Influence of pick & place machines on product quality

The impact of placement quality on SMT manufacturing costs
Introduction

ABOUT ASSEMBLEON
Assembléon Headquarters in Veldhoven (Netherlands)

Assembléon’s focus is to provide competitive solutions for the electronics manufacturing industry based upon our core strength in Pick and Place machines.
SMT process quality influencing factors

SMT PROCESS Q CRITERIA
Typical SMT process flow

- Solder paste printing
- Component placement
- Reflow soldering
SMT process requirements

Process requirements:

1. Solder paste printing
   - Right amount
   - Right place

2. Component placement
   - Right component
   - Right place

3. Reflow soldering
   - Right temperature profile
   - Good reflow
Assessment criteria for stencil printing process

1. Solder paste pattern resolution (paste transfer)

2. Bridging (‘smearing’)

3. Misalignment
Solder paste pattern resolution

0  no paste
1  irregular shape (few balls)
2  pyramid lower than stencil thickness
3  pyramid equal to stencil thickness
4  beginning flat top with "dog ears"
5  flat top side
6  scooped-out

OK !
Solder paste smearing

Criterion:
Neighboring pads
May not have contact

Smearing

Flux with incidental balls

Stencil printing

Perfect

OK!
### Solder paste pattern misalignment

<table>
<thead>
<tr>
<th>Condition</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% of paste centered on pad</td>
<td>Perfect</td>
</tr>
<tr>
<td>&lt; 25% of paste off-pad</td>
<td>Acceptable</td>
</tr>
<tr>
<td>&gt; 25% of paste off-pad</td>
<td>Not acceptable</td>
</tr>
</tbody>
</table>

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</tr>
</thead>
<tbody>
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</tr>
</tbody>
</table>

**Remedy:**
Board to stencil alignment correction
# Placement defect analysis

<table>
<thead>
<tr>
<th>Symptom (before reflow)</th>
<th>Cause</th>
<th>Defect (end of process)</th>
</tr>
</thead>
</table>
| Part misaligned         | • Mis read fiducials  
                          • Machine needs calibration  
                          • Placement error  
                          • Alignment error  
                          • Part slid off pads | • Misalignment  
                          • Solder bridging  
                          • Tombstoning |
| Incorrect part          | • Incorrect part reel loading  
                          • Tape splice error | • Incorrect part |
| Part damaged            | • Part damaged at supplier  
                          • Placement force too high | • Opens  
                          • Component cracking  
                          • Tilted part |
| Wrong polarity          | • Programming error  
                          • Tray rotated | • Wrong polarity |
| Extra / missing part    | • Part lost during pick & place | • Extra / missing part |

Pick & place
Reflow solder process requirements

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time</th>
<th>Pre-heat</th>
<th>Soak</th>
<th>Reflow</th>
<th>Reflow zone for Lead-free</th>
<th>Reflow zone for PbSn</th>
</tr>
</thead>
<tbody>
<tr>
<td>240 - 280 deg. C</td>
<td>&lt; 70 sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>235 deg. C</td>
<td>&lt; 60 sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>217 deg. C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>205 deg. C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180 deg. C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160 deg. C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Maximum soldering temperature
- Minimum soldering temperature

< 3°C / sec

< 6°C / sec

Reflow soldering
Reflow process defect analysis

**Peak temperature too high:**
- Charring
- Delamination
- Intermetallics
- Leaching
- Dewetting
- Voiding

**Cooling rate too fast**
- Solder detachment
- Pad Detachment

**Cooling rate too slow**
- Intermetallics
- Charring
- Leaching
- Dewetting
- Grain Size too large

**Reflow soldering**

- Ramp-up rate too high
  - Hot Slump
  - Bridging
  - Tombstoning
  - Skewing
  - Wicking
  - Opens
  - Solder beading
  - Solder balling
  - Components cracking.

