3	
25	15	TRUE	12	TRUE	6	TRUE	2.000	TRUE	3	
20	10	TRUE	10	TRUE	5	TRUE	2.000	TRUE	3	
16	10	TRUE	9	TRUE	5	TRUE	1.600	TRUE	4	
12	11	TRUE	8	TRUE	4	TRUE	1.500	TRUE	4	
30	10	TRUE	17	TRUE	6	TRUE	2.833	TRUE	3	
Circular Apertures		Pitch (P - mils)	Pad Dia (PD - mils)	PD OK?	Aperture Diameter (D - mils)	D OK?	Stencil Thickness (t - mils)	Area Ratio (ArR)	ArR OK?	Solder Paste Type
64	2	TRUE	1.5	TRUE	4	TRUE	0.50	TRUE	3	

Slide #11

Bottom Line Impact



Pin-in-Paste



$$V_{\text{solder}} = 2V_f + V_h - V_p$$

V_f = Fillet Volume (Pappus-Guldinus)

V_h = PWB Hole Volume

V_p = Pin Volume

Inputs

Solder Pad Diameter (mils)	76
Pin diameter mils	18
PTH diameter mils	30
PWB Barrel Length mils	58
Paste Reduction Factor	0.52

If Pin is Square.....

Length - mils	18
Width - mils	22
Equivalent Pin Dia mils	22.454

Outputs

$$V = 2V_f + V_h - V_p$$

	Cubic Mils
Vf	17585.147
Vh	40997.784
Vp	14759.202
V	61408.876
Solder Paste Volume Needed	118093.992

Stencil Metrics

Stencil Thickness - mils	7
Side: If Square Aperture - mils	129.887
Radius: If Round Aperture - mils	73.281
Rectangular? If First Side is (mils):	80
Second Side should be (mils):	210.882

Instructions: stencil metric component in Cells D32-33 or stencil aperture

Slide #12

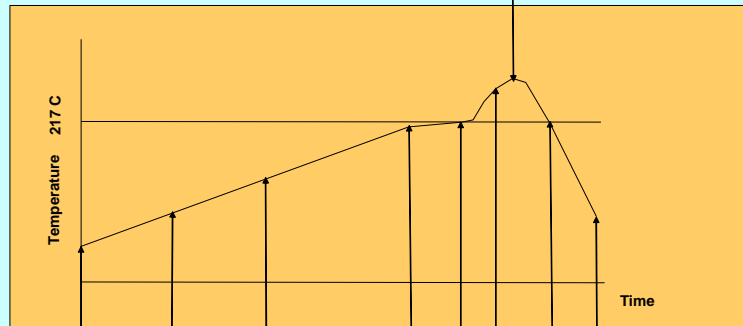
Bottom Line Impact



ReflowCoach™



INDIUM CORPORATION OF AMERICA



Time-s	0	30	100	140	190	230	260	295	325
Temp-C	30	100	150	209	217	230	217	120	

Thruput Calculator

Tunnel Length cm	249
Belt Speed cm/min	71
Product Length cm	20
Product Spacing cm	5

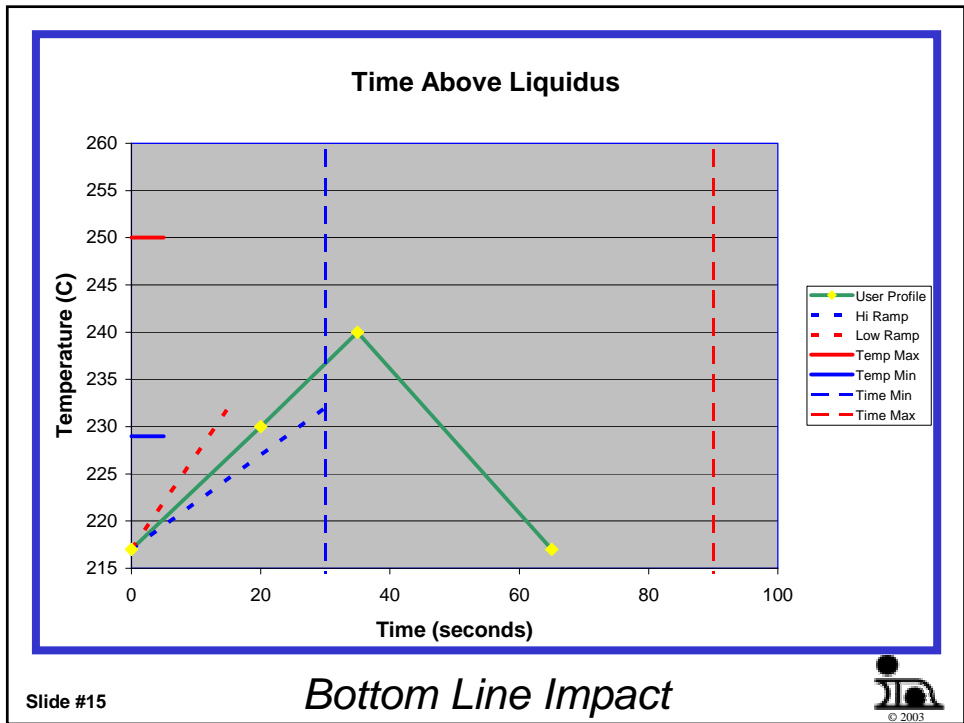
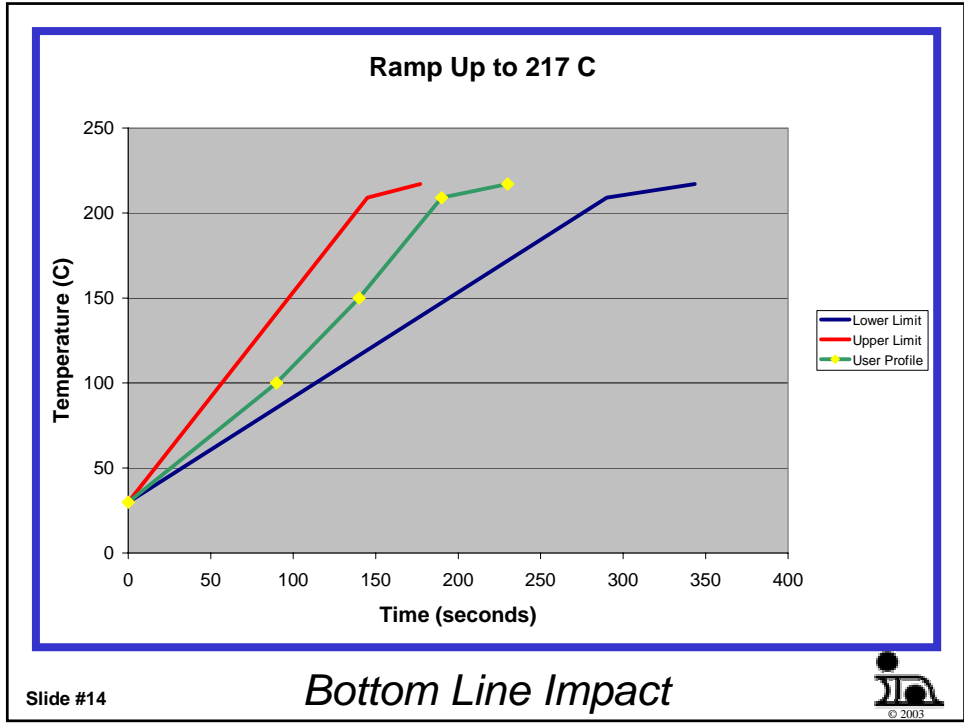
Thruput Bds/min	2.84
Profile Time (min)	3.51