- Soaking Zone too long
  - Voiding
  - Poor Wetting
  - Solder Balling
  - Opens
Acceptable part to pad misalignment (IPC-A-610D)

Acceptable - Class 1, 2
- Side overhang (A) is less than or equal to 50% width of component termination area (W) or 50% width of land (P), whichever is less.

Acceptable - Class 3
- Side overhang (A) is less than or equal to 25% width of component termination area (W) or 25% width of land (P), whichever is less.

Figure 8-12
1. Class 2
2. Class 3

Self alignment: solder to pad

Before reflow

After reflow

Reflow soldering
Relationship placement machine concept and placement quality control

PICK & PLACE RELATED ERRORS
Possible defects in SMT: defect opportunities

1. Component opportunities ($O_C$)
   - All parts that need to be assembled on board (incl. PCB)
   - Every part counts for one defect opportunity
   - Defect example: damaged parts

2. Placement opportunity ($O_P$)
   - All parts that need to be placed on board, based on bill of materials (excl. PCB)
   - Every part counts for one defect opportunity
   - Defect examples: misaligned parts, missing parts

3. Termination opportunity ($O_T$)
   - Any hole, pad or land or other surface to which a component is electrically terminated
   - Every termination counts for one defect opportunity
     (example: QFP48 $\rightarrow$ 48 leads $\rightarrow$ 48 termination opportunities)

4. Assembly opportunity ($O_A$)
   - An overall defect opportunity that is not captured within component, placement or termination opportunity defect classes
   - Defect examples: conformal coating, cleaning
## IPC-9261A Defect classification overview

<table>
<thead>
<tr>
<th>1</th>
<th>Component defects</th>
<th>2</th>
<th>Placement defects</th>
<th>3</th>
<th>Termination defects</th>
<th>4</th>
<th>Assembly defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base material damage</td>
<td>1</td>
<td>Part lead stressed</td>
<td>2</td>
<td>Wire connected wrong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Bent lead</td>
<td>1</td>
<td>Plating or other finish problem</td>
<td>2</td>
<td>Wire routing wrong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Birdcaged wire</td>
<td>1</td>
<td>Sleevings problem</td>
<td>3</td>
<td>Blow holes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Blisters, mealing, peeling</td>
<td>1</td>
<td>Solderability problem</td>
<td>3</td>
<td>Cold solder joint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Board warped or bowed</td>
<td>1</td>
<td>Spliced where not permitted</td>
<td>3</td>
<td>Disturbed solder joint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Cable made wrong</td>
<td>1</td>
<td>Unprepped part</td>
<td>3</td>
<td>Fractured solder joint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Circuitry damaged</td>
<td>1</td>
<td>Wire damage</td>
<td>3</td>
<td>Icicles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Connector damaged</td>
<td>1</td>
<td>Wire not tinned where required</td>
<td>3</td>
<td>Insufficient solder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Gold not removed</td>
<td>2</td>
<td>Cable connected wrong</td>
<td>3</td>
<td>Lead protrusion wrong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Improper stress relief</td>
<td>2</td>
<td>Parts / loose / missing / wrong</td>
<td>3</td>
<td>Part coating meniscus in joint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Incorrect terminal flange</td>
<td>2</td>
<td>Crimping wrong</td>
<td>3</td>
<td>Solder bridge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Insulation or wire damage</td>
<td>2</td>
<td>Improper mounting</td>
<td>3</td>
<td>Solder wetting unacceptable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Lead bend problem</td>
<td>2</td>
<td>Lead / cable routing wrong</td>
<td>3</td>
<td>Unsoldered connection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Lead coplanarity out of spec</td>
<td>2</td>
<td>Min. electrical clearance violated</td>
<td>4</td>
<td>Assembly not clean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Lead forming wrong</td>
<td>2</td>
<td>Part height wrong</td>
<td>4</td>
<td>Conformal coating absent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Lead / cable length wrong</td>
<td>2</td>
<td>Part misaligned</td>
<td>4</td>
<td>Conformal coating peeling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Leads bent under</td>
<td>2</td>
<td>Part extra</td>
<td>4</td>
<td>Conformal coat. present unwanted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Leads not tinned</td>
<td>2</td>
<td>Part mounted wrong</td>
<td>4</td>
<td>Solder balls / splash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Marking incorrect</td>
<td>2</td>
<td>Tilted part</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Part damaged</td>
<td>2</td>
<td>Tombstone</td>
<td></td>
<td></td>
<td></td>
<td></td>
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### 1) Component defects
- Base material damage
- Bent lead
- Birdcaged wire
- Blisters, mealing, peeling
- Board warped or bowed
- Cable made wrong
- Circuitry damaged
- Connector damaged
- Gold not removed
- Improper stress relief
- Incorrect terminal flange
- Insulation or wire damage
- Lead bend problem
- Lead coplanarity out of spec
- Lead forming wrong
- Lead / cable length wrong
- Leads bent under
- Leads not tinned
- Marking incorrect
- Part damaged

### 2) Placement defects
- Part lead stressed
- Plating or other finish problem
- Sleevings problem
- Solderability problem
- Spliced where not permitted
- Unprepped part
- Wire damage
- Wire not tinned where required
- Cable connected wrong
- Parts / loose / missing / wrong
- Crimping wrong
- Improper mounting
- Lead / cable routing wrong
- Min. electrical clearance violated
- Part height wrong
- Part misaligned
- Part extra
- Part mounted wrong
- Tilted part

### 3) Termination defects
- Wire connected wrong
- Wire routing wrong
- Blow holes
- Cold solder joint
- Disturbed solder joint
- Fractured solder joint
- Icicles
- Insufficient solder
- Lead protrusion wrong
- Part coating meniscus in joint
- Solder bridge
- Solder wetting unacceptable
- Unsoldered connection
- Assembly not clean
- Conformal coating absent
- Conformal coating peeling
- Conform. coat. present unwanted
- Solder balls / splash
Yield vs. number of defect opportunities

DPMO = 5 10 20 30 40 50 75 100 150 200 300 400 500 750 1000

Lower DPMO will increase Yield and thus reduce repair costs
Most pick & place machines are sequential

- High accelerations / decelerations
  - High forces acting on components $\rightarrow$ risk of component shift or loss
- No component position monitoring between component alignment and placement position
- In most cases: no placement force control / no presence check
Acceleration forces acting on pipettes

Risk of components shift:
- Acceleration force (= m.a) > friction force

Risk of components break loose:
- m.a.H_g > F_{vacuum} \cdot (D_o/2)

Revolver & turret heads add extra acceleration forces
Parallel pick & place principle

- Multiple parallel placement robots
- Indexing board transport
- Single placement head per robot
Total pick & place process control

- Component presence check
- Component pick correction
- Pick height control
- Component force control
- Component inspection
- Component alignment
- On-edge detection
- Component presence check
- Component presence check
- Pick
- Place
Placement head with integrated P&P process feedback

- Phi-Z module
- BA-camera module
- Laser Align module
- PCB

Auto calibration
Short accuracy loops
Component pick correction
**Force control**

Impact force is determined by:

- Velocity
  - High velocity → high impact force
- Contact stiffness
  - High stiffness → high impact force
- Impact mass
  - High mass → high impact force

\[
F_{\text{placement}} = F_{\text{impact}} + F_{\text{static}}
\]

\[
F_{\text{impact}} = v \times \sqrt{m \times k_{\text{contact}}}
\]

No force control: Risk of component cracking
Impact force control

Impact detection

Static force

PCB / Substrate
## Placement defect prevention

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| Incorrect part          | • Incorrect part reel loading  
                          • Tape splice error |                          |
| Part damaged            | • Part damaged at supplier  
                          • Placement force too high |                          |
| Wrong polarity          | • Programming error  
                          • Tray rotated |                          |
| Extra / missing part    | • Part lost during pick & place | • Extra / missing part |