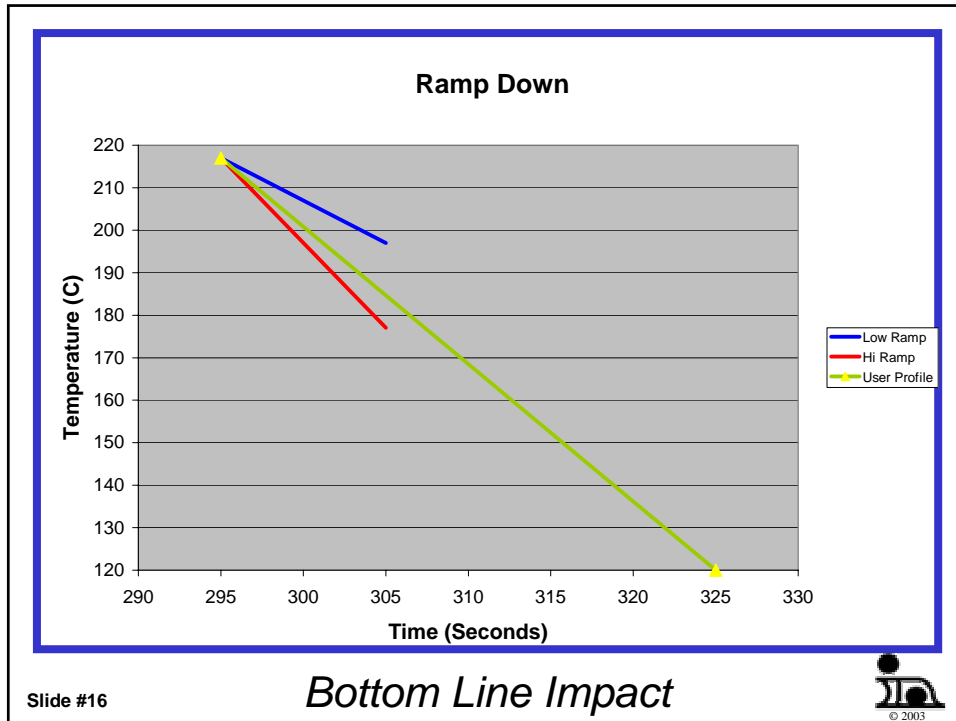
Obeys Lee Dwell Criteria? Yes

Slide #13

Bottom Line Impact








The Tools to Do the Job Right

- **Statistical Thinking**
- **DOE**
- **SPC**

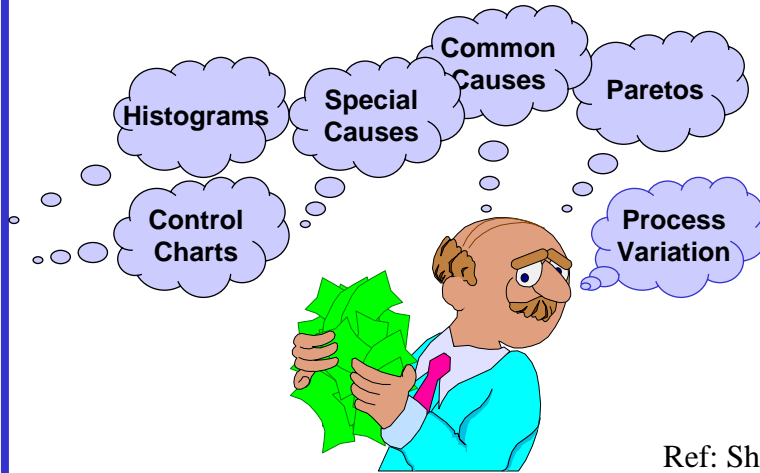
Slide #17

Bottom Line Impact



© 2003

Statistical Thinking



Ref: Sheri Flori

Slide #18

Bottom Line Impact



Statistical Thinking...

The Case of the Squirrel

- The greatest birder in MA was being harassed by squirrels
- It was a crisis
- Even squirrel proof feeders designed by NASA wouldn't work
- We needed to apply BMT!



Slide #19

Bottom Line Impact



So I Got Serious



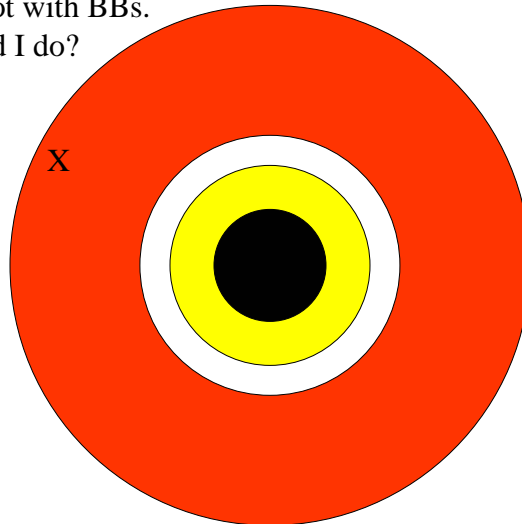
A Crossman BB/Pellet Gun

Slide #20

Bottom Line Impact



The first shot with BBs.
What should I do?

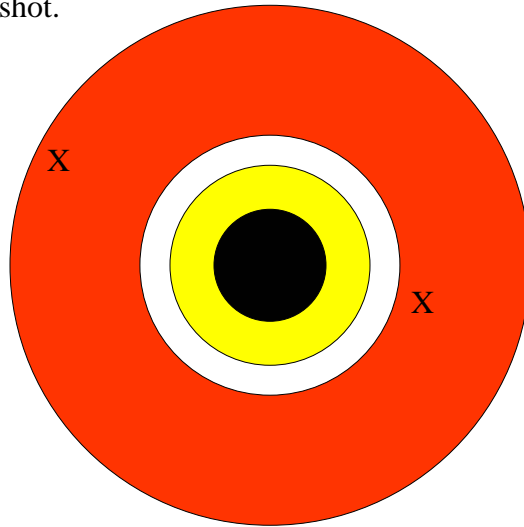


Slide #21

Bottom Line Impact



The second shot.

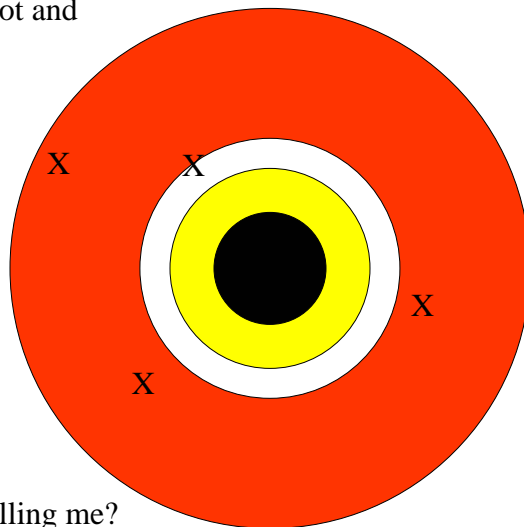


Slide #22

Bottom Line Impact



The third shot and fourth.