### Key Areas of Focus

- **Auto calibration**
  - Short accuracy loops
- **Setup verification**
- **Force control**
- **Presence check**
  - Splice detection
  - Low accelerations
  - Servo Z movement
  - On edge detection
  - Pick correction

*Proprietary Information*
Relationship DPMO and rework costs

RESULTS
DPMO results for parallel placement

**Product:** LCD television (Shenzhen, China) (790 parts / board)

**Line A: Parallel placement**

DPU$_{\text{total}}$ (5 days) = 0.0399 → $Y = 96.1\%$

**Line B: Sequential placement**

DPU$_{\text{total}}$ (5 days) = 0.2873 → $Y = 75\%$

**Difference in first pass yield:** 21.1\%
Example: Rework cost savings for LCD television

<table>
<thead>
<tr>
<th>Item</th>
<th>Parallel line</th>
<th>Sequential line</th>
</tr>
</thead>
<tbody>
<tr>
<td># Productive hours per year</td>
<td>7800</td>
<td>7800</td>
</tr>
<tr>
<td>Real output per line [cph]</td>
<td>100000</td>
<td>100000</td>
</tr>
<tr>
<td># Components per board</td>
<td>790</td>
<td>790</td>
</tr>
<tr>
<td># Defect opportunities per board</td>
<td>5700</td>
<td>5700</td>
</tr>
<tr>
<td>DPMO</td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td>DPU</td>
<td>0.04</td>
<td>0.29</td>
</tr>
<tr>
<td>First pass yield [%]</td>
<td>96%</td>
<td>75%</td>
</tr>
<tr>
<td>Average BOM cost per part [€]</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Line cycle time [s]</td>
<td>28.44</td>
<td>28.44</td>
</tr>
<tr>
<td># Repairs per hour (board level)</td>
<td>5</td>
<td>31</td>
</tr>
<tr>
<td>Average rework per hour [s]</td>
<td>2674</td>
<td>16951</td>
</tr>
<tr>
<td># Rework operators (3 shifts)</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Annual labor cost per operator [k€]</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total annual labor cost [k€]</td>
<td>7</td>
<td>45</td>
</tr>
<tr>
<td># Rework stations needed</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Annual station costs (excl. labor) [k€]</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Annual BOM rework costs [k€]</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>Total repairs per line per year [-]</td>
<td>38619</td>
<td>244847</td>
</tr>
<tr>
<td>Total repair costs per line [k€]</td>
<td>30</td>
<td>162</td>
</tr>
<tr>
<td>Average defect coverage [%]</td>
<td>90.00</td>
<td>90.00</td>
</tr>
<tr>
<td># Boards needing second order rework (per year)</td>
<td>3862</td>
<td>24485</td>
</tr>
<tr>
<td>Average second order rework per hour [s]</td>
<td>267</td>
<td>1695</td>
</tr>
<tr>
<td># Rework operators (3 shifts)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total annual labor cost [k€]</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td># Rework stations needed</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Annual station costs (excl. labor) [k€]</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Annual BOM rework costs [k€]</td>
<td>0.26</td>
<td>1.66</td>
</tr>
<tr>
<td>Second order repair costs (per year) [k€]</td>
<td>21.2</td>
<td>26.5</td>
</tr>
</tbody>
</table>

Total repair costs per line (incl. defect recov. per year) [k€] 51.2 188.6
Quality inspection methods

**AXI**
Automatic X-ray Inspection

**ICT**
In-Circuit Test

**AOI**
Automatic Optical Inspection

**AXI**
- Poor wetting
- Marginal Joints
- Voids
- Excess

**ICT**
- Dead part
- Wrong part
- Bad part
- PCB short/open
- Functionally bad

**AOI**
- Insufficient
- Bridging
- Tombstone
- Misalignment
- Bypass Caps, L’s
- Extra Parts

- Orientation
- Missing non-electrical parts
- Mark Inspection
- Paste Deposition Defects
## Defect coverage estimates