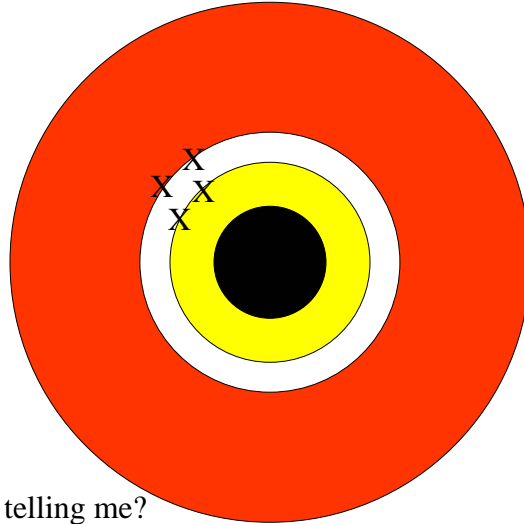
What is it telling me?

Slide #23

Bottom Line Impact



I try pellets.



What is this telling me?

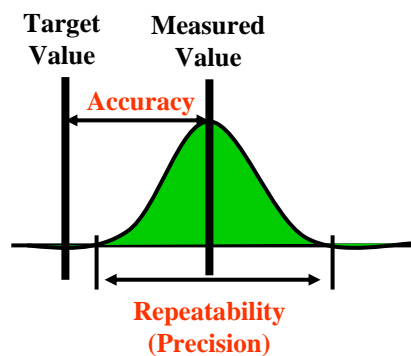
Slide #24

Bottom Line Impact



Accuracy and Precision

- **Accuracy:** How close to the measured.
- **Precision:** How repeatable
- **Examples of:**
 - Poor accuracy and precision (BB's)
 - Good precision, poor accuracy (pellets w/ bad sighting)

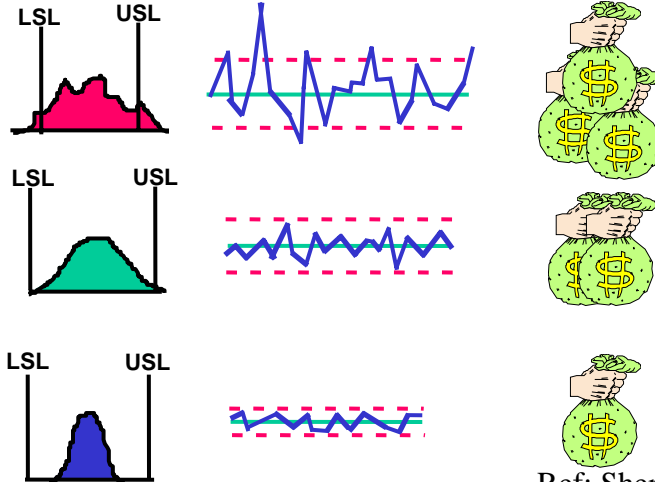


Slide #25

Bottom Line Impact



Process Variation = Lost \$



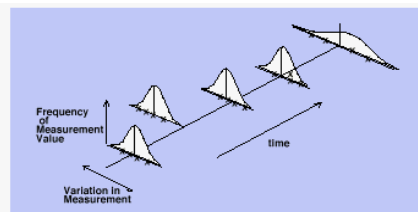
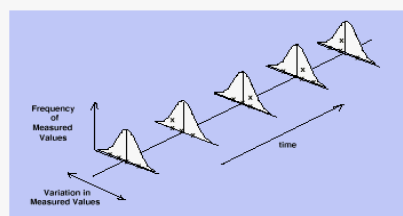
Ref: Sheri Flori

Slide #26

Bottom Line Impact



Types of Variation



Common Cause

- Natural, expected variation
- Controllable
- What are examples of CC in calibrating the pellet gun

Special Cause

- Unnatural, not expected
- Possible examples in pellet gun calibration

Knob twiddling can correct neither!