<table>
<thead>
<tr>
<th>Defect</th>
<th>HVI</th>
<th>ICT</th>
<th>AOI</th>
<th>AXI</th>
<th>BSCAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Bridge</td>
<td>80 %</td>
<td>90 %</td>
<td>70 %</td>
<td>90 %</td>
<td>90 %</td>
</tr>
<tr>
<td>1.2 Insufficient</td>
<td>60 %</td>
<td>0 %</td>
<td>90 %</td>
<td>80 %</td>
<td>0 %</td>
</tr>
<tr>
<td>1.3 Open</td>
<td>50 %</td>
<td>80 %</td>
<td>80 %</td>
<td>90 %</td>
<td>90 %</td>
</tr>
<tr>
<td>1.4 Excess</td>
<td>60 %</td>
<td>0 %</td>
<td>90 %</td>
<td>80 %</td>
<td>0 %</td>
</tr>
<tr>
<td>1.5 Residue</td>
<td>80 %</td>
<td>0 %</td>
<td>0 %</td>
<td>20 %</td>
<td>0 %</td>
</tr>
<tr>
<td>1.6 Grainy</td>
<td>60 %</td>
<td>0 %</td>
<td>50 %</td>
<td>70 %</td>
<td>0 %</td>
</tr>
<tr>
<td>1.7 Other</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td>2.1 Missing</td>
<td>80 %</td>
<td>80 %</td>
<td>90 %</td>
<td>80 %</td>
<td>100 %</td>
</tr>
<tr>
<td>2.2 Wrong</td>
<td>50 %</td>
<td>80 %</td>
<td>0 %</td>
<td>10 %</td>
<td>100 %</td>
</tr>
<tr>
<td>2.3 Misaligned</td>
<td>70 %</td>
<td>0 %</td>
<td>90 %</td>
<td>90 %</td>
<td>0 %</td>
</tr>
<tr>
<td>2.4 Tombstone</td>
<td>50 %</td>
<td>80 %</td>
<td>90 %</td>
<td>90 %</td>
<td>20 %</td>
</tr>
<tr>
<td>2.5 Inverted</td>
<td>30 %</td>
<td>80 %</td>
<td>30 %</td>
<td>10 %</td>
<td>100 %</td>
</tr>
<tr>
<td>2.6 Other</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td>3.1 Dead</td>
<td>0 %</td>
<td>30 %</td>
<td>0 %</td>
<td>0 %</td>
<td>100 %</td>
</tr>
<tr>
<td>3.2 Tolerance</td>
<td>0 %</td>
<td>30 %</td>
<td>0 %</td>
<td>0 %</td>
<td>20 %</td>
</tr>
<tr>
<td>3.3 Other</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
</tbody>
</table>

*Source: Nokia & University of Oulu, Finland, 2005*

- HVI: Human Visual Inspection
- ICT: In Circuit Testing
- AOI: Automatic Optical Inspection
- AXI: Automatic X-ray Inspection
- BSCAN: Boundary Scan

**A combination of different test methods is needed for optimal test coverage**

**Approximate test coverage: 90% (→ 10% of all defects is not detected)**
Conclusion

• Prevention is better than cure…
  – Solder paste printing
    • Selection of optimal stencil & aperture definition
    • Selection of optimal printing parameters
    • Process monitoring (stencil cleaning, paste replenishment, etc.)
  – Component placement
    • Monitoring of every pick & place process step
    • Selection of optimal P&P parameters (‘Take it easy’) 
  – Reflow soldering
    • Selection of optimal reflow temperature profile
    • Reflow process control

• Parallel placement principle gives intrinsically better placement quality
  – Continuous process monitoring
  – More time available per process step → less risks
  – Result: Typical DPMO ≤ 10 → Considerable savings on rework cost!