Slide #27

Bottom Line Impact

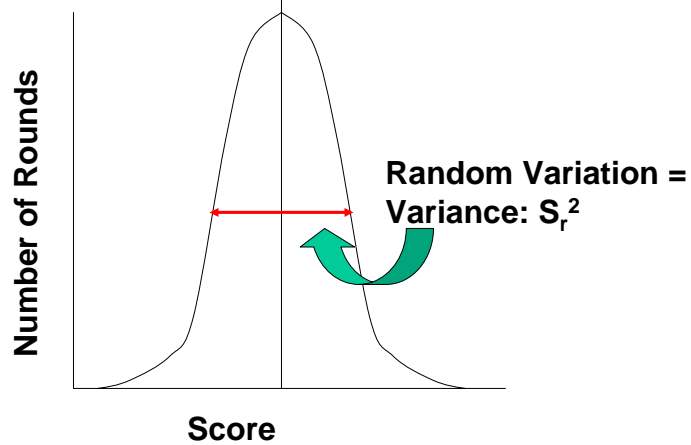


An SMT Electronic Assembly DOE Example

Bottom Line Impact



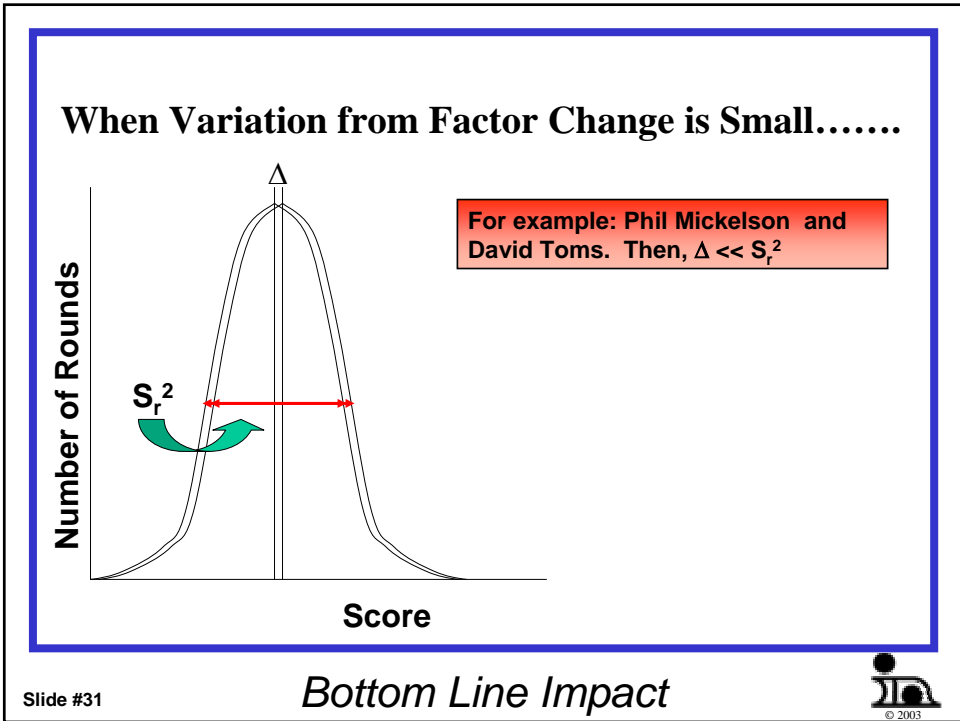
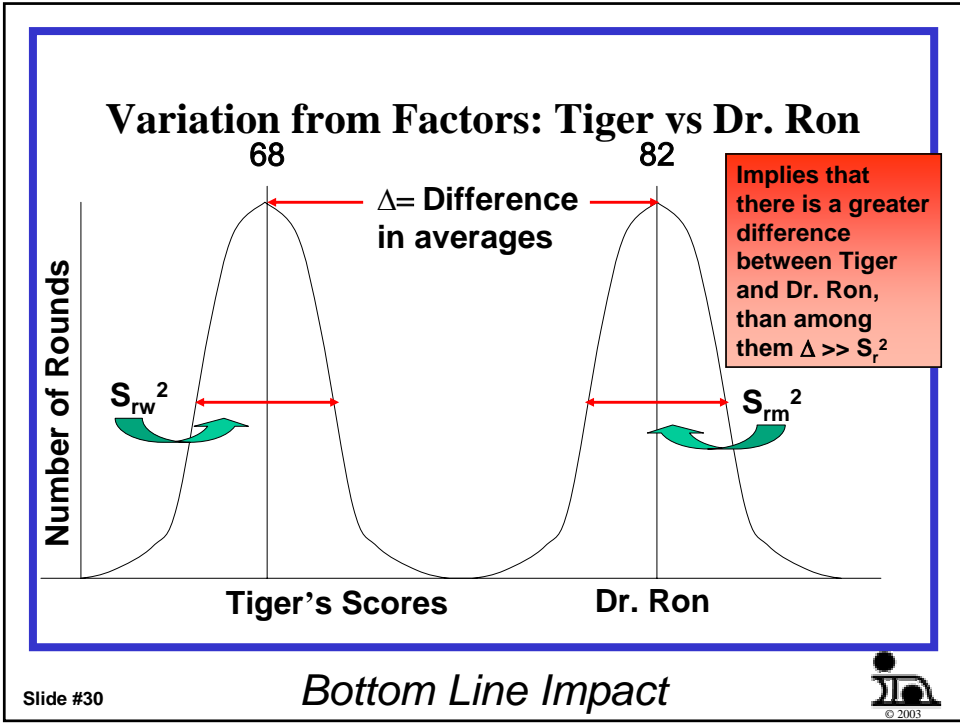
Random Variation: Dr. Ron Golf Scores Average = 82



Slide #29

Bottom Line Impact





DOE Uses ANOVA

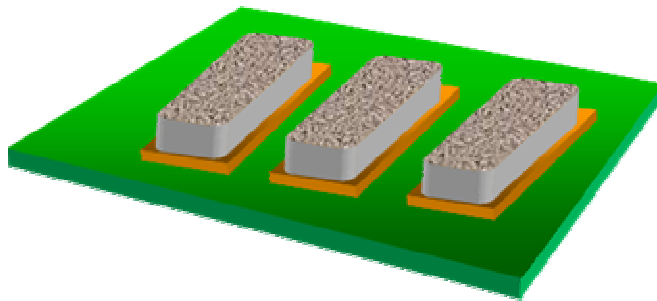
- **ANOVA (Analysis of Variance)**
 - Compares S^2 to Δ
- **The F Statistic:** $F \propto \frac{\Delta^2}{S_r^2}$
- **Large F => factors have a significant effect on result**
- **“Large” varies with sample size, typically > 4 for 95% confidence**

Slide #32

Bottom Line Impact



A Good Stencil Print



*Illustrations courtesy of MPM Corporation

Slide #33

Bottom Line Impact



High Speed UFP Printing

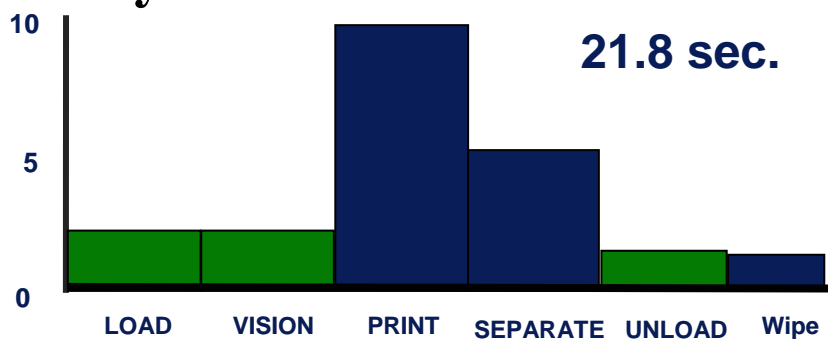
- The objective is to perform High Speed Ultra-Fine Pitch Stencil Printing.
- Print speed, separation speed and wipe frequency need to be minimized to reach this goal.
- Target is 8 second cycle time with current cycle time >20 seconds

Slide #34

Bottom Line Impact



Cycle Time Breakdown

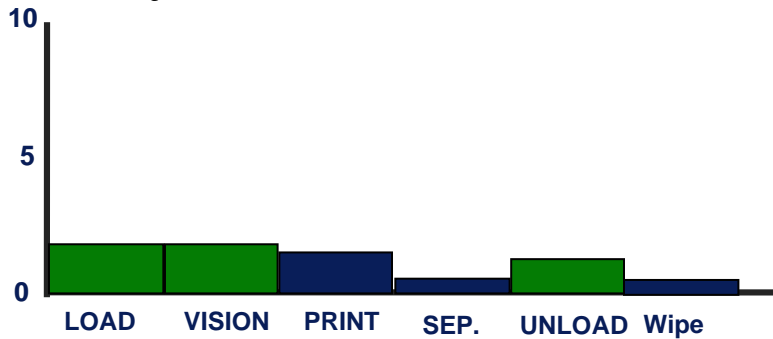


- 10 inch wide board printed at 1 inch
- 2 s Load + 2 s Vision + 10 s Print + 5 s Separate + 1.8 s Unload + 1 s Wipe = 21.8 sec

Bottom Line Impact



Cycle Time Breakdown



Objective:

1.8 s Load + 1.8 s Vision + Print + Separate + 1.5 s Unload + Wipe < 8sec

Bottom Line Impact



© 2003

Factors

- **A: Print Speed:** 1=4, 2=6, 3=8 inch/sec
- **B: Separation Speed:** 1 = 1, 2 = 1.5 sec **Number of Runs:**
- **C: Wipe Freq:** 1= 1/8, 2= 1/12 **3x2x2x2x2=48**
 – 1/8 adds 0.875 sec, 1/12 adds 0.6 secs **Not that many!**
- **D: Stencil Type:** 1= Efab, 2 = Laser
- **E: Paste:** Vendor A =1, Vendor B =2
- **Full Factorial**
- **Assume no interactions**
- **Aperture:** W= 8, t= 5, L= 64 mils=>2560 mils³
- **Desire paste volume to be +/- 10% of aperture volume**
- **Response: Solder Paste Volume**

Slide #37

Bottom Line Impact



© 2003

MiniTab Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Print Sp	2	175117	175117	87558	2.48	0.096
Separati	1	104533	104533	104533	2.97	0.093
Paste Ty	1	559008	559008	559008	15.86	0.000
Stencil	1	274519	274519	274519	7.79	0.008
Wipe Fre	1	902008	902008	902008	25.60	0.000
Error	41	1444731	1444731	35237		
Total	47	3459917				

For stencil and paste, we can reject H_0 with confidence. Hence, we can select the better choice for each of these factors and re-experiment to optimize total speed.

Slide #38

Bottom Line Impact



SPC and Variables Data

- Data relating to a specific process step
- Quantitative
- Can be used to monitor and improve process performance
- Example: Solder Paste Volume
- Variables data are crucial for an effective SPC Plan

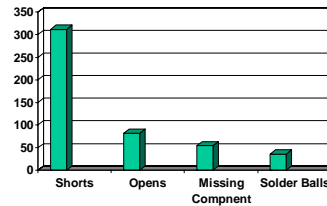
Slide #39

Bottom Line Impact



Process Data: Attribute Data

- Data that relates to the performance of the product
- Examples:
 - Shorts
 - Opens
 - Missing Component
- Important, but cannot be measured to improve process performance
- Any plan should strive to relate attribute data to variables data and develop a CIP around this relationship



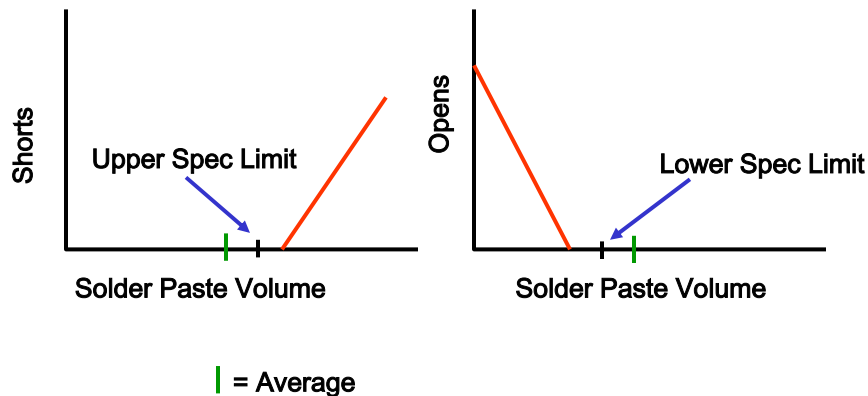
Pareto Attribute Data

Slide #40

Bottom Line Impact



Variables Data Example

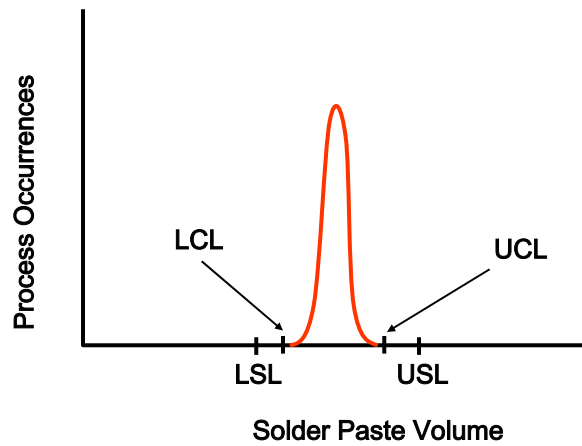


Slide #41

Bottom Line Impact



Variables Data: Solder Paste Volume

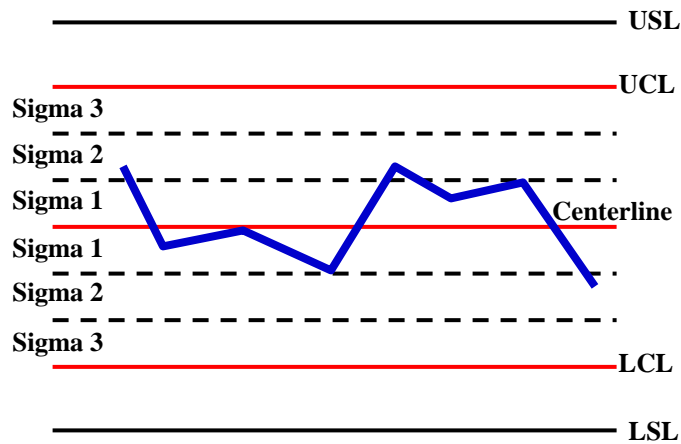


Slide #42

Bottom Line Impact



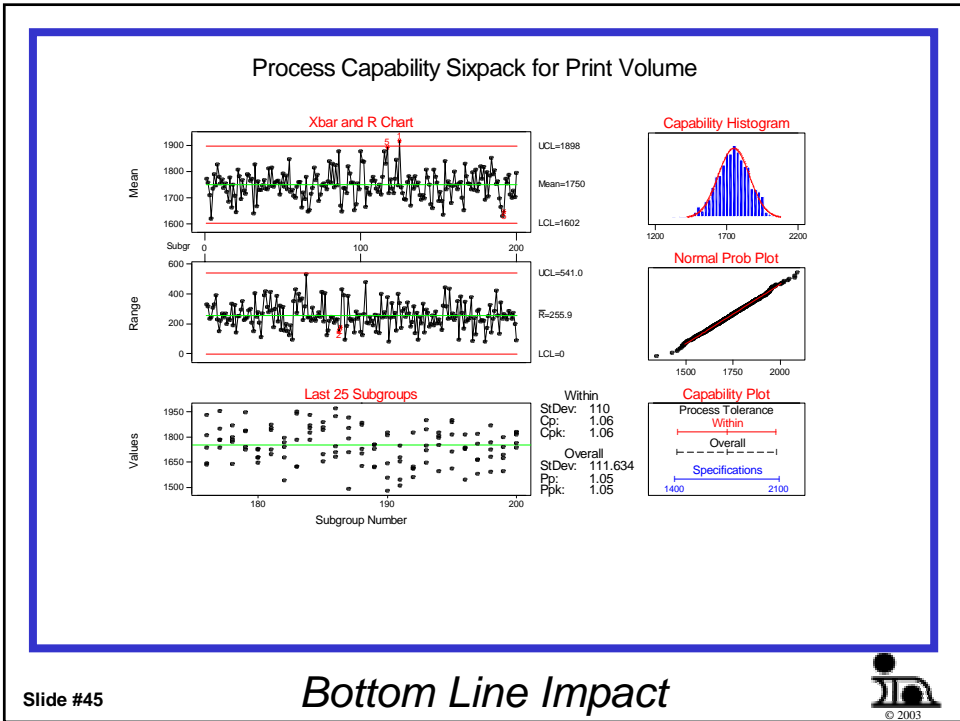
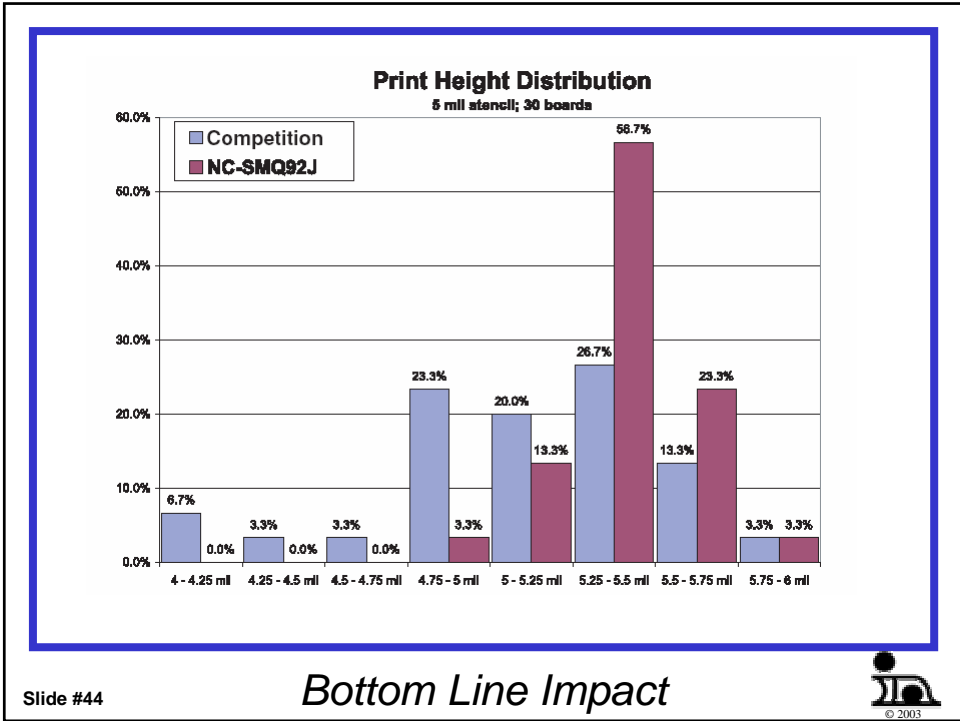
Control Chart for SPC



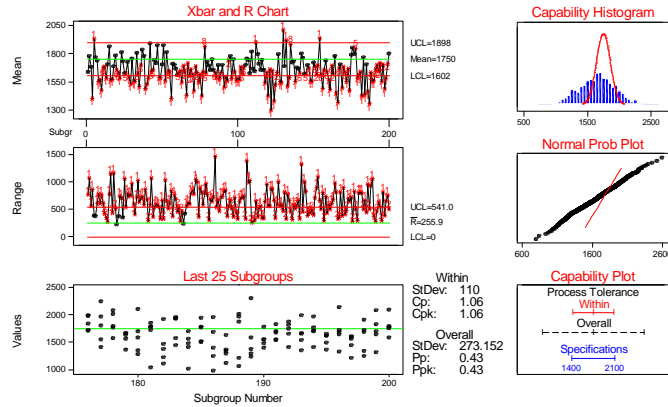
Slide #43

Bottom Line Impact





Process Capability Sixpack for Print Volume



Slide #46

Bottom Line Impact



© 2003

Summary

- **Assess Yourself**
- **Use Metrics**
- **Develop and Implement Action Plan**
- **Monitor Success**
- **Continuously Improve**

Slide #47

Bottom Line Impact



© 2003